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MEng. Independent Project On:

A FUZZY DEMATEL SYSTEMATIC APPROACH FOR RISK ANALYSIS IN THE CASE OF ADDIS ABABA'S ROAD CONSTRUCTION PROJECTS ©

In partial fulfillment of the requirements for the Degree of Masters of Engineering in Construction Technology and Management

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UNDERTAKING

I hereby declare that this paperwork entitled ***"A FUZZY DEMATEL SYSTEMATIC APPROACH FOR RISK ANALYSIS IN THE CASE OF ADDIS ABABA'S ROAD CONSTRUCTION PROJECTS"*** is my original work. The work has not been presented for any other university and is not concurrently submitted in candidature of any other degree, that all sources of material used for the project have been duly acknowledged.

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ABSTRACT

Construction industry is a complex, dynamic and challenging industry that each process and activities in creating new things are susceptible to risk. In its dynamic nature, there is always a change in interpretation of and compliance with many applicable laws, codes, and regulations; gathering of considerable amount of resources, including labor, equipment, and material; and communications with and coordination among multiple parties, such as the owner, the design professional, other contractors and subcontractors, and suppliers, all of whom may have different purposes and goals. In relation to the dynamic nature of the industry, many factors that are not planned and expected might arise during the construction process. In this context, both the Ethiopian road construction industry in general and Addis Ababa's Road construction sector in particular demonstrate a significant need for an effective risk analysis approach to evaluate the impact of various risks and uncertainties on project performance. An effective risk analysis method should account for the dynamic nature of risks throughout the project life cycle and incorporate feedback loops that influence overall risk outcomes. This project paper proposes and applies a Fuzzy DEMATEL-based systematic approach; an enhanced and practical method that explicitly identifies, quantifies, and analyzes key risk influences. Forty-Five major risks were identified, grouped into 21 categories, and analyzed within a Systematic, hierarchical framework. The findings confirm that Procurement Risks, Economy-Related Uncertainties, Time Uncertainties/Risks, and Technological Uncertainties are the most critical risks impacting the achievements of the project goals. The identified risk factors have also been organized into a causal hierarchical risk structure, with the most prominent risk categories ranked accordingly.

KEY WORDS: Road Construction, Risk Analysis, System Dynamics, Project Management, Fuzzy Set Theory, DEMATEL

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LIST OF ABBREVIATIONS

DEMATEL	Decision-Making Trial and Evaluation Laboratory
AACRA:	Addis Ababa City Roads Authority
PRU:	Project-Related Uncertainties
MR:	Management Risks: Organization-related uncertainties
FR:	Financial Risks: Finance-related uncertainties
IRC:	Interest/Demand-Related Conflicts
HRC:	Human capital risks: Human-related uncertainties
CCR:	Companies' Capabilities Risks
IR:	Insurance Risks
PR:	Procurement Risks
DCM:	Design, Construction, Operation and Maintenance risks
CR:	Country Risks
SU:	Social Uncertainties
TC:	Technological Uncertainties: New Construction Trends
II:	Institutional Influences
HSE:	Health, Safety and Environmental risks
SCR:	Site Condition Risks
ROW:	Right of Way Obstructions
GIU:	Government-Intervention Related Uncertainties
ERU:	Economy-Related Uncertainties
TU:	Time Uncertainties/Risks
QU:	Quality Uncertainties/Risks
CU:	Cost Uncertainties/Risks
W:	Weight of each risk category Importance
Q:	Influence of each risk categories

CHAPTER ONE: INTRODUTION

1.1 GENERAL

An overview of the main findings of the research is provided in the first chapter, Introduction. This chapter's primary topics of discussion are the general state of the nation, the Ethiopian construction industry and its economic impact, the introduction of the road construction industry, the development of road construction in Ethiopia in general and Addis Ababa in particular, and risk management frameworks and trends. Additionally, this chapter presents the research's general and specific objectives, studies' importance and beneficiaries, and its organization.

1.2 CONSTRUCTION INDUSTRY AND ETHIOPIAN CONSTRUCTION OUTLOOK

The International Standards Industrial Classification (ISIC) Rev. 3 of the United Nations (1996) defines construction as an economic activity that focuses on building, repairing, renovating, or expanding fixed assets, including buildings, infrastructure improvements, and other engineering projects, such as roads, bridges, and dams (EEA, 2006/07). This industry comprises various establishments engaged in activities such as site preparation, complete construction or parts thereof, civil engineering, building installation, completion, and renting of construction or demolition equipment with operators. It encompasses all construction activities, regardless of whether they are conducted by private or public firms and whether they are contractual or self-performed. (EEA, 2006/07).

In Ethiopia, while the definition used by the National Accounts department of the Ministry of Finance and Economic Development (MoFED) aligns with ISIC, it specifically includes construction and maintenance activities for residential buildings in both urban and rural settings, non-residential structures such as factories, offices, hotels, schools, and hospitals, and other construction work like roads, dams, and power lines (MoFED, 2005). Activities like quarrying, gravel crushing, and brick manufacturing, which do not fall under the industry's purview, are often included in construction output due to practical limitations (MoFED, 2005).

Despite many obstacles and limitations, Ethiopia's construction sector currently contributes significantly to employment and economic growth. Throughout their lifecycle, from conceptual design to execution, the vast scope of construction projects frequently results in a variety of environmental, sociopolitical, and unanticipated difficulties that can compromise quality and cause major schedule and expense overruns (Nadeem et al., 2010). Establishing a systematic risk management system is essential to successfully addressing these issues and achieving project goals related to budget, schedule, quality, safety, and environmental sustainability (Zou, Zhang, and Wang, 2005).

Development Challenges

According to the (Bank, 2023) reports, Ethiopia is grappling with multiple, interlinked crises that have significantly impacted its development trajectory. Conflict, particularly in the northern regions since November 2020, has devastated lives, infrastructure, and livelihoods. At the same time, the lingering effects of the COVID-19 pandemic continue to weigh heavily on the economy. While exports and foreign direct investment showed some recovery in 2020/21 and employment has begun to rebound, urban job levels remain below pre-pandemic standards. Many households and businesses continue to struggle with income losses, and poverty rates are believed to have increased.

The country which was struggling hard to ensure equitable access to development efforts to all regions due to combination of factors including uneven topography is further experiencing severe difficulties. Ethiopia's landlocked location, challenging topography, inadequate infrastructure, a weak human capital base, and a lengthy history of government intervention in the economy are some of the factors that hinder economic growth and make the country's aim to achieve middle-income status more challenging ((AfDB), 2020).

In general, a number of issues hinder the growth of Ethiopia's construction sector, particularly in urban areas. Nearly all road projects finish with more money and time spent than anticipated or agreed upon, as well as problems with design quality that cause them to deteriorate before the intended lifetime term. Obstacles in the ROW limit, a lack of sense of belonging among the stakeholders, a lack of liquid assets, a lack of experienced professionals during the planning, designing, implementation, and operation/maintenance of road projects, and inadequate management are some of the main causes of these issues. As a result, multiple project management approaches must be applied from the project's inception to its completion. These techniques include controlling the project's numerous risks at each point of its life cycle (Tegabu, 2015).

Addis Ababa, a chartered city and a “political capital of Africa”, was founded in1887 by Emperor Menelik II and became the capital city of Ethiopia in 1889. Since then, the city has become the capital and the country’s largest commercial and cultural hub. It is also the seat of the Ethiopian federal government and more than 400 international governmental and non-governmental organizations. Besides being a founding city of the Organization of African Unity (OAU) in 1963, which later renamed and re-organized as the African Union (AU) in 2002, it is home to the third largest diplomatic community in the world, hosting the United Nations Economic Commission for Africa (UNECA) which was established in the city in 1958. According to the 2007 population census, the city had a total population of 3,384,569 inhabitants, who came from different regions of Ethiopia and the total population was projected to be around 5 million in the year 2020 (Reference: https://worldpopulationreview.com/world-cities/addis-ababa-population/ (accessed June 18, 2020). Now, Addis Ababa's 2023 population is estimated at 8,938,683. In 1950, the population of Addis Ababa was 392,000. Addis Ababa has grown by 331,674 in the year 2022, which represents a 3.85% annual change (Review, 2023)
The Addis Ababa City Administration now has a plan in place to elevate the city to middle-level status by 2030. The administration has also established a plan to build a number of megaprojects, such as condominiums, whose construction is accelerating on the outskirts of the city, increasing the amount of built-up land. Furthermore, the city is receiving a significant influx of automobile imports. Like any other city, Addis Ababa has to deal with the typical metropolitan problems of inadequate and subpar infrastructure, a lack of public services, a housing shortage, bad sanitation, high unemployment, and high transit costs. When the city was first being established, the terrain and the absence of a master plan had a negative effect on the construction of planed streets (Tegabu, 2015).

In order to mitigate these challenges, the Addis Ababa city government, in collaboration with the Federal Government has launched a 10-Year Development Plan, based on the 2019 Home-Grown Economic Reform Agenda, which will run from 2020/21 to 2029/30 (Bank, 2023).

1.3 THE CURRENT TREND OF RISK MANAGEMENT IN ETHIOPIA

A construction risk refers to any potential loss related to time, cost, quality, or safety. Since each construction project is unique and project environments are becoming increasingly complex, various types of risks may arise. In simple terms, project risk refers to the likelihood of an event occurring that could negatively affect project objectives, based on how likely the event is and what impact it would have if it happens (Amin Vafadarnikjoo, 2015). The total risk in a project is the combined effect of all individual risks. Effective risk management is essential for ensuring successful and timely project completion.

Increasing Public-Private Partnerships (PPPs), international investments, and Ethiopia's ambitious infrastructure expansion have made risk management in the country's road construction industry more prominent. But problems like supply chain interruptions, inflation, and political unpredictability call for organized risk reduction techniques.

Risk management in Ethiopian road projects has always been reactive, concentrating on fixing problems as they appear. Recent patterns, however, show a move toward proactive risk management, which has been inspired by global standards like the Project Management Body of Knowledge (PMBOK) and ISO 31000. The Ethiopian Roads Authority (ERA) has followed international best practices by integrating risk assessments into procurement and feasibility studies.

Despite progress, key challenges; weak enforcement of risk policies, limited local expertise in quantitative risk modeling, Corruption and bureaucratic delays in approvals persist.

The Ethiopian Road construction industry is gradually institutionalizing risk management, but gaps remain in technology adoption, financial risk hedging, and regulatory enforcement. This assessment summarizes current risk management trends in Ethiopia's road construction sector by referencing academic studies, government publications, and industry best practices.

Complex Nature of Risks in Road Projects

Due to the inherent complexity of road and highway construction, risk assessment is a difficult procedure. Risks are frequently linked; for example, technological problems might cause delays and higher expenses. Delays might thereby raise expenses and overhead. Every project's unique circumstance, such as its goals, organizational structure, and environmental influences, must be taken into account during risk assessments. While some initiatives prioritize time, others may favor quality or expense. The unique context of the project determines whether a given risk is predominantly seen as a cost or scheduling issue. The main features of risk assessment are examined in the sections that follow. In the construction sector, risk treatment procedures are still uneven and poorly understood. The tools, procedures, documentation, and communication used in risk management are less standardized than those used in other project management domains.

Shahbodaghlou et al. (2012) add that project risks arise from diverse areas—political, economic, social, technological, geographic, and implementation-related factors. These risks often intensify one another and have both direct and indirect effects on project outcomes. Therefore, risks should not be assessed only by their likelihood and direct impact. A risk's priority should be based on its prominence; meaning its overall effect on project goals and its influence on other risks.

To manage project risks effectively, it's necessary to categorize them in a structured way. This allows for a detailed and systematic analysis of individual risk sources. According to PMI's PMBOK Guide (2008), the Risk Breakdown Structure (RBS) helps identify, organize, and manage project risks. It also familiarizes risk managers with recurring risk sources and improves overall risk handling efficiency. The RBS frequently illustrated in the PMI's PMBOK Guide is depicted in Figure 1. below.

N.B: the Risk Breakdown Structure lists the categories and sub-categories within which risks may arise for a typical project. Different Risk Breakdown Structures will be appropriate for different types of projects and different types of organizations.

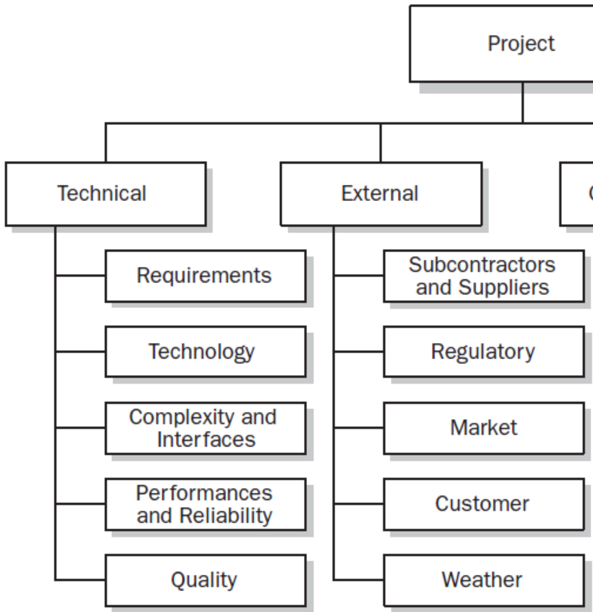

Figure 1. Sample Risk Breakdown Structure –RBS, (Source: PMBOK Guide 4th edition, 2008)

Figure 1 outlines four main risk categories: Technical, External, Organizational, and Project Management.

- Technical risks are associated with the technologies used in the project.
- External risks arise from factors beyond the project manager's control, such as inflation or environmental conditions.
- Organizational risks occur due to limited resources within the organization.
- Project management risks involve issues related to planning, estimating, controlling, and communication.

Given the complexity and uncertainty of modern projects, prioritizing risks requires a structured assessment method. A systematic approach supports group decision-making through pair-wise comparisons, where experts evaluate the presence and strength of relationships between different risks. This process helps identify the most significant risks and build a hierarchical model that shows their interconnections and influence.

1.4 STATEMENT OF THE PROBLEM

Despite the popularity of the construction industry for involving many stakeholders and contribution to the economic growth, projects fail to achieve their intended goals due to poor risk management. These failures could be expressed in terms of sever project delay, cost overruns and poor quality (Nasirzadeh, Afshar, & Khanzadi, 2008).

Additionally, these failures may occur at any point during the project, so a thorough risk analysis and management strategy is essential to improving project performance and preventing or reducing project failures while preserving the construction industry's ability to contribute to the economy. Nevertheless, the number of risks and their interdependencies are growing as a result of project development and the complexity of the environment in which the projects are carried out. Accordingly, a more effective and realistic method is suggested to streamline the construction industry's risk assessment procedure (Sukran Seker, 2017). The impact of various risks on project goals is evaluated during the risk analysis phase, which is the most crucial stage of the risk management process, according to Farnad Nasirzadeh (2008). Therefore, an integrated systematic risk analysis approach is required to account for the complex character of projects as well as the growing number and interdependency of risks in the road building business in Addis Ababa.

1.5 OBJECTIVE OF THE RESEARCH

1.5.1 General

This study highlights the need for a new fuzzy-based, systematic approach to risk assessment in Ethiopia’s road construction sector. It introduces and contextualize the methodology to the road construction sector for creating a structured, hierarchical model of risk relationships using fuzzy logic, specifically through the Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) technique.

1.5.2 Specific Objectives of the Research

1) To identify the most significant and influential risks within Addis Ababa’s Road construction industry.

2) To propose a systematic risk analysis framework using the Fuzzy DEMATEL approach for Addis Ababa's Road construction sector.
3) To construct a hierarchical model or causal relationship diagram for analyzing risks which are found in the Addis Ababa's Road construction industry.

The research aims to enhance understanding of the importance of risk management in achieving successful project outcomes. This, in turn, supports improved accessibility and mobility by expanding the city's road network.

Additionally, it serves as a practical guide for risk identification, evaluation, and allocation in road construction and other major infrastructure projects.

Ultimately, the study seeks to pinpoint the root causes of delays, cost overruns, and quality issues, and to suggest actionable solutions for completing road projects within the allocated budget and timeframe, without compromising on quality.

1.6 SIGNIFICANCE OF THE RESEARCH

The significance of this project is to point out prominent risk categories in the construction industry and try to draw a causality diagram for risk interrelationship.

Generally, the construction industry will get:

- ✓ Information on the prominent risks and risk categories that highly affect project objectives.
- ✓ A causal relationship diagram based on identified risks in the Addis Ababa's Road construction industry.
- ✓ Effective project and/or Risk managers who will be able to draw conclusions based on the level of impacts each risk categories impose on the project goals.
- ✓ An effective method of risk analysis approach based on expert's opinions.

After examining current risk management practices, the likelihood and relevance of various risk variables, the application of risk management processes, and their allocations, the study also offers a conceptual risk management framework for controlling risks in Addis Ababa City Road projects. Additionally, it offers helpful advice and recommendations for improving risk management procedures.

1.7 SCOPE AND LIMITATIONS OF THE RESEARCH

The primary goal of this project is to tell the construction industry about the risks that will be prioritized based on their prominence values in the model and their impact on the risk factor structure.

This will be achieved by implementing a systematic risk assessment based on pairwise comparison decision making methods following risk identification. A selected population of experts from different fields will then determine whether or not there are interrelationships between any two risks and the degree of influence of those relationships.

Furthermore, this project, A FUZZY DEMATEL SYSTEMATIC APPROACH FOR RISK ANALYSIS IN THE CASE OF ADDIS ABABA’S ROAD CONSTRUCTION PROJECTS, will account experts with more than 3 years of experience to effectively gather data to identify and categorize risks so that excellent result can be found.

This project's scope is restricted to using Addis Ababa as a case study to evaluate and manage risks in urban road construction. The results are assessed in light of previous studies to determine methods for reducing different risks. In order to emphasize the significance of efficient risk management in accomplishing project goals, this study applies a single analytical strategy to examine particular risk analysis tools and techniques. However, a number of issues that arose throughout the study prevented the suggested methodology from being tested in a prototype road construction project.

1.8 ORGANIZATION OF THE RESEARCH

There are five chapters that make up this project paper. A general overview, the construction industry and the Ethiopian construction context, the current state of risk management in Ethiopia, the problem statement, research objectives, the significance of the study, its scope and limitations, the research structure, and the intended beneficiaries are the nine sections that make up Chapter One, which also provides the introduction and background. Chapter Two examines the body of research on the subject. The research concept and the techniques for gathering and analyzing data are described in Chapter 3. The results and discussion, along with a risk analysis and decision-support framework, are presented in Chapter 4. The last chapter, Chapter 5, offers a summary of the findings, suggestions for further research, and recommendations.

1.9 BENEFICIARY OF THE RESEARCH

From this research paper, all stakeholders in the construction industry will be beneficiary. As poor Risk Management the primary problem of this developing industry, this research will be useful in many situations. Some of the advantages that all parties involved in the road construction sector will receive from this research are listed below.

- ✓ It will assist all stakeholders in anticipating and mitigating potential outcomes and issues during project preparation.
- ✓ When choosing whether or not to proceed with a project given the state of the workplace at the moment.
- ✓ When it's necessary to enhance safety and control possible hazards in the workplace.
- ✓ When planning for things like natural disasters, equipment or technological failures, and failures of working methods.
- ✓ When preparing for changes in the workplace, such as the entry of new competitors, modifications to political stability in the nation, or changes in government policy.

In addition to the above listed points, the study output is beneficial to students, professionals, researchers as an input for future studies in risk analysis and management areas.

CHAPTER TWO: LITERATURE REVIEW

2.1 GENERAL

Chapter Two focuses on several core areas: the road construction industry in Addis Ababa, definitions of risk and uncertainty, risk management practices in road construction, risk identification and analysis techniques, and the application of the Fuzzy-DEMATEL method for risk analysis.

This literature review aims to provide a comprehensive understanding of the Ethiopian road construction sector, particularly in Addis Ababa. It explores scholarly work on risk concepts, risk analysis methods, and management strategies, drawing from both local and international research. Sources include academic journals, conference papers, and studies published in fields such as civil engineering, construction management, project risk analysis, and fuzzy logic applications. Additional context was obtained from local reports, newspapers, and magazines to better understand the practical challenges facing Addis Ababa's Road infrastructure.

To support this review, extensive searches were conducted using electronic databases such as ScienceDirect, Web of Science, and Google Scholar, along with Addis Ababa University's digital library. Keywords like construction risk, project risk, risk management, risk modeling, risk allocation, and real estate risk were used in various combinations to ensure a comprehensive literature search.

This chapter is divided into four main sections:

1. An overview of the road construction industry in Ethiopia, with a focus on Addis Ababa.
2. Definitions and concepts of risk, risk management, and mitigation strategies.
3. A review of risk analysis principles, including risk prioritization techniques proposed by various researchers.
4. A discussion of common risk types and categories in road construction, based on an extensive review of relevant literature.

2.2. ROAD CONSTRUCTION INDUSTRY IN THE CONTEXT OF ADDIS ABABA

The Addis Ababa City Roads Authority (AACRA) was established in 1998 by the city administration to oversee the planning, development, and maintenance of road infrastructure. The whole road network of Addis Ababa was roughly 1,300 km long at the time of its establishment, consisting of 400 km of asphalt-surfaced highways and 900 km of gravel roads (AACRA, 2012). Since then, AACRA has improved and expanded the city's road system, particularly in the last ten years (Tegabu, 2015).

As of recent records, the total road length in Addis Ababa has grown to 6,573 km, up from 5,365 km in 2014. Asphalt roads now account for around 2,616 km, or 44% of the network (World Highways, accessed May 19, 2023). AACRA aims to increase road coverage to 25% of the city area. According to its 2014 annual report, road density had reached 23.46 km/km² by the end of that Ethiopian fiscal year (AACRA, 2022).

Notwithstanding these successes, numerous ongoing and finished road projects encounter diverse difficulties at different stages of their execution. Scope modifications, bad design, right-of-way (ROW) disputes, contractor poor performance, and quality flaws are common problems that frequently lead to project delays, cost overruns, and decreased value (Hassen, 2017).

In addition, many older roads in the city were not planned using modern standards, resulting in narrow lanes and outdated infrastructure that struggle to accommodate the rapidly growing number of vehicles. Even outside peak hours, traffic congestion has become a regular problem (Tegabu, 2015).

As Temesgen (2015) noted, many road projects in Addis Ababa suffer from long delays, excessive costs, and substandard quality. Some projects have been terminated mid-construction and handed over to new contractors or completed by AACRA's in-house teams. These challenges are largely attributed to poor project and infrastructure management, as well as design flaws, which in turn lead to high post-construction maintenance costs.

Emran (2017) and Nadeem et al. (2010) also highlight that delays can result in significant losses in service delivery, which, if quantified, represent substantial economic damage. Delays also reduce public satisfaction and client trust. Therefore, efficient project management is critical to minimizing such losses.

Urban road projects face additional obstacles related to the slow clearance of obstructions from Right-of-Way (ROW) areas. This not only reduces productivity but also contributes to time and cost overruns. The sources of risk in these projects can generally be grouped into five categories: risks during project initiation, design, bidding, implementation, and operation or maintenance.

Widespread delays in Addis Ababa’s Road construction projects have disrupted daily transport, with some roads left unmaintained for extended periods. Poor drainage systems have led to water stagnation during rainy seasons, causing severe traffic congestion and discomfort for road users. These issues have negatively impacted both residents’ quality of life and the city’s broader development. Based on performance reviews, nearly all road projects implemented by AACRA since its inception in 1998 have experienced delays and cost overruns (Tegabu, 2015).

Due to Addis Ababa's faster rate of urbanization than other major Ethiopian cities, the city's construction sector is vital to the expansion of the national economy. Even though urban areas receive relatively less investment than rural areas, they nonetheless account for more than 60% of the national GDP. Given its potential to advance national development, increased investment in urban infrastructure is both economically justified and required.

2.3 INTRUDUCTION to RISK and UNCERTAINTY

Risk and uncertainty characterize situations where the actual outcome for a particular event or activity is likely to deviate from the estimate or forecast value. And due to the deviation of actual outcome or project objectives, risk analysis becomes an important part for many large and medium-sized construction projects; meanwhile the correct and reasonable project risk analysis can be conducive to risk management (Raftery, 2003). In road construction specifically, the primary concerns revolve around delays and cost overruns caused by unmanaged risks.

Traditionally, stakeholders such as clients, consultants, and contractors rely on past experiences and personal judgment for risk analysis and management. However, this approach lacks systematic depth. To address this gap, the current study focuses on developing a causality-based risk relationship diagram and identifying and prioritizing key risk categories that significantly impact road construction projects in Ethiopia. The objective is to facilitate timely project execution and control cost overruns.

The literature review begins by introducing fundamental concepts before delving into thematic analyses of relevant global studies.

2.4. Risk and Risk Management

2.4.1 Risk: Definition

The Project Management Institute (PMI) in its Guide to the Project Management Body of Knowledge (PMBOK®, 2003) serves as a foundational reference for risk-related definitions. According to Pennock and Haimes, risks can be broadly categorized into two types:

1. Technical risk: The possibility that a project may fail to meet its performance targets.
2. Programmatic risk: Primarily associated with cost overruns and schedule delays. This also encompasses productivity issues and other operational inefficiencies.

Recognizing this distinction is crucial, as many risk assessments focus solely on technical factors, neglecting broader influences such as project scenarios volatility and external disruptions.

As defined in the PRINCE2 Guide (2009), a risk is an uncertain event or set of events that, if they occur, will impact the achievement of project objectives. Risk is typically evaluated based on:

- Probability: The likelihood of the event occurring.
- Impact: The degree to which the event affects the project.

The guide further distinguishes between:

- Threats: Events with potential negative consequences.
- Opportunities: Events that may positively influence project outcomes.

Other definitions expand this concept. The Concise Oxford Dictionary describes risk as exposure to danger or loss. Ayele Tirfie (2013, cited in Temesgen, 2015) defines risk simply as the possibility of loss. Similarly, various researchers define risk in terms of the likelihood of harm or failure, including hazardous work conditions, environmental factors, and management practices.

In project management, risk is broadly defined as an uncertain event or condition that, if it occurs, can impact one or more project objectives either positively or negatively (PMBOK®, 2000). Other authors, such as Lewis (2010), Garvey (2009), and Clement & Gido (2006), emphasize the adverse consequences of risk on cost, schedule, quality, and scope.

The Acquisition Community Connection (2011) asserts that risk is a reflection of the uncertainty around the attainment of performance objectives within predetermined parameters. Thus, risk encompasses both opportunities (positive impacts) and threats (negative impacts), depending on how uncertainties manifest.

Risk affects every aspect of a project, including supplier performance, design, technological readiness, and environmental factors. These risks are tied to a future root cause—a fundamental issue that may trigger consequences. Each risk comprises:

- A potential future cause,
- The likelihood of its occurrence, and
- The expected consequence or impact.

Raftery (2003) also classifies risk into two directions:

- Upside risk: Outcomes better than expected.
- Downside risk: Outcomes worse than expected.

Risks and uncertainties affect not only the overall project budget and timeline but also individual components, subcontractors, and activities. This includes assumptions related to inflation, labor strikes, or adverse weather. **For this study**, the definition by PRINCE2 (2009) and PMI (2013) is adopted—risk is "an uncertain event or condition that, if it occurs, has a positive or negative impact on a project's objectives."

2.4.2. Risk Management:

Risk management is interpreted differently by various scholars, though most agree on its systematic nature. Edwards and Bowen (1998), and El et al. (2015), as cited in Milka (2016), describe it as a structured approach to identifying and responding to risk. The PMBOK® Guide (2000) defines project risk management as "the systematic process of identifying, analyzing, and responding to project risk." Similarly, PRINCE2 (2009) outlines risk management as the structured application of techniques to recognize, assess, and mitigate risks.

Shehu and Sommerville (2006, cited in Temesgen, 2015) and Tegabu (2015) describe risk management as the continuous monitoring and control of risks to limit their impact on project objectives. It involves:

- Risk identification,
- Risk analysis,
- Response planning, and
- Ongoing monitoring and control.

This process begins early in the project lifecycle, ideally during the planning phase, and continues throughout the execution and completion phases.

Zavadskas et al. (2010) and Milka (2016) agree that risk management includes repeated cycles of identification, analysis, and response based on feedback and changing circumstances. The goal is not only to avoid negative outcomes but also to capitalize on opportunities that may arise from uncertainties.

As outlined by Caltrans (2007), the risk management process supports project teams in evaluating alternatives and making informed decisions to enhance the likelihood of meeting critical objectives—sometimes sacrificing secondary goals to achieve higher-priority outcomes such as timely delivery.

Royer (2000, cited in Temesgen, 2015) emphasizes that poorly managed risks are among the top causes of project failure. Effective risk management enables project managers to:

- Reduce negative impacts on scope, schedule, cost, and quality,
- Maximize potential opportunities,
- Avoid crisis-driven management.

The PMBOK® Guide (2000) recommends assigning dedicated personnel (e.g., a risk officer) under the project manager's supervision to ensure consistent risk management. Organizations implementing structured risk management systems should treat the implementation as a separate project, with clear objectives, proper planning, allocated resources, and regular monitoring.

Potts (2008, cited in Temesgen, 2015) breaks down risk management into three stages:

1. Identification – Determining what might go wrong,
2. Analysis – Assessing the probability and impact,
3. Response – Planning actions to mitigate risk.

Similarly, Lewis (2010) proposes:

1. Identifying risks and threats,
2. Prioritizing them using risk scoring,
3. Developing contingency plans for high-priority risks.

According to PRINCE2 (2009), effective risk management requires:

1. Identification: Recognizing risks that might hinder project success.
2. Assessment: Evaluating likelihood, impact, and urgency.
3. Control: Developing mitigation strategies, assigning responsibilities, and monitoring responses.

This study follows the risk management procedures outlined in PMBOK® (2013), which includes:

- Risk Management Planning,
- Risk Identification,
- Qualitative Risk Analysis,
- Quantitative Risk Analysis,
- Risk Response Planning,
- Risk Monitoring and Control.

These steps can be initiated as early as the bidding phase of a construction project to guide the allocation of contingency reserves. As projects evolve, new risks may emerge, while others may be resolved, requiring ongoing updates and refinements to the risk management strategy (David B, 2006).

Figure 2. Cylindrical Nature of the Risk Management Process, (Source: (David B, 2006)

According to a survey by Railan (2001), a project risk management program that is used successfully would include a number of characteristics. These include:

- ✓ User requirements that are clear, stable, and feasible.
- ✓ A strong connection with users, the industry, and other relevant parties.
- ✓ An organized and systematic approach to risk management is essential to the acquisition process.
- ✓ A strategy for acquisition that aligns with risk management and risk level.
- ✓ Regular evaluation of the project and its associated risks.
- ✓ A well-defined set of success criteria (such as performance baseline thresholds) for every aspect of cost, schedule, and performance.
- ✓ Metrics to track how well risk-handling tactics are working.
- ✓ A successful program for testing and evaluation.

- ✓ Formal documentation.

These results provide a great foundation for establishing a uniform procedure for highway project risk management since they are immediately applicable to the planning, designing, and construction of highway systems.

i. Risk Management Planning

Risk management planning involves outlining how risk-related activities will be carried out throughout the life cycle of a project (PMI, 2013). As described by the Acquisition Community Connection (2011, cited in Temesgen, 2015), it refers to the structured and systematic development of strategies and methodologies for identifying, assessing, and managing risks. This process includes setting priorities for risk handling, creating mitigation plans, monitoring the progress of risk responses, and ensuring the necessary resources are allocated for implementing risk management strategies. Additionally, it plays a role in designing training programs and facilitating the flow of risk-related information among project stakeholders.

The primary benefit of risk management planning is to ensure that the scope, intensity, and visibility of risk management efforts align with both the project's level of risk and its overall importance to the organization. The risk management plan also serves as a communication tool to gain the agreement and support of all stakeholders, ensuring consistent and effective implementation throughout the project's duration (Temesgen, 2015). A well-structured plan increases the likelihood of success for other risk management processes, enables timely allocation of resources, and provides a standardized basis for evaluating risks. Ideally, this planning should begin at the project's inception and be completed early in the planning phase (PMBOK, 2013).

According to the Acquisition Community Connection (2011), several essential components are required for effective risk management planning. These include:

- ✓ Defining project objectives, goals, and constraints
- ✓ Establishing risk management terminology
- ✓ Providing training on risk processes and procedures
- ✓ Assigning roles and responsibilities for risk management

- ✓ Creating structured procedures for risk identification, assessment, mitigation, and monitoring
- ✓ Developing a formal Risk Management Plan

It is further explained that risk planning typically starts during the concept exploration phase and is continuously refined as the project progresses through various stages. The fundamentals of risk planning provide foundational knowledge on initiating and carrying out the process successfully.

As noted by Caltrans (2007), the main output of this process is the Risk Management Plan, which outlines and organizes all risk management activities to be integrated into the overall project plan.

ii. Risk Identification

Risk identification refers to the process of recognizing the sources and types of risks that may affect a project and documenting their characteristics for current and future reference (Flanagan & Norman, 1993, as cited by Temesgen, 2015). According to the Acquisition Community Connection (2011), risk identification involves discovering, defining, describing, and effectively communicating potential risks before they evolve into actual problems that could negatively impact the project. Accurate and thorough identification is crucial, as it serves as the foundation for all subsequent risk management efforts. The objective is to identify as many potential risks as possible, resulting in a comprehensive risk list that can later be analyzed and prioritized by project stakeholders. This process also aims to determine the origins and nature of each risk, clarify risk responsibilities, and recognize possible conditions that could trigger risk events in a construction project (Wang & Chou, 2003).

Risk identification is widely considered the first and one of the most critical steps in the risk management process. Without it, analyzing, evaluating, or mitigating risks becomes impossible. Wang and Chou (2003) and Andi (2006), as referenced by Milka (2016), emphasize that the primary goal in practice should be to identify key and critical risks rather than attempting to consider every possible risk, which would be inefficient and counterproductive. The main benefit of this step, as outlined in the PMBOK (2013), lies in its ability to document potential risks and empower project teams to anticipate and prepare for future challenges.

How the list of identified risks is handled depends largely on the complexity and scale of the project. For simpler, low-cost projects with minimal uncertainty, risks might only be tracked as a list of warning indicators. However, in large-scale, high-cost projects where uncertainty is high, the identified risks feed into a more detailed and structured process involving risk assessment, mitigation planning, resource allocation, monitoring, and continuous updating (David B., 2006).

There are various techniques for identifying risks, including brainstorming, structured walkthroughs, process analysis, and systematic inspections. No matter which method is used, it is critical to involve personnel from key functional areas to ensure comprehensive identification and avoid overlooking potential risks. This highlights the need for risk identification to be an ongoing activity. Even in the later stages of project execution, multiple iterations of the identification process may be required to effectively address emerging risks and maintain project objectives. According to Caltrans (2007, as cited by David B., 2006), designated project stakeholders identify both threats and opportunities by utilizing the following:

1. A project-specific Risk Breakdown Structure (RBS)
2. Their personal knowledge of the current or similar projects
3. Consultations with individuals who have in-depth knowledge of the project or its context
4. Insights from experts familiar with comparable projects and environments

Risk Identification Techniques

The team gathers the project's risk events to start the risk identification process. Depending on the project's nature and the team members' risk management abilities, the identification process will differ, but most identification processes start with a review of the problems and uncertainties that the project development team has raised (David B, 2006).

It's critical to identify the actual threats that are most likely to materialize during the risk identification process, where common sense and reason must win out. According to Acquisition Community Connection (2011), there are a number of techniques and resources available for recording risk statements. The PMBOK (2013) outlines methods and procedures for identifying and classifying risks. These methods and procedures typically include brainstorming, risk checklists, expert opinion/structured interviews, questionnaires, historical data, prior experience, testing and modeling, evaluation of other projects, scenario analysis, and project plan analysis.

Depending on the strategy that works best for the team, these methods can be applied separately or in combination.

Table 1. Risk Identification Tools and Techniques (Source: (David B, 2006)

Project-Specific Documents	**Programmatic Documents**	**Techniques**
▪ Project description	▪ Historical data	▪ Brainstorming
▪ Work breakdown structure	▪ Checklist	▪ Scenario planning
▪ Cost estimate	▪ Final project reports	▪ Expert interviews
▪ Design and Construction Schedule	▪ Risk response plans	▪ Nominal group methods
▪ Procurement plan	▪ Organized lessons learned	▪ Delphi methods
▪ Listing of team's issues and concerns	▪ Published commercial databases	▪ Crawford slip methods
	▪ Academic Studies	▪ Influence or risk diagramming

According to the Acquisition Community Connection (2011) and PMI (2013), the previously mentioned risk identification techniques can be further detailed as follows:

- **Documentation Reviews:** This involves systematically reviewing project documents such as plans, assumptions, records from previous projects, contracts, and other relevant materials. The quality of these documents, as well as their consistency with project requirements and assumptions, can help highlight potential risks.
- **Information Gathering Techniques:** Several methods fall under this category:
    1. Brainstorming: The objective is to generate a comprehensive list of project risks. This is typically done by the project team, often with input from external experts across disciplines. A facilitator leads the session, which may take the form of open brainstorming or structured approaches like the nominal group technique, where ideas are gathered through mass interviews.
    2. Interviewing: Speaking with experienced team members, stakeholders, and subject matter experts provides valuable insights for identifying risks.

3. Root Cause Analysis: This technique identifies a problem, uncovers its underlying causes, and helps the team develop preventive measures.

- **Checklist Analysis:** Checklists can be created from historical data, lessons learned from similar past projects, and other sources. The lowest levels of a risk breakdown structure can also serve as checklists. While checklists are quick and easy to use, they should not replace comprehensive risk identification efforts. Teams should look beyond the checklist, updating and refining it over time. It's important to review and enhance the checklist during project closure to capture new lessons for future use.
- **Assumptions Analysis:** Every project plan is built on a set of assumptions. This analysis examines those assumptions for accuracy, stability, consistency, and completeness. It helps identify risks that might arise if these assumptions prove to be invalid.
- **Diagramming Techniques:** These tools help visualize potential risks and their causes:
  1. Cause and Effect Diagrams (also known as Ishikawa or fishbone diagrams) help trace risks back to their root causes.
  2. System or Process Flow Charts illustrate the relationships and causal mechanisms between various elements within a system.
  3. Influence Diagrams show causal relationships, sequences of events, and connections between variables and outcomes.
- **SWOT Analysis:** This technique analyzes the project from the perspectives of Strengths, Weaknesses, Opportunities, and Threats. It broadens the scope of identified risks by considering both internal and external factors. The process begins by identifying organizational strengths and weaknesses as they relate to the project. It then explores how strengths create opportunities, how weaknesses may lead to threats, and how strengths might counteract threats or how opportunities could help address weaknesses.
- **Expert Judgment:** Risks can also be identified through consultation with experts who have relevant experience with similar projects or industries. The project manager should identify and engage these experts to provide input on potential risks. It is important to remain aware of possible biases in their assessments during this process.
- **Surveys:** This technique involves developing a set of questions aimed at uncovering risks in specific areas. One limitation of surveys is that respondents may be reluctant to complete

them or may provide inaccurate or incomplete information. Since surveys are typically a hands-off method, they often lack the context and deeper insights behind the responses. As a result, the usefulness of survey data can be difficult to assess, especially when answers are subjective or when questions are narrowly focused.

- **Working Groups:** Working groups provide an effective forum for discussing specific areas or topics within a project to identify risks that might not be immediately obvious to the core risk identification team. These groups usually consist of individuals who are focused on particular aspects of the project and can contribute detailed knowledge from their area of expertise.
- **Experiential Knowledge:** This refers to information gained through personal experience. While valuable, it is essential to carefully assess whether such knowledge is relevant and applicable to the current project context before relying on it for risk identification.
- **Documented Knowledge:** This is information that has been formally recorded about a specific subject or area. It can offer useful insights into potential risks, but as with experiential knowledge, it is important to confirm its relevance to the current project and to be aware of any limitations or conditions attached to it.
- **Risk Lists:** These are compilations of risks identified in similar programs or situations. While risk lists can serve as a helpful starting point, caution is needed to ensure that the risks are still relevant to the current project and to understand any caveats that may apply.
- **Risk Trigger Questions:** These are lists of conditions, events, or situations within specific areas (such as performance, cost, schedule, software, or program management) that could lead to risks. They are based on risks identified in other programs and help teams proactively consider where similar risks might arise.
- **Lessons Learned:** This is a form of experiential knowledge that has been documented and compiled from previous projects. It can provide guidance for identifying risks on the current project. However, as with other knowledge sources, its applicability should be carefully evaluated in the context of the present project.
- **Historical Information:** Similar to documented knowledge, historical information refers to data and insights from past projects that are generally accepted as accurate and reliable.

This type of information can help identify risks, but it should still be reviewed for relevance.

- **Engineering Templates:** These are flowcharts and guides covering various development processes. They provide preliminary, high-level guidance for assessing activities from a top-down perspective. While they outline engineering tasks and specify inputs, outputs, and key considerations, they may not cover all critical elements. Teams must take care to identify and address any missing aspects.
- **Critical Path Templates:** These templates offer an organized method for lowering risk across various roles and during the course of the project life cycle. They also assist in mapping out possible risk regions.

Helping the experts identify potential threats is the key to success with any risk identification tool or technique. The group should analyze and pinpoint project occurrences by distilling them to a level of specificity that enables an assessor to comprehend the importance of any risk and pinpoint its origins (i.e., risk drivers).

This is a practical approach to managing the many and diverse potential risks that can surface during highway design and construction projects. Risks are things that team members think could have a bad effect on the project.

Following their identification, the risks ought to be categorized into similar risk classes. In subsequent stages of the risk analysis process, risk classification facilitates easier risk management and helps eliminate redundancy. Risk classification also makes it possible to create databases, risk registries, and risk checklists for upcoming projects.

Risks Factors

The majority of project risks have a clear source, notwithstanding their interdependencies and relationships. The following are the typical sources of project risks:

- ✓ Problems with performance, scope, quality, or technology;
- ✓ Concerns about the environment, safety, and health;
- ✓ Uncertainty about scope, cost, and schedule; and
- ✓ Political issues

The Basis of Risk

Taking into account the risk's origin is helpful when performing a risk assessment. Risks fall into one of two categories: internal or external. Uncertainties that occur inside the project team's control and scope are referred to as internal risks. A cost estimate or schedule are two examples of project documents that might be linked to the majority of internal risks. Internal risks typically relate to things that are intrinsically unpredictable, such how much concrete will cost or how long it will take to clear the right-of-way? External risks are effects that are typically put on the project by organizations beyond the project's boundaries. According to Wideman (1992), these risks typically relate to effects that are generally predictable but intrinsically unpredictable. Examples of common external risks include interactions with the public, other organizations, or authorities, as well as financial limitations and policies.

Risk Characteristics

There are various approaches to characterize risk characteristics. One popular idea in many technological domains divides risks into three categories: *known, unknown, and unknown-unknown*. An object or circumstance is said to be *known* if there is no room for doubt and everything about it is known. An identified uncertainty is represented as a *known-unknown*; we know it exists but not its precise significance. An *unknown-unknown* is a circumstance or element that is wholly unexpected and that we have not yet encountered or even imagined.

The fact that many dangers have triggers is another crucial feature. Triggers, sometimes referred to as warning signs or risk symptoms, are evidence that a risk has occurred or is likely to happen. Triggers should be kept an eye on during the risk management process and are frequently identified during the risk identification phase. Early documentation of these triggers improves the whole risk management process and facilitates efficient risk monitoring.

iii. Risk Assessment

Risk analysis involves the systematic evaluation of variables that are subject to uncertainty. Its goal is to factor in the inherent unpredictability of costs, durations, or other project elements when estimating the final cost or timeline of a project. This process helps the project manager or director assess the likelihood of staying within budget or meeting deadlines (Mack, 1995, as cited by Milka, 2016).

As outlined in PMBOK (2013), risk analysis is one of the six key processes in project risk management. It aims to strengthen decision-making by encouraging project leaders to fully apply their knowledge and experience while formally addressing risk and uncertainty. However, human decision-making in this context often involves balancing precision against relevance, and the results are sometimes expressed in imprecise, qualitative terms (Shahbodaghlou, 2012).

There are two primary parts to risk assessment. The first assesses how likely a risk is to occur, with a range of very unlikely to highly probable (David B, 2006). The impact or severity of the risk's repercussions, should it materialize, is evaluated in the second. Risks can have a direct impact on a project by raising expenses or delaying completion dates. Certain risks have wider effects, affecting the environment, public opinion, safety, or health. Others may result in indirect consequences, such the requirement for more preparation, supervision, or evaluations. Examining prospective risk events, their likelihood of occurring, and their potential repercussions methodically is the main goal of risk assessment (David B, 2006).

Clement and Gido (2006, as cited by Tegabu, 2015) describe risk assessment as linking the systematic identification of risks with the rational management of significant risks. The key inputs for risk analysis are the risks identified during the risk identification phase. The two main variables in this process are the probability of occurrence and the impact on project objectives. Each risk is assessed based on how likely it is to happen and how severely it might affect the project. Based on this analysis, risks can then be prioritized, guiding the development of risk response plans.

Table 2 illustrates the timeline from alternative analysis and conceptual design through to construction completion, highlighting various risk issues, objectives, and expected outcomes influenced by project risks.

Table 2. Risk Assessment: timing, issues, Objectives, and Outcomes (Source: (David B, 2006)

Project Phase	Status	Typical Risk Issues
Long-Range Planning/ Programming	▪ The general alignment and mode are the main focus. ▪ Environmental evaluations are not complete, and project specifications are not specified. ▪ Funding may not have been committed. ▪ Uncertain public support	▪ Fatalities or major economic effects on the environment ▪ Uncertainty in funding ▪ Uncertain public and political backing ▪ Completing competing projects and interests
Preliminary Engineering	▪ Thorough explanation of the project's objectives ▪ Environmental reviews (Record of Decision) are almost finished. ▪ Although preliminary permissions have been obtained, long-term finance commitments are still pending. ▪ Expensive and unpredictable timetable	▪ Alterations to the project's budget and scope ▪ Environmental compliance costs ▪ Proper procurement techniques ▪ Modifications to the design specifications ▪ Right-of-Way purchase ▪ Technical ambiguities ▪ Inaccurate unit pricing and quantity errors or omissions ▪ Conditions of the Market ▪ Uncertainty in funding
Final Design	▪ Project objectives are shared with contracting partners. ▪ Well-defined project scope, budget, and timeline ▪ There are only a few outstanding concerns because all construction permissions, including permits and agreements, are still pending for all costs and design details.	▪ Alterations to the project's budget and scope ▪ Inaccurate unit pricing and quantity errors or omissions ▪ Modifications to the design specifications ▪ Market dynamics and permit specifications
Construction	▪ Design finished; project identified ▪ Funding, policy, and other commitments already in place ▪ Construction is underway.	▪ Quality of construction and contractor performance ▪ Final approval and acquisition of the right-of-way ▪ Unexpected site/workplace circumstances ▪ Modifications to the Field Design ▪ Safety in Construction

Table 3. Risk Assessment and Expected Outcomes (Source: (David B, 2006)

Objectives for Risk Assessment	Expected Outcomes
▪ Determine the political, public acceptance, and approvals difficulties to implementation. ▪ Determine the costs by option in order of magnitude. ▪ Determine the main hazards in design and construction.	▪ Improved comprehension of the engineering, construction, and environmental challenges that each project alternative faces ▪ Risk cost order of magnitude and potential total cost range for each choice
▪ For all significant project components, the identification, measurement, and probability of the main scope, budget, and schedule risks ▪ An overall estimate of the likely project expenses ▪ Alternative design concepts and procurement methods' risks	▪ A list of the main project risks ▪ A fair assessment of the risks involved and the likely overall project expenses and time ▪ An extensive collection of risk-reduction techniques ▪ Initial risk management strategy with an emphasis on constructability and design risks ▪ Initial planning for risk allocation
▪ For every project component, the scope, financial, and schedule risks are identified, measured, and their likelihood is assessed. ▪ Base costs, risk costs, and the overall likely project costs are defined in detail. ▪ Verification that the contingencies in the project budget and schedule are appropriate	▪ Risks are ranked according to their effects on the overall project cost and time. ▪ Calculate the expected overall project costs and time, as well as the risk costs. ▪ Costs and advantages of risk allocation and mitigation techniques ▪ Plan for risk allocation and management
▪ Focused evaluation of construction issues, their root causes, and their effects on budget and schedule ▪ Finding and systematically assessing potential remedial measures	▪ Analysis of particular issues ▪ Benefits and costs of potential corrective measures ▪ corrective action plan that will enable project owners and sponsors to prevent cost overruns and preserve (or recover) the timeline

There are numerous risk analysis techniques commonly used in project and construction management. These include sensitivity analysis, scenario analysis, stochastic analysis, the expected monetary value (EMV) method, the risk-adjusted discount rate method, and real options analysis (Gehner et al., 2006). A comprehensive risk assessment typically combines both qualitative and quantitative approaches. Qualitative assessment is valuable for screening, ranking, and prioritizing risks, as well as for shaping effective risk mitigation and allocation strategies. Quantitative assessment, on the other hand, focuses on estimating the numerical and statistical dimensions of the project’s risk exposure.

According to the Acquisition Community Connection (2011) and Flanagan and Norman (1993), the purpose of this stage in the risk management process is to evaluate all risks identified during the risk identification phase. This involves determining the likelihood of each risk occurring and estimating its most probable impact. The assessment may include both qualitative and quantitative evaluations of how likely the risks are and their potential effects on cost, schedule, and performance. In the early stages of a project, data for quantitative analysis may not always be available, making qualitative analysis the primary tool. The balance between qualitative and quantitative methods depends on the availability of reliable data and the need to manage costs effectively. In some cases, conducting a quantitative analysis may not be cost-effective or may add little value to the development of the Project Risk Management Strategy or Risk Management Plan.

Therefore, the choice of method whether qualitative, quantitative, or a combination depends on available time, budget, and the type of risk statements (descriptive or numeric) required for the specific project.

Outputs from Risk Assessment and Allocation Process

The outputs of the risk assessment process can vary based on the type and complexity of the project. Common outputs include:

- Expected value analyses for cost and schedule, along with probability estimates for other potential outcomes
- Value-of-information and value-of-control assessments
- Contingency estimates for cost and duration
- Sensitivity analysis focused on specific risks
- Risk mitigation strategies and management plans
- Risk-based recommendations for project contracting or procurement approaches

- Risk allocation decisions that align team members with customer-focused performance objectives

2.4.3. Risk Analysis

PMI's PMBOK (2013), classififed Risk Analysis as Qualitative and Quantitative Risk Analysis.

2.4.3.1 Qualitative Risk Analysis

According to PMI (2013), qualitative risk analysis is the process of ranking risks for more study or action by evaluating and integrating their impact and likelihood of occurrence. The process of ranking risks for additional study or action by evaluating and integrating their impact and likelihood of occurrence is also known as qualitative risk analysis. Typically, risk identification results in a lengthy list of risks that may be divided into different categories. Time and resource constraints, however, prevent all threats from receiving the same level of attention. Furthermore, not every threat merits the same degree of consideration. The goal of the qualitative risk analysis phase is to identify the greatest opportunities and the biggest threats, so risks should be given priority for additional attention (AMA, 2011).

Direct judgment, choice rating, option comparison, and descriptive analysis of the threats that have been discovered are all part of qualitative risk assessment. The PMBOK (2013) states that qualitative risk analysis typically establishes priorities for plan risk responses quickly and affordably. It also provides the groundwork for quantitative risk analysis, if necessary. To keep up with changes in project risks, which may lead to quantitative risk analysis or straight to plan risk responses, it is carried out on a frequent basis throughout the project's life cycle. Risk data quality evaluation, risk categorization, risk urgency assessment, risk probability and impact assessment, probability and impact matrix, and expert opinion are some of the methods and resources used. This process's main advantage is that it helps project managers concentrate on high-priority risks and lower uncertainty. The importance of a risk may be increased by the time-sensitive nature of risk-related actions. Clarifying the judgment of the risk's significance to the project is another benefit of evaluating the caliber of the information already available on project risks (Tegabu, 2015).

2.4.3.2 Quantitative Risk Analysis

Quantitative risk analysis, though not commonly applied in construction projects, can be a highly valuable tool for supporting project management decisions. This process employs techniques such as Monte Carlo simulation and decision analysis to evaluate and validate key project assumptions (PMI, 2003). For instance, it can help:

- Determine the probability of achieving specific project objectives
- Identify realistic and achievable targets for cost, schedule, or scope

According to Flanagan and Norman (1993), quantitative risk analysis provides a numerical estimate of the likelihood that a project will meet its cost and schedule goals. Similarly, PMBOK (2013) defines it as the process of numerically analyzing the impact of identified risks on the project's overall objectives. This analysis involves evaluating the combined effect of all identified and quantified risks. Quantitative risk analysis is generally applied to risks that have already been prioritized during the qualitative risk analysis phase, specifically those that could significantly affect the project's competing demands. One of its main purposes is to consolidate the individual impacts of various risks into a comprehensive estimate of the overall project risk.

A range of techniques can be used for quantitative risk assessment, including: probability analysis, sensitivity analysis, scenario analysis, simulation (e.g. Monte Carlo), correlation analysis, portfolio theory, Delphi method, influence diagrams, and decision trees.

Quantitative risk analysis typically follows the qualitative risk analysis phase. However, in some cases, this process may not be feasible due to insufficient data for building reliable models. In such situations, the project manager must rely on expert judgment to assess whether quantitative analysis is necessary and practical.

Importantly, the goal of quantitative risk analysis is not limited to generating numerical estimates of risk exposure. It also serves to provide a solid foundation for evaluating the effectiveness of risk management strategies and risk allocation decisions.

There are numerous tools and methods available for quantitatively assessing and integrating risks. The choice of method usually requires balancing analytical sophistication with practicality and ease of use. The following five criteria can guide the selection of an appropriate quantitative risk analysis technique:

1. The method should incorporate the explicit knowledge of the project team regarding site conditions, design, political environment, and project strategy.
2. It should enable a rapid response to changing factors, such as market conditions, price fluctuations, or shifts in contractual risk allocations.
3. The method should support the determination of appropriate cost and schedule contingencies.
4. It should facilitate clear communication among project team members and with senior management about project uncertainties and their potential impacts.
5. The methodology should be straightforward and easy for the team to use and understand.

iv. Risk Mitigation and Response Planning

Risk mitigation is a risk response strategy in which the project team takes proactive measures to reduce the probability of occurrence or the potential impact of a risk. This approach aims to lower the likelihood and/or impact of an adverse event to levels that fall within acceptable thresholds. Acting early to minimize a risk's probability or consequences is generally more effective than attempting to address the damage after the risk has materialized. Mitigation efforts may involve steps such as prototype development, especially when scaling up from a bench-scale model to a full-scale process or product. When it is not feasible to reduce the probability of a risk, mitigation strategies may instead focus on minimizing its impact by addressing the key factors that determine the severity of its consequences. A well-prepared risk response plan should also include clearly defined trigger points or warning indicators that signal when mitigation actions need to be implemented.

The primary goals of risk planning and mitigation are to investigate and specify suitable reaction tactics for high-priority risks found in the qualitative and quantitative risk assessments. This procedure guarantees that every risk that needs to be addressed has a designated owner who is responsible for carrying out the intended course of action. It also defines who is in charge of carrying out each response strategy.

Effective risk mitigation and planning may require organizations—such as highway agencies—to establish formal policies, procedures, goals, and accountability standards. Institutionalizing these practices helps build a strong risk management culture, which in turn can lead to improved cost control from project planning through construction. It also promotes better risk allocation, ensuring that project teams are aligned with customer-focused performance objectives.

A clear understanding of the risks, their potential magnitude, and available response options allows for informed decision-making about when, where, and to what extent risk exposure should be addressed.

The process of creating options and courses of action to maximize favorable chances while lowering risks to the project's goals is known as risk response planning. This process's main advantage is that it integrates required resources and activities into the project's budget, timeline, and management plan while effectively prioritizing risks (PMBOK, 2013). Alternatively put, risk response planning is making choices backed by careful risk assessments (Gehner et al., 2006, as referenced by Milka, 2016). These choices demonstrate the organization's readiness to take on specific risks and use one or more of the four broad categories of risk responses (Alsalman, 2012, as quoted by Milka, 2016).

Risk response planning includes formulating specific action plans to reduce either the likelihood or the impact of each identified risk. It involves establishing trigger points that indicate when these actions should be executed and assigning responsibility for carrying them out to designated individuals. For each agreed-upon and funded risk response, it is essential to understand how the response will address the risk, and to assign ownership to a single person who will ensure its implementation (Tegabu, 2015). Effective risk responses should be proportionate to the significance of the risk, cost-efficient, realistic within the project’s context, agreed upon by all relevant stakeholders, and assigned to a responsible owner (PMBOK, 2013).

According to Acquisition Community Connection (2011), risk response planning involves determining and documenting appropriate actions for each risk that has been identified as significant to the project. In some cases, risks may pose such a substantial threat that the project team decides to avoid them entirely. Alternatively, the team may choose to transfer the risk to another party that is better equipped to manage or absorb its potential impact.

Clement and Gido (2006), as cited by TMA, emphasize the importance of using a structured approach when developing a risk handling strategy. This approach involves creating detailed plans and defining decision points that specify how each identified risk will be addressed. It also includes outlining when and how risk mitigation plans will be implemented once the decision is made to act on them.

In the context of construction projects, Flanagan and Norman (1993) identify four primary risk response strategies. Similarly, PMBOK (2013) highlights that since risks can represent either threats or opportunities that affect project success, risk response planning must account for both. For negative risks (or threats), the main response strategies are avoidance, transfer, mitigation, and acceptance. For positive risks (or opportunities), the strategies include exploit, share, enhance, and acceptance.

Risk Response Options for Threats

Effective risk response options are built on the foundation of thorough risk identification, assessment, and analysis. In the construction industry, implementing a series of well-planned risk response actions can help parties avoid, mitigate, or manage the risks they face. As outlined by Wideman (1992) in the Project Management Institute's standard Project and Program Risk Management: A Guide to Managing Risks and Opportunities, risks can be addressed in several ways:

- Left unrecognized, unmanaged, or ignored (by default).
- Recognized but deliberately not acted upon (absorbed as a matter of policy).
- Avoided through appropriate preventive measures.
- Reduced by adopting alternative approaches.
- Transferred to other parties via contracts or insurance.
- Retained and absorbed through prudent allowances.
- Managed using a combination of the above strategies.

Risk retention: Risk retention refers to both the voluntary and involuntary acceptance of potential risk consequences (Laster, 1999). In this approach, risks and their possible impacts are consciously accepted as part of the investment decision, taking into account the investor's risk appetite (Wiegelmann, 2012, as cited by Milka, 2016). Risk retention is particularly suitable for risks that result in small, repetitive losses that can be reasonably absorbed. For example, in motor insurance, many individuals choose to retain a fixed amount of loss (an excess or deductible) in exchange for a lower premium, while others may prefer the opposite. The level of risk retention typically depends on financial capacity and the likelihood of loss. Additionally, not all risks can be transferred, and even when transfer is possible, it may not be economically viable. In such cases, retaining the risk becomes necessary.

Risk reduction: Risk reduction involves preventing or minimizing loss by lowering the likelihood of a risk event occurring or by limiting its potential impact (Haller, 1986, as cited by Milka, 2016). This strategy is most applicable to risks that develop gradually rather than appearing suddenly (Hagos, 2016). According to Wiegelmann (2012), risk reduction strategies can be either proactive or reactive, and they can even be put into place after a risk has already occurred. Sharing it with others is a popular way to lower risk exposure. For example, by incorporating liquidated damages provisions into subcontractor agreements, a general contractor can shield themselves from having to pay liquidated costs for late completion. Adopting certain contractual structures, including management fee contracts, can also lessen the possibility of direct loss and expenditure claims and lessen hostile attitudes from contractors.

Risk transfer: Risk transfer involves shifting the financial consequences of risks to external parties, such as insurers or subcontractors (Laster, 1999, as cited by Milka, 2016). This approach does not eliminate the source of the risk; it simply assigns responsibility for its impact to another party. Another way to transfer risks is to divide the risk and profit among several partners or to completely shift the risk to a third party. Although risk transfer is frequently regarded as one of the safest risk management strategies, it can be expensive and isn't always appropriate for all risks. For instance, certain contractual provisions may transfer risks to clients or suppliers (Wiegelmann,2012).

According to Mead (2007, cited by Milka Hagos, 2016), contractual exclusions, liability limitations, indemnification clauses, guarantees, performance bonds, and the inclusion of risk premiums are examples of risk transference mechanisms. Crucially, risk transfer only transfers responsibility to a new party; it does not lessen the gravity of the original danger. Transferring risk can occasionally unintentionally increase exposure if the recipient is not aware of the danger they are taking on. The most popular way to transfer risk is through insurance, which turns an unpredictable risk into a fixed, predictable expense.

Risk avoidance:

Risk avoidance is a risk response strategy in which the project team takes deliberate action to eliminate a threat or shield the project from its potential impact. This often involves modifying the project management plan to remove the threat entirely (Tegabu, 2015). Risk avoidance essentially means refusing to accept certain risks. A simple example is choosing not to enter into a contract that carries unacceptable risk.

Typically, risk avoidance is associated with decisions made during pre-contract negotiations, but it can also apply to choices made during project execution. The goal is to prevent risks from materializing by reducing their likelihood to zero. When a risk already exists, avoidance means intentionally forgoing potential opportunities that might be linked to that risk (Haller, 1986, as cited by Milka Hagos). This approach is generally appropriate only when a risk presents significant exposure that surpasses the organization's risk appetite, and when other management measures are insufficient. A more practical example of risk avoidance is the inclusion of exemption clauses in contracts, which are designed either to avoid certain risks entirely or to limit the consequences that might arise from them (Tegabu, 2015).

Risk acceptance: According to the risk acceptance strategy, the project team decides to accept a risk without acting to mitigate it right away—that is, until the risk materializes. When using alternative ways to manage a particular risk is either impractical or not cost-effective, this approach is employed. It shows that the project team has either failed to find a better solution or has chosen not to alter the project management plan to address the risk (Tegabu, 2015).

Risk acceptance can take two forms: passive or active. In passive acceptance, no specific action is taken beyond documenting the risk and its acceptance, leaving the team to respond if and when the risk materializes. The team may also periodically review the risk to ensure it hasn't changed significantly. In contrast, active acceptance involves preparing for the risk by establishing contingency reserves such as additional time, budget, or resources to address the risk if it occurs.

Risk Response Options for Opportunities

Exploit: The exploit strategy is chosen for opportunities where the organization aims to ensure that a positive risk is fully realized. This approach focuses on eliminating uncertainty related to the opportunity by guaranteeing that it will occur.

Enhance: The enhance strategy seeks to increase either the likelihood or the positive impact of an opportunity. This is achieved by identifying and strengthening key factors that drive these beneficial risks, thereby improving the chances of their occurrence.

Share: Sharing involves transferring part or all of the ownership of an opportunity to a third party that is better positioned to capture and maximize the benefit for the project.

Accept: Accepting an opportunity means the organization is prepared to take advantage of the positive risk if it arises but will not take proactive measures to pursue it. This passive strategy applies to both threats and opportunities.

v. Risk Monitoring and Control

Risk monitoring, according to Hagos (2016), is the process of evaluating how effectively all units and functions' activities match predetermined standards. It assesses if the company has met its objectives, whether risk management procedures adhere to set guidelines, whether the company is effectively organized with a suitable risk culture, and whether roles and duties are well-defined. Data collection and analysis techniques like benchmarking and key indicator analysis are used to monitor risks. The results are communicated both externally to pertinent parties and internally to the responsible functions.

The PMBOK (2013) defines risk control as the process of putting risk response plans into action, tracking identified risks, keeping an eye on residual risks, finding new risks, and assessing how well the risk management procedure is working throughout the project. By strategically applying risk management techniques, it also entails actively addressing threats that have been discovered and evaluated in order to control substantial possible losses. The main advantage of this technique is that it allows for continual optimization of risk responses while improving the overall effectiveness of risk management throughout the project life cycle. Throughout the project life cycle, planned risk responses that are part of the risk register are carried out; nevertheless, the project work should be regularly checked for new, evolving, and out-of-date risks (Tegabu, 2015).

Techniques like variance and trend analysis, which are used in the Risk Control process, necessitate the utilization of performance data produced during project execution. The Control Risks method also aims to ascertain whether the project assumptions are still true, whether an analysis reveals that an estimated risk has changed or may be withdrawn, Contingency reserves for cost or schedule should be adjusted in accordance with the current risk assessment, and risk management rules and procedures are being followed.

In addition to updating organizational process assets, such as project lessons learned databases and risk management templates, for the benefit of future projects, this process may entail selecting alternate approaches, carrying out a backup or contingency plan, taking corrective action, and adjusting the project management plan (Tegabu, 2015).

In order to determine whether there have been any changes in the likelihood of occurrence or the potential impact of any risks, risk control and monitoring throughout the project require regular evaluation of the risk management matrix (Clement and Gido, 2006). Monitoring outcomes may also serve as the basis for identifying new hazards and developing additional management options. A key component of the monitoring process is the creation of a system of cost, schedule, and performance management indicators that the project manager may use to evaluate the program's overall progress. The indicator system should be designed to provide early warning of potential problems so that management measures can be taken. Instead of fixing problems, risk monitoring is a proactive way to track the outcomes of risk management and spot emerging threats (Tegabu, 2015).

2.4.4. Risk Analysis Methods and Approaches

Choosing an appropriate risk analysis method depends on understanding what input data are available and what type of risk output is desired. In other words, the kind of output a method produces is a key factor in method selection. Generally, techniques that require greater rigor, rely on stricter assumptions, or demand more detailed input data tend to generate results that are richer in information and more useful for decision-making.

The results from risk analyses are typically categorized into three types based on their primary outputs:

1. Single-parameter output measures
2. Multiple-parameter output measures
3. Complete distribution output measures

The choice of output type depends on the objectives of the analysis. For example, if an agency needs only approximate risk estimates for project selection purposes, single-parameter outputs (such as mean values) or multiple-parameter outputs (such as mean and variance) may be sufficient. However, if the goal is to determine an appropriate contingency for a project, more detailed information such as the shape of the output distribution's tails or the cumulative distribution is necessary. Similarly, if the aim is to identify and manage key risk drivers, the chosen method should support sensitivity analysis (David B, 2006).

The following sections describe some commonly used quantitative risk analysis methods, along with their input requirements and output capabilities. These methods range from simple empirical approaches to complex, statistically based models.

Traditional Methods

Traditional risk analysis methods are empirically developed and primarily focus on establishing cost contingencies for projects. In these methods, risk factors are assigned to various project elements based on historical experience regarding their relative risk. For instance, pavement material costs might be considered low-risk, whereas right-of-way acquisitions could be seen as high-risk. The overall project contingency is calculated by multiplying each element's estimated cost by its respective risk factor. This approach is valued for its simplicity and its ability to produce a cost contingency estimate. However, it incorporates the project team's risk knowledge only indirectly through the assigned risk factors (David B, 2006).

Analytical Methods

Analytical methods also known as second-moment methods use probability calculus to compute the mean and standard deviation of project outcomes, such as total cost. These methods apply formulas that relate the mean values of input variables to the mean value of the output, and similarly, relate the variances of inputs to the variance of the output. They are most appropriate when the output is a simple sum or product of the input variables.

Simulation Models

Simulation models, often referred to as Monte Carlo methods, use computer-based probabilistic calculations that rely on random number generators to sample from probability distributions. The aim is to assess how multiple uncertainties affect a specific quantity of interest such as total project cost or duration.

Monte Carlo simulations offer several advantages. They can model cost and schedule risks in situations too complex for analytical methods, explicitly incorporate the risk knowledge of the project team, and provide insights through sensitivity analysis about how individual risk events influence project cost and schedule. While Monte Carlo methods are widely used in project risk analysis due to the rich and detailed insights, they provide into the impact of risk on project cost and schedule, their successful application requires specialized knowledge and training. Users must be able to define precise input data, including the probability distribution type, mean, standard deviation, and distribution shape for each variable. Despite these demands, the ability of Monte Carlo simulations to produce detailed and illustrative results makes them one of the most common tools for risk analysis in complex projects.

Probability Trees, Decision Trees and Influence Diagrams

Probability trees are simple diagrams that illustrate the effects of a sequence of multiple events. When these trees are used to assess different decision paths, they are referred to as decision trees. These tools are particularly effective in modeling how related variables interact, as they allow for explicit representation of conditional probabilities among project variables.

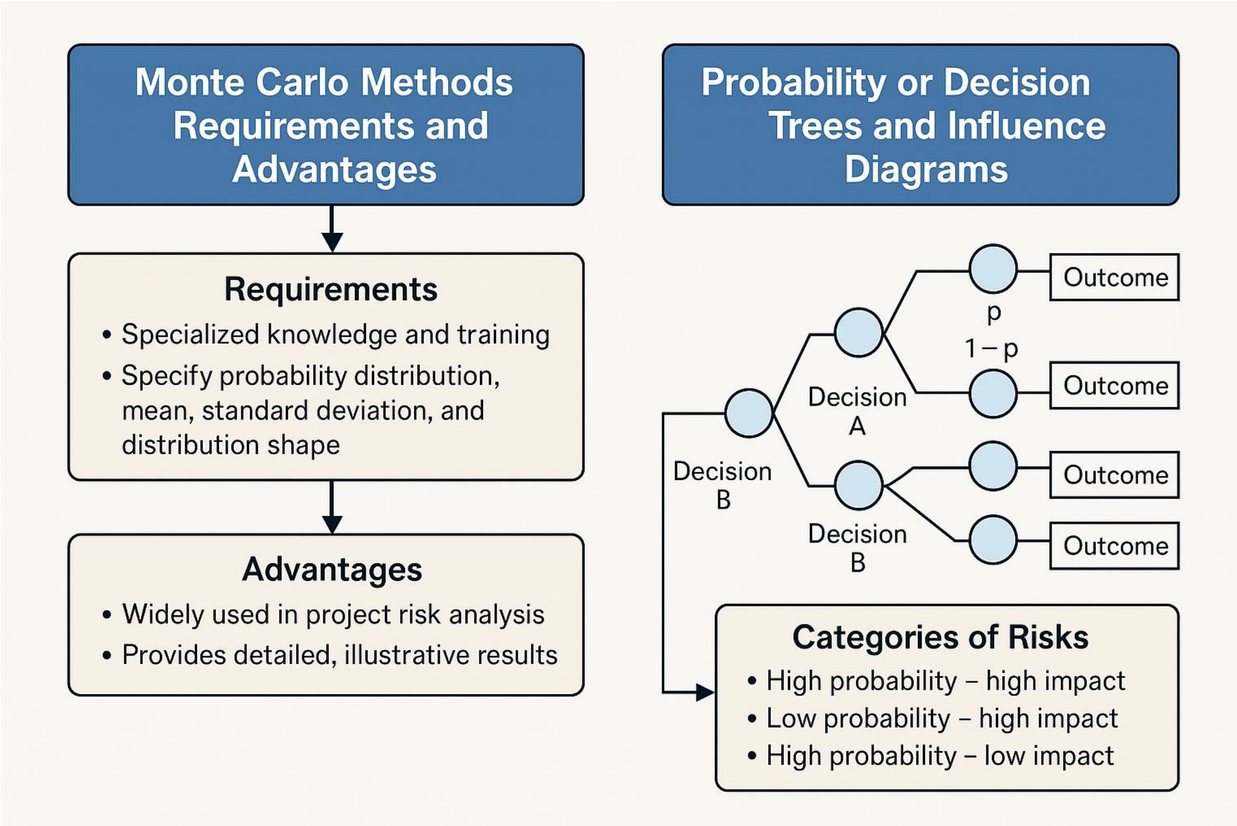

Figure 3. Comparison between Monte Carlo Simulation and Probability Tree/Influence Diagram

In most projects, risks do not occur in isolation. Instead, they tend to interact, some risks increase the likelihood of others, while some risks may eliminate the possibility of others occurring. Quantitative risk analysis typically focuses on individual risks to build a clear understanding of each one. However, it is sometimes essential to assess how combinations of risks might collectively influence project outcomes, especially regarding overall cost and schedule impacts. This requires a quantitative model capable of capturing and quantifying these combined effects (AMA, 2011).

For decision-making purposes, risks are often categorized into four main groups based on their level of probability and impact:

- High probability – high impact
- Low probability – high impact
- High probability – low impact
- Low probability – low impact

Table 4. Impact Scales for Four Project Objectives (Source: PMBOK Guide-5th edition, 2013)

Defined Conditions for Impact Scales of a Risk on Major Project Objectives (Examples are shown for negative impacts only)					
Project Objective	Relative or numerical scales are shown				
	Very low /0.05	Low /0.10	Moderate /0.20	High /0.40	Very high /0.80
Cost	Insignificant cost increase	< 10% cost increase	10 – 20% cost increase	20 – 40% cost increase	> 40% cost increase
Time	Insignificant time increase	< 5% time increase	5 – 10% time increase	10 – 20% time increase	> 20% time increase
Scope	Scope decrease barely noticeable	Minor areas of scope affected	Major areas of scope affected	Scope reduction unacceptable to sponsor	Project end item is effectively useless
Quality	Quality degradation barely noticeable	Only very demanding applications are affected	Quality reduction requires sponsor approval	Quality reduction unacceptable to sponsor	Project end item is effectively useless

The implications might be either good or negative, upside or downside, since risks are categorized according to their degree of impact and uncertainty. The low probability-low impact risk is the least significant kind of risk. To find out if it has the ability to move non-essential operations onto the critical path, even this kind of risk must be evaluated. As a result, the top project management organizations now commonly acknowledge that risk management need to be a significant and essential component of project management (Nasirzadeh, Afshar, & Khanzadi, 2008).

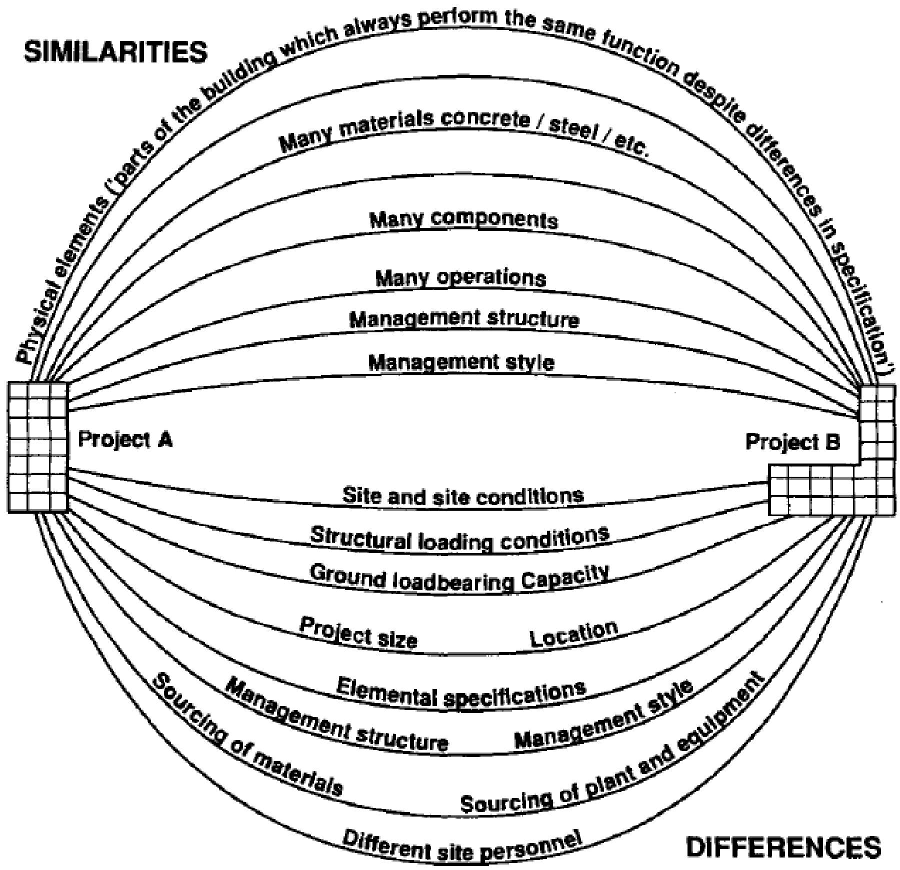

Figure 4. Project Heterogeneity (Raftery, 2003)

Over the past ten years, numerous scholars have put forth various and complex methods for risk assessments. The expert investigation approach and structural decomposition are currently the most often utilized techniques among many of these risk analysis techniques. The expert investigation method primarily consists of brainstorming, Delphi, curtain scene analysis, and other techniques; the structural decomposition method will break down the project risk based on the law of the thing itself and the individual's past experience. Examples of these techniques include fault trees, decision trees, and probability trees (Liu, 2014; Zhu, 2011). The two approaches described above thoroughly examine the different risk variables that arise throughout the building of a project, but they did not consider the connections among them. The reality is that due to the intricate engineering project construction conditions, the risks associated with project construction are not only significantly higher but also interact with one another (Liu, 2014).

Contrary to the traditional approach's foundation and widely used methods, the System Dynamics model can quantitatively analyze the significance of the various project risks, simulate the development trend based on information about the project's current status, and demonstrate how risk variables interact using the feedback loop (Liu, 2014; Xu, 2006).

Risk Analysis and Its Limitations

The risk analysis phase is often considered the most critical stage in the risk management process, as it involves evaluating the potential consequences of various risks on project objectives. This analysis not only helps in understanding the possible impacts but also assists in identifying the key factors that influence project performance, enabling timely and appropriate responses. Despite its importance, traditional risk analysis methods suffer from several shortcomings (Nasirzadeh, Afshar, & Khanzadi, 2008):

- Failure to address dynamic risk behavior: Conventional risk analysis techniques generally overlook the dynamic and evolving nature of risks throughout a project's life cycle. They also fail to account for feedback loops that can significantly influence overall risk impacts. Since many risks in projects stem from complex cause-and-effect relationships, these traditional methods often fall short in accurately assessing actual risk impacts (Nasirzadeh, 2008; APM Publishing Ltd Guide, 2004). Moreover, while risk events can greatly affect project cost, schedule, and quality, conventional techniques typically evaluate consequences in isolation focusing on either cost or time, but not both simultaneously.
- Inability to capture indirect risk effects: Traditional approaches often lack the capacity to quantify the complete impact of risks because they ignore indirect effects. Most of these methods rely heavily on qualitative analysis, limiting their ability to provide a comprehensive view of risk implications (Nasirzadeh, Afshar, & Khanzadi, 2008).

Recent major project failures have further exposed the weaknesses of traditional risk management and project management practices, particularly their inability to address strategic and systemic issues effectively (Bowers, Rodrigues, Alexandre, & John, 1996).

2.5 System Dynamics: A More Holistic Approach

The System Dynamics (SD) approach offers an alternative that addresses the limitations other methods have on considering the direct and indirect impact and interrelationship of risk categories. It allows risks to be modeled as feedback loops, enabling the quantification of their direct and indirect impacts on key project objectives such as time, cost, and quality. Compared to traditional risk analysis methods, SD provides a more robust means of assessing risks by explicitly considering the complex interactions and feedback mechanisms that exist among project components. Furthermore, System Dynamics simulation models serve as valuable tools for predicting and evaluating risk impacts before they occur, creating a “learning laboratory” where the full range of potential effects can be examined (Nasirzadeh, Afshar, & Khanzadi, 2008).

System dynamics is a methodology designed for understanding and managing complex, dynamic systems by constructing and using simulation models. Originally developed in the late 1950s for industrial system analysis, SD has since been applied successfully to a variety of areas, including social, environmental, and industrial project management challenges (Nasirzadeh, Afshar, & Khanzadi, 2008).

SD modeling is particularly valuable in scenarios involving processes that change over time and that rely on feedback, the exchange of information between system elements (Liu, 2014). A key aspect of SD is identifying and representing feedback processes, which, together with stock-and-flow structures, time delays, and nonlinear relationships, shape system behavior. These feedback loops are crucial for modeling decision-making processes and project management strategies (Liu, 2014). In construction projects, SD models map out risks and their causal relationships, helping to illustrate how different risks interact and affect the project as a whole.

Given the highly complex, dynamic, and interdependent nature of construction projects with their multiple feedback processes, System Dynamics modeling is well-suited for addressing most challenges encountered in this domain.

System Dynamics Modeling

System dynamics models are primarily designed to represent and analyze the behavior of dynamic systems over time. This modeling approach uses computer-based simulation techniques to study how systems evolve. The concept was originally developed at the Massachusetts Institute of Technology (MIT) by Dr. Jay Forrester, who made a significant breakthrough in the field in 1958 (as cited in Liu, 2014). Dr. Forrester's foundational works, Industrial Dynamics and Systems Theory, laid the groundwork for the development of system dynamics (Liu, 2014). Since then, system dynamics modeling has matured considerably and is now widely applied across various disciplines and contexts.

At the heart of system dynamics modeling is the establishment of causal relationships between variables. A causal loop diagram is used to illustrate and analyze the complex interactions among the internal variables of a system. These variables can form single or multiple feedback loops, where interrelated elements create causal chains. The strength (or polarity) of these causal links can either reinforce or weaken one another. Since the polarity between different variables may vary, the system as a whole develops a nonlinear feedback structure.

Liu (2014) created a causal relationship diagram based on a range of identified project risks, including schedule risk, construction quality risk, cost risk, environmental risk, technology risk, design risk, and benefit risk. This diagram, which depicts the interactions and feedback among these risks, is shown in Figure 5.

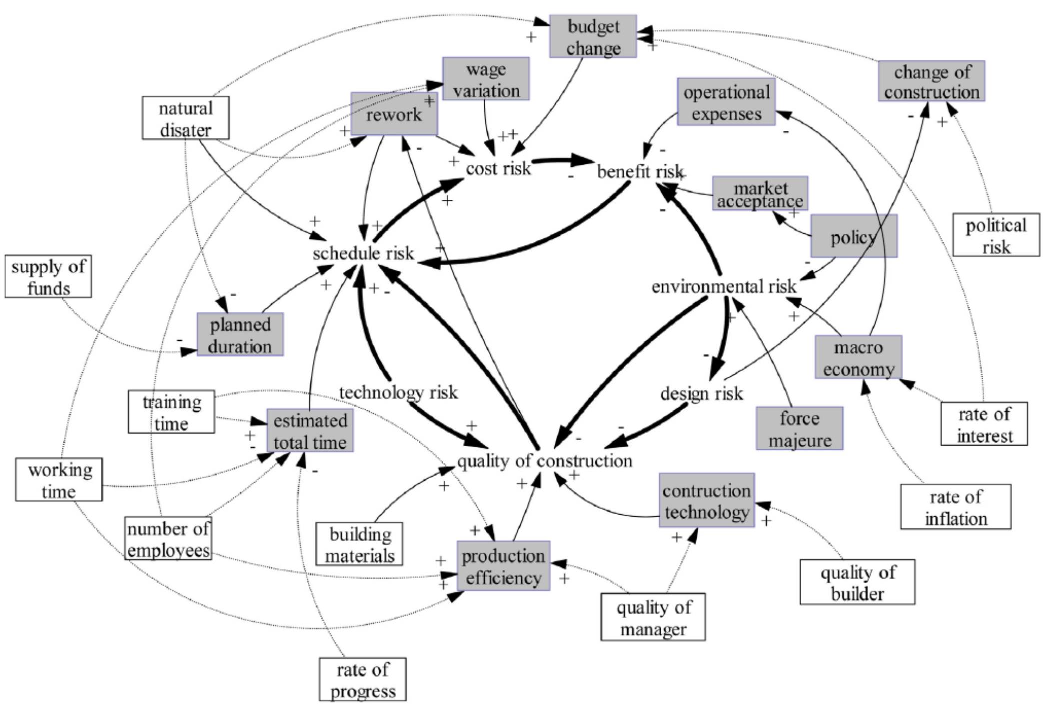

Figure 5. Causal relationship diagram for risk analysis of project construction (Liu, 2014)

Variables in the System Dynamics Model

In system dynamics models, different types of variables play specific roles in representing the system. State variables, typically shown without boxes in diagrams, describe the current condition of the entire system at any given moment. Collectively, these state variables define the system's overall status. Auxiliary variables, represented by gray boxes, serve as intermediaries between source actions and decisions. They help to express decisions influenced by feedback mechanisms. Input variables, shown as blocked or solid shapes, are external to the system; they are not influenced by other variables within the model.

The connections between variables illustrate how one variable influence another, with arrows indicating the direction of impact. A "+" sign on an arrow means the relationship is proportional: as one variable increases, so does the other. A "–" sign indicates an inverse relationship: as one variable increases, the other decreases (Liu, 2014).

Selection of Model Variables

Based on the characteristics of the project, appropriate state variables can be chosen to represent key areas of risk. These may include schedule risk, construction quality, cost risk, environmental risk, technology risk, design risk, and benefit risk. For each state variable, suitable auxiliary variables are selected to capture factors influencing that risk (Liu, 2014). For instance:

- Schedule risk might include auxiliary variables such as natural disasters, rework, planned duration, and estimated total time.
- Cost risk could involve rework, wage variation, and budget changes.
- Construction quality may be influenced by construction materials, production efficiency, and construction technology.
- Benefit risk might depend on operational expenses and market acceptance.
- Environmental risk could include factors such as policy changes, macroeconomic conditions, and force majeure events.

2.6 FUZZY DEMATEL METHOD

2.6.1 Fuzzy Sets

In real-world decision-making, objectives and constraints are often not precisely defined, leading to ambiguity and uncertainty in the decision process (Zadeh, 1965). To address this challenge, Lotfi Zadeh introduced fuzzy logic in 1965 as a framework for managing vague, imprecise, or incomplete information, especially where human judgments are subjective or inconsistent. Unlike Boolean logic, which classifies an element as either belonging (1) or not belonging (0) to a set, fuzzy logic uses fuzzy sets where elements have degrees of membership. These degrees are quantified using a membership function, allowing for partial inclusion that better reflects the nuances of human reasoning and complex real-world scenarios (Muhammad Nazir Muhammad, 2017).

2.6.2 Fuzzy DEMATEL

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method was originally developed in 1973 in Geneva as a tool for analyzing and solving complex, uncertain problems (Jiunn-I Shieh, 2010). DEMATEL focuses on modeling and visualizing cause-and-effect relationships among decision criteria, transforming ambiguous relationships into clear, justifiable structures. The key output of DEMATEL is a digraph that visually distinguishes causal factors from effect factors within the system being studied (Doraid Dalalah, 2011).

According to Akyuz and Celik (2015), DEMATEL is widely regarded as one of the most practical techniques for identifying and interpreting cause-and-effect relationships among criteria during evaluation processes. Moreover, as highlighted by Tzeng et al. (2007, cited in Muhammad Nazir Muhammad, 2017), DEMATEL helps reduce the number of criteria to be considered by focusing on the most influential ones thereby improving organizational decision-making efficiency through clearer prioritization on the digraph map.

However, the use of precise (crisp) numerical values is often inadequate because human judgments are inherently imprecise and many assessment criteria are subjective or affected by uncertainty (Nazeri and Naderikia, 2017). This is where Fuzzy DEMATEL proves valuable. By integrating fuzzy logic into DEMATEL, the method better accommodates the ambiguity of expert opinions and enables more reliable analysis in multi-criteria decision-making (MCDM) contexts (Muhammad Nazir Muhammad, 2017).

Fuzzy DEMATEL in Construction Risk Assessment

Babak A. Samani (2005a, 2012b) was a pioneer in applying Fuzzy DEMATEL for construction risk assessment. He successfully implemented the method in complex projects such as Iran's oil and gas sector and the Persian Gulf Sea Bridge, producing logical and actionable results. His work demonstrated that Fuzzy DEMATEL can generate a valid and practical hierarchical model for managing risks in large-scale infrastructure projects.

Main Steps of the Fuzzy DEMATEL Method

Following the approach suggested by Babak A. Samani (2005a, 2012b), this study adopts the following key steps for applying Fuzzy DEMATEL:

1. Selection of Expert Group: Identify and assemble a panel of experts with relevant knowledge and experience.
2. Define the Decision Goal and Criteria: Clearly state the decision objective, construct a fuzzy linguistic scale, and develop a comprehensive list of evaluation criteria.
3. Construct the Direct-Relation Matrix: Collect expert judgments through pairwise comparisons of criteria using a five-point fuzzy linguistic scale.
4. Normalize the Direct-Relation Matrix: Standardize the direct-relation matrix to make it suitable for further analysis.
5. De-fuzzification: Convert fuzzy numbers into crisp values for clearer interpretation.
6. Derive the Total-Relation Matrix: Calculate the total-relation matrix from the normalized matrix to capture both direct and indirect relationships.
7. Compute D and R Values: Calculate the sum of rows (D) and columns (R) in the total-relation matrix to quantify the degree to which each criterion influences others (D) and is influenced by others (R).

Table 5. Fuzzy scale for pair-wise comparison of evaluation criteria (Shahbodaghlou, 2012)

Degree of Influence	Linguistic Term	Fuzzy Value	Crisp Value
Very High Influence	(VH)	(0.75,1.0,1.0)	4
High Influence	(H)	(0.5,0.75,1.0)	3
Low Influence	(L)	(0.25,0.5,0.75)	2
Very Low Influence	(VL)	(0,0.25,0.5)	1
No Influence	(No)	(0,0,0.25)	0

Construction Risks

Shahbodaghlou et al. (2012), drawing on field studies and expert opinions, identified 45 significant risks that can influence a company's involvement in a construction project, particularly from the perspective of private general contractors during the initial stages of a project. These risks were systematically classified into 10 major categories based on their defining characteristics. The categories are summarized below:

1. Country Risks

Country risk refers to the broad range of uncertainties that impact all companies operating within a specific national context. As described by Advanced Engineering Associate International (AEAI) and cited by Shahbodaghlou (2012), it primarily relates to the risks associated with investing and doing business in a particular country. These can include political instability, economic volatility, regulatory changes, or socio-cultural disruptions that may jeopardize project success.

2. Companies' Capabilities Risks

The overall success of a construction project largely depends on the capabilities of the participating companies, the efficiency of the project's governance structure, and the strength of underlying infrastructure including legal, informational, cultural, and educational systems. Many of these risks arise internally, within the organization, and are shaped by factors such as corporate strategy, policies, cash flow, organizational design, management practices, and IT infrastructure. Effective leadership, employee competency, motivation, and a strong organizational culture enhance a company's capability and reduce exposure to internal risks.

3. Management Risks

Management risks stem from poor, misguided, or self-serving decisions by project leadership that hinder the achievement of project objectives. These risks materialize when managerial actions fail to serve the best interests of stakeholders, or when decisions negatively impact project performance. They reflect the possibility that managerial choices may create conditions where the project team would have been better off had those decisions not been made.

4. Human Capital Risks

The human element is central to construction project success. Human capital risk relates to employee behaviors or events whether occurring within or beyond the workplace that may disrupt operations or diminish organizational value. As noted by Seymour Adler (2008) and cited by Shahbodaghlou (2012), the availability of a skilled, motivated, and competent workforce is a critical determinant of project outcomes.

5. Financial Risks

Financial risks, as defined by AEAI (2010) and referenced by Shahbodaghlou (2012), involve the uncertainties surrounding the ability to secure adequate financing and achieve expected returns sufficient to repay debt obligations. In construction, the challenge often lies in obtaining and managing the substantial funding required for complex projects, as well as addressing unforeseen financial difficulties during execution.

6. Insurance Risks

Insurance risks represent the uncertainties associated with obtaining and maintaining appropriate insurance coverage and bonding. These risks can expose a project to significant vulnerabilities if claims are denied or if insurance provisions prove insufficient.

7. Procurement Risks

Procurement-related risks emerge from the acquisition of goods and services necessary for project execution. Given that procurement activities can account for 40% to 60% of a large project's budget, risks in this area including supplier failures, contract disputes, or material delays can significantly affect the achievement of primary project goals.

8. Health, Safety and Environmental Risks

Like all construction projects, HSE risks are critical and require robust management. A weak safety culture within the organization exacerbates these risks, increasing the likelihood of accidents, health hazards, or environmental damage.

9. Site Condition Risks

Risks arising from unexpected or differing site conditions have long been a concern in construction contracts. Such risks must be thoroughly assessed, as unanticipated ground conditions, topographical challenges, or environmental factors can lead to cost overruns, delays, or design modifications.

10. Design, Construction, Operation and Maintenance Risks

This group of risks primarily emerges during the implementation phase of construction projects. These risks are generally influenced by other risk categories (such as country, financial, or organizational risks) rather than exerting a direct influence on them. They are common across nearly all construction projects, making them relatively easy to identify during risk assessment processes.

From another perspective, Caltrans (2007, as cited by Temesgen, 2015) emphasizes that project risks can be effectively managed by categorizing them and assigning responsibility for each risk to specific team members. This structured approach ensures accountability and proactive risk mitigation. The primary risk categories and examples of risks within each, as defined by Caltrans (2007, as cited by Temesgen, 2015), are outlined below:

1. Design Risks

Design risks arise from challenges or deficiencies in project design and technical planning. Typical design-related risks include:

- Incomplete or inadequate design documentation
- Unforeseen geotechnical or groundwater conditions
- Incorrect technical assumptions made during the planning stage
- Incomplete surveys and inaccurate site data (e.g., for bridges)
- Late changes to material specifications, foundation design, or geotechnical requirements

- Design exceptions that were not anticipated
- Consultant designs falling short of agreed standards
- Constructability issues that remain unresolved
- Complex hydraulic or structural features not properly accounted for
- Incomplete quantity estimates leading to cost inaccuracies
- Constraints caused by unexpected construction windows or adverse weather (e.g., rainy seasons)
- Adjustments due to new or revised design standards
- Staging and sequencing of construction that proves more complex than initially planned

2. External Risks

External risks are driven by factors outside the immediate control of the project team, including stakeholders, regulatory bodies, and market conditions. Examples include:

- Land acquisition challenges due to unwilling landowners
- Objections or resistance from local communities
- Excessive or unrealistic stakeholder expectations
- Political shifts affecting project support
- Late-stage change requests from stakeholders or newly involved parties
- Threats of litigation
- Market-driven increases in material costs
- Delays or complications in obtaining permits or regulatory approvals
- Changes in environmental regulations or storm-water requirements
- Labor shortages, strikes, or external scheduling pressures

3. Environmental Risks

Environmental risks relate to compliance with environmental regulations, unexpected environmental impacts, or deficiencies in environmental planning. Examples include:

- Incomplete environmental studies or analyses
- Lack of critical project data or maps at the start of environmental assessments

- Emergence of new information post-clearance requiring re-evaluation
- Necessity for alternative designs to mitigate or avoid environmental impacts
- Additional environmental approvals needed for staging or borrow sites
- Design changes that trigger fresh environmental review
- Unanticipated concerns from native communities or discovery of sensitive resources
- Noise, floodplain encroachments, or cumulative impacts that were not foreseen

4. Organizational risks

Organizational risks arise from internal weaknesses, resource gaps, or procedural delays within the implementing agency or contractor. Common examples are:

- Assignment of inexperienced or underqualified staff
- Loss of key personnel at critical project stages
- Inadequate time allocated for project planning
- Overloaded or unavailable functional units
- Delays due to internal formalities or slow approval processes
- Poor understanding of complex funding procedures
- Shifts in organizational priorities or budgetary allocations
- Overlapping scopes, conflicting objectives, or inconsistent cost, time, and quality targets
- Lack of specialized technical staff or availability of required capital funding (for right of way or construction)

5. Project Management Risks

Project management risks stem from weaknesses in defining, planning, or coordinating the project. These risks can derail project timelines, budgets, and objectives. They include:

- Vague or poorly defined project purpose, scope, or objectives
- Incomplete or unclear project requirements, schedules, and deliverables
- Ineffective control over team priorities or workloads
- Delays caused by consultants, contractors, or unplanned work
- Estimation or scheduling errors

- Scope creep and lack of escalation for unresolved conflicts
- Miscommunication or lack of coordination among stakeholders
- Underestimated resource needs or unrealistic timelines
- Delays in early phases that jeopardize subsequent stages
- Cost escalations in land acquisition or construction
- Additional demands from policy changes, statutes, or new agency directions
- Inadequate local agency support
- No planned public awareness or campaign
- Unexpected agreements needed; and a shift in the program's priorities
- Inconsistent goals for scope, cost, time, and quality

6. Right Of Way Risks

Right of way risks stem from the complexities of securing land access and resolving associated legal or administrative issues. Typical risks in this category include:

- Utility relocations requiring significantly more time than anticipated
- Prolonged resolution of objections to ROW appraisals, increasing costs or causing delays
- Incomplete or underestimated ROW data sheets
- Overlooked need for permits granting site access, which disrupts scheduling
- Condemnation processes that take longer than expected
- Delays in acquiring parcels owned by state or federal agencies
- Seasonal constraints affecting utility relocation timing
- Utility companies facing internal challenges (e.g., workload, finances, or schedule misalignment)
- Expiration of temporary construction easements before work is completed
- Shortage of qualified expert witnesses or appraisers to support ROW negotiations

7. Construction Risks

Construction risks arise during the actual execution of works and can significantly affect project performance. These risks include:

- Underestimated contract duration
- Permit work windows that are too short for required tasks
- Change orders driven by differing site conditions
- Inadequate designs for temporary excavation or shoring systems
- Falsework designs that fail to meet structural requirements
- Discovery of unidentified utilities during construction
- Need for unexpected dewatering due to water table variations
- Expiration of temporary construction easements mid-project
- Overlooked electrical power lines creating conflicts
- Poor coordination of street or ramp closures with the local community
- Insufficient or constrained space for construction activities or staging
- Design changes during construction requiring new approvals from resource agencies
- Demolition delays due to sensitive habitats or environmental restrictions
- Long lead times for specialized utility components (e.g., custom steel towers or pipes)

8. Engineering Services Risks

These risks relate to deficiencies in technical investigations, engineering designs, and service planning. Examples include:

- Large-diameter foundation piles requiring tunneling or mining provisions not reflected in contract documents or communicated early
- Bridges built at grade that later need excavation without planned tunneling or mining provisions
- Discovery of hazardous materials (e.g., lead paint, asbestos, contaminated soil) in structures or soil
- Lack of necessary access to adjacent properties to address constructability concerns
- Existing structures identified for modification not assessed for seismic retrofit, scour risk, or load capacity
- Geotechnical or foundation work not adequately planned or included in work programs
- Seasonal and permitting constraints not fully identified or incorporated in schedules
- Complex hydraulic designs requiring detailed investigation and planning

- Overly optimistic or unverified assumptions in advance planning studies
- Design adjustments between planning and detailed design phases (e.g., alignment, profile, cross-sections)
- Environmental constraints unexpectedly impacting bridge construction
- Aesthetic requirements emerging late in the process
- Delays in geotechnical exploration due to pending permits, agreements, or right-of-entry permissions
- Traffic management and lane closure requirements delaying geotechnical work

2.7 Identification of Risk Categories and Their Factors

Part One: Internal Uncertainties

This study categorized internal uncertainty into key focal areas to help identify and control risk sources that come from the project's operational, planning, or design boundaries. The internal uncertainties and risk categories that have a major impact on construction projects' success are described in this section. To guarantee that projects are completed on schedule, within budget, and to the necessary quality standards, each category identifies certain difficulties and elements that need to be carefully controlled.

1. **Project-Related Uncertainties (Abbr.: PRU)**: These risks stem from uncertainties linked directly to the project itself. They encompass unpredictable elements that can affect planning, execution, and outcomes, such as:

- Uncertainty surrounding site conditions or location characteristics
- Contractual uncertainties, such as ambiguities in contract terms or formulation
- Unpredictability in the duration of specific activities, affecting detailed scheduling
- Fluctuations in resource costs, leading to budget uncertainties
- Uncertain complexity or technical requirements that exceed initial assumptions
- Uncertainty in the availability or limitations of key resources

2. **Management Risks: Organization-Related Uncertainties (Abbr.: MR):** Management risks arise from ineffective, misguided, or underperforming leadership that undermines project objectives. These risks reflect situations where poor management decisions create more harm than benefit, reducing the project's chance of success. Examples include:

- Frequent turnover of project managers or key personnel

- Weak or disorganized management structures
- Inadequate project planning, budgeting, and scheduling
- Delays in selecting and engaging subcontractors

3. **Financial Risks: Finance-Related Uncertainties (Abbr.: FR)**: Financial risks relate to uncertainties in securing or managing project finances, often influenced by broader economic conditions. A change in the financial stability or policy of any party within the project team can jeopardize project progress. These risks include:

- Lack of solid economic justification for the project
- Weak banking infrastructure affecting financial transactions
- Absence of foreign banks, limiting access to international financing

4. **Interest/Demand-Related Conflicts (Abbr.: IRC)**: While all project stakeholders aim to complete the project on time, within budget, and to the specified quality, their differing priorities and constraints can create conflicts. These conflicts can erode cooperation and hinder effective management, especially when adapting to project changes.

5. **Human capital risks: Human-related uncertainties (Abbr. HRC)**: Human capital risks arise from uncertainties related to workforce capabilities and dynamics. The performance of human resources is shaped by individual traits, social backgrounds, cultural norms, education levels, and working conditions. This variability creates significant management challenges in complex projects. Common issues include:

- Shortage of qualified professionals and skilled labor
- Low motivation and productivity among existing staff
- Ineffective training programs that fail to build necessary skills
- Challenges in attracting and hiring competent professionals

6. **Companies' Capabilities Risks (Abbr.: CCR)**: These risks are linked to the overall strength and readiness of the companies involved in the project. A company's capability is determined by its strategy, policy framework, cash flow, organizational structure, management systems, and technological infrastructure. Success also depends on strong leadership, skilled personnel, and a positive organizational culture. Examples of related risks include:

- Limited capability of contractors to manage complex projects

- Absence of a robust project execution system

7. **Insurance Risks (Abbr.: IR)**: Insurance risks reflect uncertainties related to the reliability and adequacy of insurance coverage and bonding in the construction sector. Examples include:

- Limited capacity of local insurance providers to cover construction-related risks
- Lack of participation by foreign insurance companies, limiting options for coverage

8. **Procurement Risks (Abbr.: PR)**: Procurement risks arise from challenges in acquiring the goods and services needed for the project. Given that procurement often represents 40% to 60% of a major project's budget, these risks can substantially impact primary project objectives. This includes:

- Low-quality construction materials that fail to meet project specifications
- Ineffectiveness of manufacturers in producing essential equipment
- Difficulties with international procurement (e.g., foreign currency access, letters of credit)
- Barriers to purchasing essential planning and design software

9. **Design, Construction, Operation and Maintenance Risks (Abbr.: DCM)**: These risks emerge during project implementation and are common across nearly all construction projects. They span the entire project life cycle, from design through to operations and maintenance. Examples include:

- Inexperience in managing the specific type of project
- Design deficiencies or errors
- Change orders that disrupt schedules and budgets
- Force majeure events (e.g., natural disasters, unforeseen external shocks)
- Operational challenges affecting facility performance
- Maintenance risks that threaten long-term asset reliability

<u>Part Two: External uncertainties</u>

Construction project management is highly sensitive to external uncertainties—factors outside the direct control of the project team but capable of significantly impacting internal operations. Changes in the external environment, such as government policies, market conditions, or societal expectations, often require adjustments to project plans and processes. Key external uncertainties in construction projects are outlined below:

10. **<u>Country Risks (Abbr.: CR):</u>** Country risks refer to broad uncertainties that affect all companies operating within a particular nation. These risks are primarily associated with the viability of investing or executing a project in a country, often driven by external forces such as political or economic instability. Typical country risks include:

- Multinational sanctions that restrict trade or investment
- The possibility of war, conflict, or civil unrest
- Political instability or government upheaval
- National or regional economic recession
- Corruption that impedes fair business practices
- Delays in securing government permits
- Slow and expensive customs procedures
- Weak or insufficient infrastructure

11. **<u>Social Uncertainties (Abbr.: SU)</u>**: Social uncertainties arise from the interaction between a project and the wider community. Public acceptance of a project and its perceived social impact can shape the success or failure of project implementation. For instance, resistance from local communities can restrict the hiring of foreign workers or delay approvals. Adverse social consequences linked to a project's location or function can trigger strong opposition, disrupting construction progress. Furthermore, shifts in social conditions may influence staff behavior and strain industrial relations within the project team.
12. **<u>Technological Uncertainties: New Construction Trends (Abbr.: TC)</u>**: Technological uncertainties relate to the introduction or adoption of new construction methods, materials, or tools. A project’s technology encompasses both its physical processes such as materials and equipment, and the human expertise of managers, designers, and technical staff. Unanticipated changes in technology may require redesigns, adoption of alternative

materials, or new construction techniques. While new technologies generally enhance efficiency in areas like planning, cost control, quality management, and decision-making, they also introduce risks if integration is poorly managed or if the technology proves incompatible.

13. **Institutional Influences (Abbr.: II)**: Institutional influences stem from professional bodies, regulatory agencies, and educational institutions that set standards for conduct, engagement, and competency in construction. These bodies can impact project organization and decision-making through rules on professional ethics, licensing requirements, or educational standards, potentially constraining flexibility or altering project governance structures.
14. **Health, Safety and Environmental Risks (Abbr.: HSE)**: Health, safety, and environmental (HSE) risks are critical concerns in all construction projects. A weak safety culture or neglect of environmental responsibilities exacerbates these risks. Given the often unique and sensitive nature of project sites, HSE considerations must be prioritized to protect workers, communities, and ecosystems. Examples include:

- Inadequate provision of safety equipment and non-compliance with environmental regulations
- High-risk projects where health, safety, and environmental hazards are significant and complex

15. **Site Condition Risks (Abbr.: SCR):** Site condition risks arise from the physical characteristics of the project location, which can significantly affect construction execution and costs. These risks must be carefully assessed as they can lead to substantial losses or, if managed well, notable savings. Relevant site-related risks include:

- Geotechnical challenges, such as poor soil conditions or unexpected subsurface issues
- Construction in earthquake-prone zones, which may require specialized designs and safety measures
- Hydrological risks such as unforeseen weather events or flooding
- Presence of sensitive environments like mangrove forests that require special protection
- Heavy traffic volumes near or within the project site that complicate logistics and safety

- Long distances from key material sources leading to transportation delays and cost increases
- Remoteness from major manufacturers (often concentrated in central regions), adding complexity to procurement and delivery schedules

16. **Late Removal of Right of Way Obstructions (Abbr.: ROW)**: The process of acquiring and preparing land needed for development, including securing all relevant legal interests, is known as "right-of-way clearance." Whether as a result of eminent domain procedures, sluggish land acquisition, or unresolved utility modifications, delays in clearing the ROW can put important tasks on the project's critical path and endanger schedules. To avoid project delays, problematic parcels (such as those requiring intricate negotiations or legal action) must be identified and addressed early on.
17. **Government-Intervention Related Uncertainties (Abbr.: GIU)**: Government policies and interventions can profoundly reshape project management dynamics. Shifts in tax policies, investment incentives, safety regulations, planning laws, or building codes may require fundamental changes to project plans, operational procedures, or budgets. Additionally, new contract laws or regulatory frameworks can alter the legal relationships between project stakeholders, influencing risk allocation, responsibilities, and contractual obligations. Such changes often force revisions to schedules, designs, or resource allocations, increasing both cost and complexity.
18. **Economy-Related Uncertainties (Abbr.: ERU)**: Economic fluctuations create a dynamic and often unpredictable environment for construction projects. Key risks include:

- Uncertain inflation and interest rates that affect financing costs, cash flow management, and overall project affordability
- Volatile currency exchange rates, especially for projects involving imported materials or international contractors
- Shifts in economic activity that influence supply and demand—e.g., booming economies may lead to material and labor shortages, driving up costs and delaying schedules
- Impact on supplier stability, as changes in economic conditions can weaken the financial health of suppliers, lenders, and subcontractors

- Monopolistic market behavior or reduced competition that can further escalate costs or limit resource availability
- Economic instability can directly disrupt the procurement of essential resources: finance, labor, concrete, steel, brick, hardware, and other inputs compromising the project schedule and coordination among all participating parties.

19. Time Uncertainties/Risks (Abbr.: TU): The potential for delays that prevent a construction project from being completed within the planned schedule.

20. Quality Uncertainties/Risks (Abbr. QU): The possibility that the completed construction work will not meet the required standards, specifications, or client expectations.

21. Cost Uncertainties/Risks (Abbr.:CU): The threat of the project exceeding its allocated budget due to unforeseen circumstances or mismanagement.

3. METHODOLOGY

3.1 Introduction

Risk and uncertainties, construction project risks, risk characterization and origin, risk management procedures, risk analysis, and risk management techniques were covered in the previous chapter.

The research tools and technique are covered in this chapter. Types of research, research strategies, research approaches, and data gathering and analysis techniques were all taken into account when creating the research process. This chapter will cover the resources and research methodology.

3.2 Research Strategy

The research is conducted using both quantitative and qualitative research methodologies, depending on the study's goal, the type of data, and its availability. To obtain the required data, some of the data were gathered in descriptive form, while others were gathered in numerical form. Both qualitative and quantitative methods are used in this study because it uses literature reviews and focus groups to identify risk categories, while quantitative methods are used to examine how these categories affect project objectives, analyze the seriousness of the risk factors identified, and identify and rank the most important risk categories in the Addis Ababa city road projects. As a result, the research study will adhere to the steps shown in Figure 6 below.

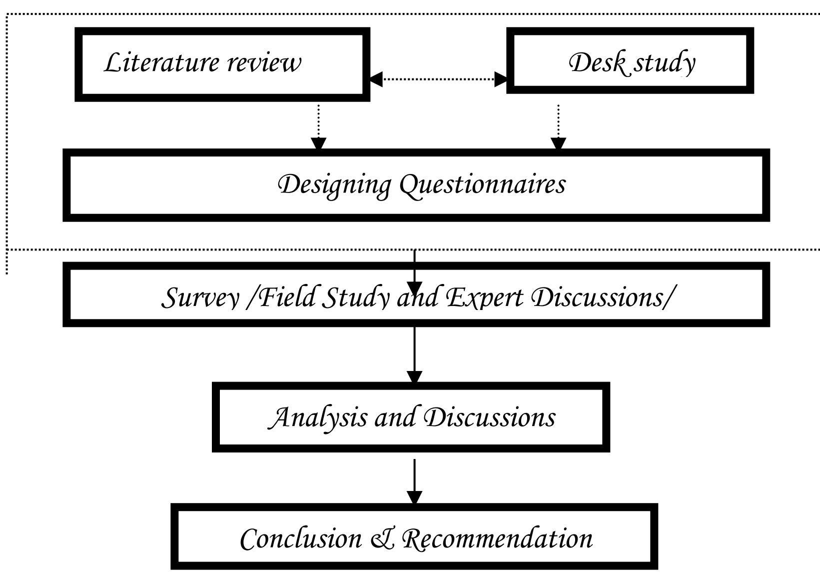

Figure 6. Flow Chart of Research Methodology

3.3 Research Population, Sampling and Data Collection

In this research, extra effort will be made to get representative expert groups and increase the level of precision needed from this research.

In order to accomplish the goals of the study, pertinent information was gathered. Primary data sources, such as focus groups and surveys, and secondary data sources, such as desk research, books, prior studies, publications, and journals, were used to gather the data. Regarding the risk management culture and construction project phases of these two massive government-owned enterprises, the Addis Ababa City Roads Authority and Ethiopian Roads Administration were the subject of the desk study. A variety of officials were interviewed in order to bolster the desk research. The focus group talks provided insights into important hazards, their effects, and project management practices while exposing several risk factors that are now plaguing the road construction industry.

Clients, consultants, and contractors participated in a questionnaire survey about AACRA's projects. Because it is rarely feasible to investigate the complete population, sampling was required. Determining the sample size is one of the primary challenges in sampling. In addition to being consistent, impartial, effective, and sufficient, the sample should be able to forecast the population's behavior as precisely as feasible.

The required sample size for the research was statistically determined using the following expression (Kish, 1995 cited in Ayalew, 2009: 55):

$n = n_0 / [1+ (n_0 / N)]$ …………………………………………… [Equation 3.1]; and

$n_0 = (p*q)/ V^2$ ………………………………………….......... [Equation 3.2]

Where:

n_0: First estimate of sample size;
p: The proportion of the characteristic being measured in the target population;
q: Complement of p or 1-p;
V: The maximum standard error allowed;

N: The population size; and

n: The sample size

p was set at 0.5. The population size consisted of 32 projects within AACRA, including ongoing, provisionally accepted, and terminated projects. A maximum standard error (V) of 10% (or 0.1) was established for the sample size determination, resulting in a required sample of 15 respondents. However, to ensure broader representation, a total of 30 questionnaires were distributed to employer representatives, consultants, and contractors. Additionally, all senior project management staff at AACRA were included in the survey.

3.4 Data Quality Assurance

Data quality assurance is description of routine measures to assure data quality. So, in order to assure the quality of data in this research paper, the researcher shall give ample time to get representative expert groups and collect data.

3.5 Method of Data Analysis

In this research both quantitative and qualitative method of data collection will be used. Since this research data depends up on expert's opinions, historical dataset or records of different projects, the input data for the study will be collected through survey questionnaire, interviews, and case study with archival records. Data analysis is done using FUZZY-DEMATEL Excel Program (Dr. Md Shamimul Islam,2019).

In this research, new Risk Analysis approach that will explicitly accounts increases in the number of risks along with the number of interrelationships between them will be presented.

We utilize Fuzzy DEMATEL Systemic approach to prioritize risk categories in Addis Ababa's Road construction projects. The methodology first introduces Fuzzy Set Theory to deal with uncertainty in expert's judgments and it will be followed by DEMATEL method. We considered triangular fuzzy numbers to consider different weights for the experts and then use these numbers in DEMATEL to rank the risk categories of projects. Furthermore, in practice the risks of project are usually dependent and there would be a level of interrelationships between them. Therefore, DEMATEL method is utilized to consider the sophisticated links between risks categories.

In order to be capable of achieving the research objectives the methodology sequences are stated as follows:

1. Literature Reviews: It will present the earlier related works on risk analysis and management for construction project using System Dynamics and Fuzzy DEMATEL Systemic Approach.
2. Major Risk Categories will be identified using literature review, field study (questionnaires), expert interviews.
3. Questionnaire and/or Interviews: This questionnaire and/or interviews will be answered by group of well experienced experts in the construction industry to get the influence of risks on one another.
4. Using FUZZY-DEMATEL Excel Program (Dr. Md Shamimul Islam,2019)., the Crisp values of W (weight of each risk category importance) and Q (influence of each risk category) will be calculated.
5. Lastly, a hierarchical structure of elements in a complex system can be achieved based on their idea generation, incorporating their assessments and judgments, and using the pair-wise comparison matrix and graph theory. This will allow the final structure to illustrate the cause-and-effect relationship of system elements as well as the strength of relationships' influence.

4. Questionnaire Data Analysis and Discussion

4.1. Introduction

This chapter discusses the outcomes of the data analysis conducted using the questionnaire. Instruction, Connotation Explanation, General Profile, Basic Information, Ranking of Risk Factors, and the total inter-relationship matrix table comprised the six sections of the questionnaire. Major stakeholders, including clients, contractors, and consultants, were given the questionnaire. Response registration, validity testing, ranking, and correlations are all part of the data analysis process. A FUZZY-DEMATEL Excel program was used to analyze the data (Dr. Md Shamimul Islam, 2019). Prioritizing risk factors, examining the likelihood of risks, examining their effects on project objectives and the relationships between them, and examining risk management procedures throughout the project's life cycle are all included in the analysis.

4.2. Questionnaire Data Analysis

4.2.1 Educational Background and Work Experience of Survey Respondents

Most of the respondent's educational background is a BSc Degree with a total population percentage of 61.90% while 38.09% of the respondents do have a Master's Degree.

The questionnaire was disseminated via mail and in-person delivery, and completed forms were promptly collected. The following table and figure show the results of the analysis of the survey data based on the participants' experience level.

Table 6. Respondents Work Experience

Respondents Work Experience		
Years of Experience*	**Population in Number**	**Remark**
1 to 3 Years	0	
4 to 6 Years	8	Adequate.
7 to 10 Years	5	Adequate.
11 Years and Above	8	Adequate.
Total Number	**21**	

Note: *Corrective coefficients to adjust for differences in years of work experience have not been applied.

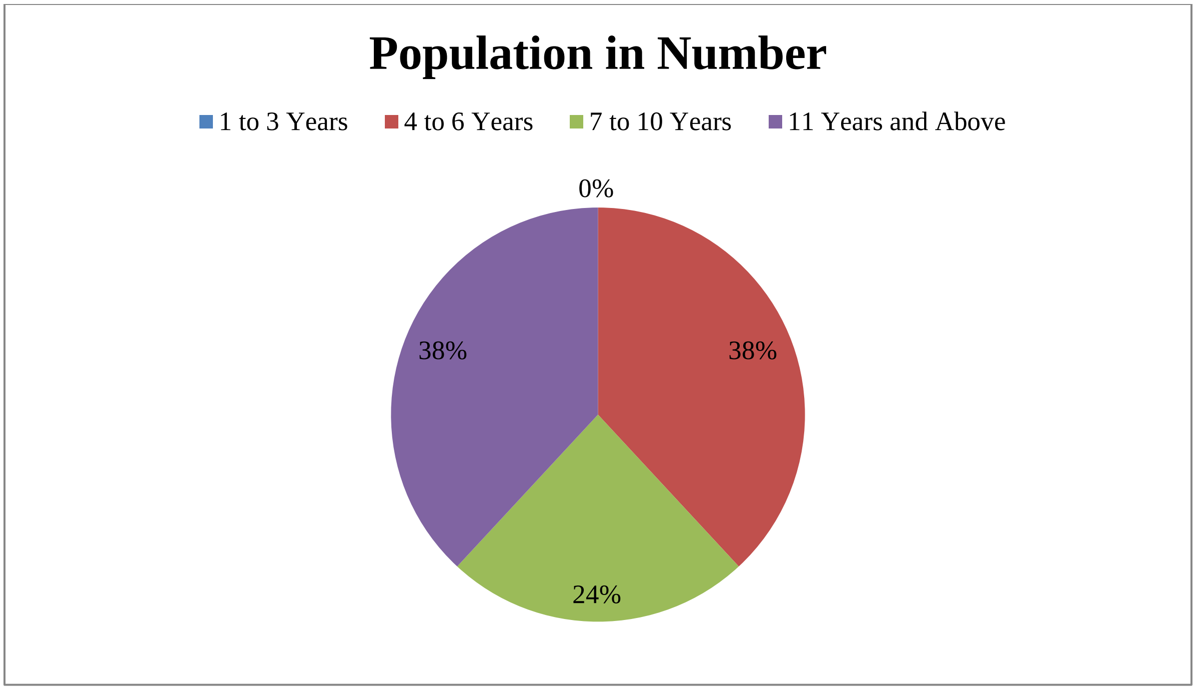

Figure 7. Respondents Population in Number (Based on their Experience)

4.2.2 Questionnaire Distribution and Response Rate

The survey included 30 questionnaires, achieving a response rate of 83.33%, despite the questionnaire requiring a high level of expertise and commitment. Of the responses received, four were excluded due to incomplete information. As a result, 21 completed questionnaires were used for the analysis.

4.3. Discussion of Results

Awareness of the importance of risk management is growing within the road construction industry; gaining a better understanding of risks and learning how to handle them provides benefits that far outweigh the costs of adopting these practices.

Incorporating risk management into major capital projects is clearly beneficial. Understanding potential risks and developing strategies to manage them improves project performance and aligns all stakeholders such as agencies, contractors, and consultants with project goals and public needs. In the U.S., several organizations have adopted structured risk management plans based on industry standards like those from the Project Management Institute (PMI) and the Association for the Advancement of Cost Engineering International (AACEI) (David B, 2006). A 1979 study by the Massachusetts Institute of Technology titled A Quantitative Method for Analyzing the Allocation of Risk in Transportation Construction found that improving contract clarity and management greatly enhanced the management of contractual risks (Ashely, 1979). The broad impact of risk on project outcomes underscores the need for serious attention.

The U.S. Department of Energy (DOE) emphasized in its 2003 report that risk management must be a team effort because risks affect all aspects of a project and influence every team member's action and plan. Risk planning, assessment, and monitoring must be structured and systematic to be fully effective. A formal approach allows project teams to identify, understand, and address the most critical risks efficiently, especially in complex acquisition projects.

Moreover, the DOE report stresses that risk management must be proactive, aiming to recognize issues long before they occur and to create strategies that increase the chance of success (U.S. Department of Energy, 2003).

As highlighted by David B (2006), risk management is especially vital in highway project development, starting from the early planning stages through to project completion. These projects involve long durations, public sector regulations, community interactions, and large-scale physical works, all of which increase the importance of managing risks effectively. Global best practices suggest that risk planning should begin early and continue throughout the project life cycle, becoming an integral part of the management process for major highway initiatives.

The Risk assessment is a critical management function involving both qualitative and quantitative approaches. Managers typically assess risks based on their potential worst-case outcomes and likelihood of occurrence, focusing on strategies to avoid or mitigate those risks. Analysts, conversely, apply quantitative methods, evaluating risks through measurable outcomes and probability estimates. Risks are categorized by severity; low, moderate, or high. Low-risk events are generally excluded from further analysis unless future reassessment warrants reevaluation. Moderate-risk events may be frequent but low in impact or rare but potentially severe. The former are usually addressed collectively through cost or schedule contingencies, while the latter require individual monitoring and possible mitigation plans.

High-risk events demand direct management action due to their likelihood and/or significant impact. Risk assessment methods can be adapted to suit projects of various sizes, from small roadworks to large infrastructure programs, helping to identify and prioritize issues throughout project phases. Rigorous assessments require detailed input parameters, such as probability distributions of risk variables, which may be continuous or discrete. Key statistical measures; mean, mode, and standard deviation; help define the central tendency and dispersion of these variables. A wider dispersion indicates greater uncertainty and therefore higher risk, making these parameters essential to accurate and effective risk evaluation.

After using the FUZZY-DEMATEL Excel Program (Dr. Md Shamimul Islam,2019) and assigning the corresponding positive triangular numbers to the given linguistic terms of comparison and completing the method's steps listed on Section 3.5, the fuzzy values of $W = (R_i + D_i)$ and $Q = R_i - D_i$ have been calculated for each risk category. Using de-fuzzification operation, the crisp values of W and Q have been obtained.

Table 7. Fuzzy and Crisp values of “W” and “Q” for each risk category.

S.N	**Risk Category**	**Risk Abbr.**	D	R	W	Q
					D+R	D-R
1	Project-Related Uncertainties	PRU	8.6403	9.0349	17.67521	(0.3947)
2	Management Risks: Organization-related uncertainties	MR	7.5785	8.7686	8.76856	(1.1900)
3	Financial Risks: Finance-related uncertainties	FR	6.8243	8.1367	8.136736	(1.3124)
4	Interest/Demand-Related Conflicts	IRC	7.4874	7.6974	7.697449	(0.2101)
5	Human capital risks: Human-related uncertainties	HRC	7.2062	8.3302	8.330248	(1.1241)
6	Companies’ Capabilities Risks	CCR	8.0564	7.6271	7.627115	0.4293
7	Insurance Risks	IR	6.9143	7.1349	7.134903	(0.2206)
8	Procurement Risks	PR	8.6595	7.4136	7.413552	1.2460
9	Design, Construction, Operation and Maintenance risks	DCM	8.4968	9.7751	9.77505	(1.2783)
10	Country Risks	CR	7.8394	7.7054	7.705447	0.1340
11	Social Uncertainties	SU	7.5771	7.2184	7.218389	0.3587
12	Technological Uncertainties: New Construction Trends	TC	7.4754	6.5635	6.563455	0.9120
13	Institutional Influences	II	7.1779	6.9338	6.93381	0.2440
14	Health, Safety and Environmental risks	HSE	7.8627	8.0721	8.072068	(0.2093)
15	Site Condition Risks	SCR	8.3861	9.0858	9.085813	(0.6998)
16	Late Removal of Right of Way Obstructions	ROW	8.2190	7.9700	7.970019	0.2490
17	Government-Intervention Related Uncertainties	GIU	8.0598	7.4230	7.423043	0.6367
18	Economy-Related Uncertainties	ERU	8.9399	7.7211	7.721109	1.2188
19	Time Uncertainties/Risks	TU	8.7117	7.6007	7.600732	1.1110
20	Quality Uncertainties/Risks	QU	7.6916	7.6578	7.65785	0.0337
21	Cost Uncertainties/Risks	CU	8.7722	8.7062	8.706203	0.0660
				Max	17.67521	1.2460
				Min	6.563455	(1.3124)
				Average	8.343655	(0.0000)

As discussed in the fuzzy DEMATEL method, the crisp values of W and Q should be assigned to the horizontal and vertical axis of coordinating system of final hierarchical model, respectively. The final hierarchical model has been acquired by mapping the dataset of (*W def*, *Q def*) proving final systematic structure of the risk categories.

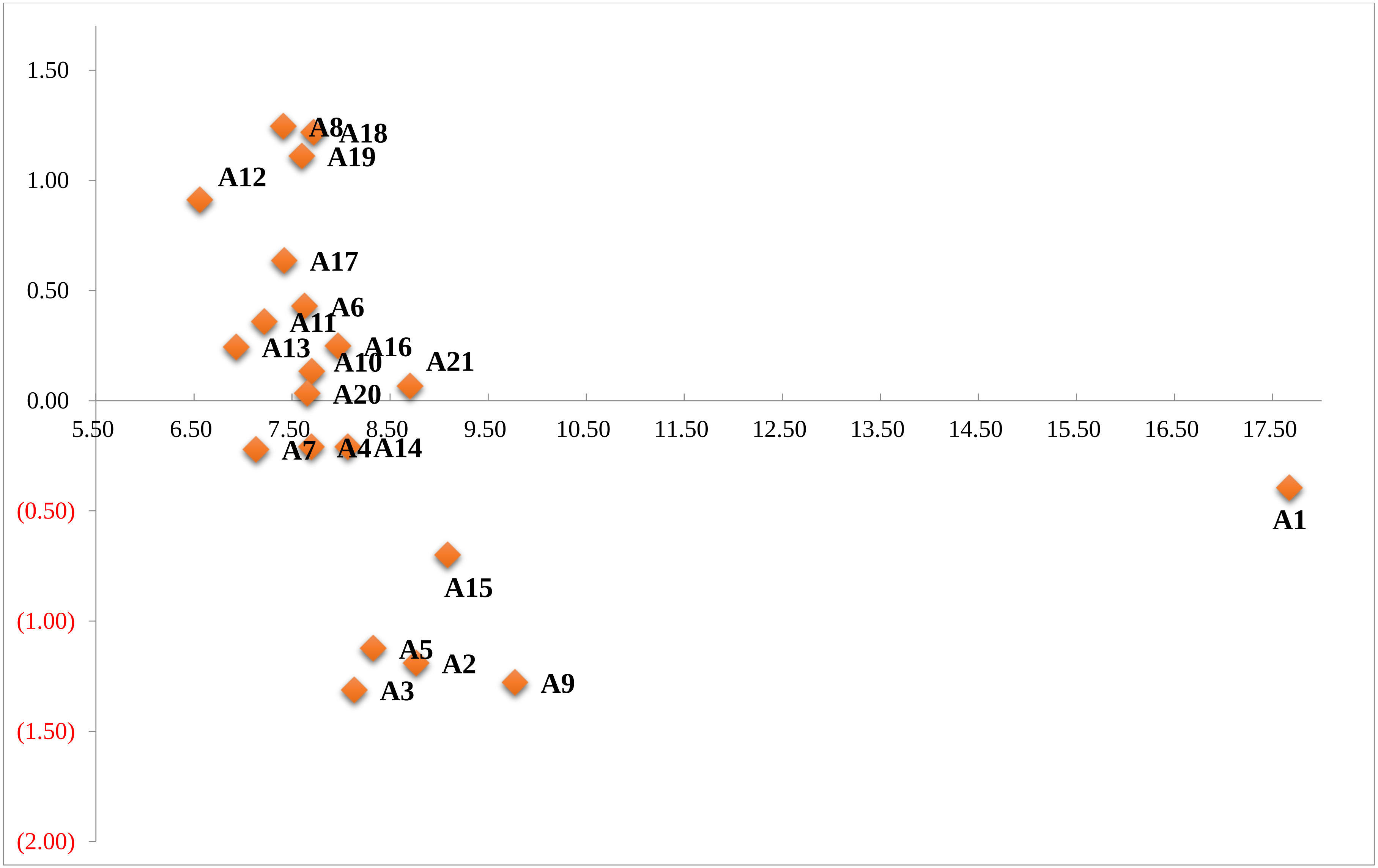

Figure 8. Hierarchical Model/Structure

The crisp value of W indicates weight of each risk category importance and the crisp value of Q specifies influence of each risk category and divides the risk categories into a cause or effect group. When Q is positive, the risk category belongs to the cause group. Otherwise, if the Q is negative, the risk category belongs to the effect group.

4.3.1. Differentiating the Cause-and-effect group

By taking the Q Value obtained from the analysis the cause-and-effect groups are identified.

Cause Group

- Companies' Capability Risks
- Procurement Risks
- Country Risks
- Social Uncertainties
- Technological Uncertainties
- Institutional Influences
- Late Removal of Right of Way Obstructions
- Government Innervations Related Uncertainties
- Economy-Related Uncertainties

Effect Group

- Project-Related Uncertainties
- Management Risks: Organization-related uncertainties
- Financial Risks: Finance-related uncertainties
- Interest/Demand-Related Conflicts
- Human capital risks: Human-related uncertainties
- Insurance Risks
- Design, Construction, Operation and Maintenance risks
- Health, Safety and Environmental risks
- Site Condition Risks

4.3.2. Ranking of Risk Categories

Table 8. Ranking of Risk Categories according to findings

S. N	Risk Category	Risk Abbr.	Code	∑Col.	∑Rows	W	Q	According to this Paper Findings	According to the Findings of Shahbodaghlou, B. A. (2012)
				D	R	D+R	D-R	Ranking	Ranking
1	Project-Related Uncertainties	PRU	A1	8.640	9.035	17.675	-0.395	16	
2	Management Risks: Organization-related uncertainties	MR	A2	7.579	8.769	8.769	-1.190	19	3
3	Financial Risks: Finance-related uncertainties	FR	A3	6.824	8.137	8.137	-1.312	21	2
4	Interest/Demand-Related Conflicts	IRC	A4	7.487	7.697	7.697	-0.210	14	
5	Human capital risks: Human-related uncertainties	HRC	A5	7.206	8.330	8.330	-1.124	18	4
6	Companies' Capabilities Risks	CCR	A6	8.056	7.627	7.627	0.429	6	7
7	Insurance Risks	IR	A7	6.914	7.135	7.135	-0.221	15	6
8	Procurement Risks	PR	A8	8.660	7.414	7.414	1.246	1	8
A9	Design, Construction, Operation and Maintenance risks	DCM	A9	8.497	9.775	9.775	-1.278	20	9
10	Country Risks	CR	A10	7.839	7.705	7.705	0.134	10	1
11	Social Uncertainties	SU	A11	7.577	7.218	7.218	0.359	7	

S. N	Risk Category	Risk Abbr.	Code	∑Col.	∑Rows	W	Q	According to this Paper Findings	According to the Findings of Shahbodaghlou, B. A. (2012)
12	Technological Uncertainties: New Construction Trends	TC	A12	7.475	6.563	6.563	0.912	4	
13	Institutional Influences	II	A13	7.178	6.934	6.934	0.244	9	
14	Health, Safety and Environmental risks	HSE	A14	7.863	8.072	8.072	-0.209	13	14,10
15	Site Condition Risks	SCR	A15	8.386	9.086	9.086	-0.700	17	5
16	Late Removal of Right of Way Obstructions	ROW	A16	8.219	7.970	7.970	0.249	8	
17	Government-Intervention Related Uncertainties	GIU	A17	8.060	7.423	7.423	0.637	5	
18	Economy-Related Uncertainties	ERU	A18	8.940	7.721	7.721	1.219	2	
19	Time Uncertainties/Risks	TU	A19	8.712	7.601	7.601	1.111	3	12
20	Quality Uncertainties/Risks	QU	A20	7.692	7.658	7.658	0.034	12	13
21	Cost Uncertainties/Risks	CU	A21	8.772	8.706	8.706	0.066	11	11
					Max	17.675	1.246		
					Min	6.563	-1.312		
					Avg.	8.344	0.000		

From the above table, we can witness that the following Risk Categories are the prominent risks ranked as follows.

Table 9. Top 5 Prominent Risks (Ranking according to the Analysis)

S. N	**Risk Category**	**Risk Abbr.**	**Code**	**W**	**Q**	**According to this Paper Findings**
				D+R	D-R	Ranking
1	Procurement Risks	PR	A8	7.414	1.246	1
2	Economy-Related Uncertainties	ERU	A18	7.721	1.219	2
3	Time Uncertainties/Risks	TU	A19	7.601	1.111	3
4	Technological Uncertainties: New Construction Trends	TC	A12	6.563	0.912	4
5	Government-Intervention Related Uncertainties	GIU	A17	7.423	0.637	5

Table 10. Top 5 Prominent Risks (Ranking according to Shahbodaghlou, B. A. 2012)

S. N	**Risk Category**	**Risk Abbr.**	**W**	**Q**	**According to the Findings of Shahbodaghlou, B. A. (2012)**
			D+R	D-R	Ranking
1	Country Risks	CN	1.67	1.17	1
2	Financial Risks: Finance-related uncertainties	FN	1.61	0.72	2
3	Management Risks: Organization-related uncertainties	MG	1.85	0.60	3
4	Human capital risks: Human-related uncertainties	HC	1.34	0.60	4
5	Site Condition Risks	SC	0.72	0.54	5

In the top-right section of Figure 7—where the highest values of prominence (W = 7.4136) and influence (Q = 1.2460) are observed—Procurement Risks (PR) are particularly notable. These risks are highly prominent within the system and exert strong influence over other risk categories, while remaining relatively unaffected by them. Therefore, effective mitigation of Procurement Risks should involve proactive engagement with external factors, as outlined in the final hierarchical model. Addressing these high-impact, system-wide risks serves as a strategic starting point for broader risk management.

Similarly, on the right side of the coordinate system, where both prominence (W = 7.7211) and influence (Q = 1.2188) remain high, Economy-Related Uncertainties (ERU) are positioned. These risks are among the most prominent in urban road construction projects and significantly amplify the impact of other risks. Due to their high influence value, ERUs are also highly susceptible to being affected by other risks particularly Procurement Risks. The positioning of Time Uncertainties and Technological Uncertainties (related to new construction trends) below PR and ERU in the diagram suggests that ERUs are primarily influenced by Procurement Risks more than by any other category.

On the lower half of the coordinate system, Design, Construction, Operation, and Maintenance Risks (DCM) as well as Financial Risks (FR) show negative influence values (Q < 0), placing them in the "effect group" of the causal diagram. Management Risks (MR), representing organization-related uncertainties, also fall into this group contrary to the findings of Shahbodaghlou (2012), who identified Financial, Management, and Human Capital Risks as part of the "cause group" with higher prominence. Overall, risks located below the horizontal axis are significantly influenced by those positioned above it, such as Procurement Risks, Economy-Related Uncertainties, Time Uncertainties, and Technological Uncertainties.

In the lower-right quadrant of Figure 7, where prominence is high (W > 9.08) but influence is negative (Q < 0), Site Condition Risks (SC) are found. Although these risks are highly important within the model, as indicated by their prominence, they exert minimal influence on other risk categories (Q = -0.6997). This suggests they are crucial to consider but do not significantly shape the overall risk dynamics.

Previous studies have identified Country Risks as a highly prominent category. However, in contrast to Shahbodaghlou (2012), who ranked Country Risks, followed by Financial, Management, and Human Capital Risks, as the most prominent; the current model finds Country Risks to be less significant. Here, Country Risks have a prominence value of W = 7.7054 and an influence value of Q = 0.1340, positioning them lower in importance relative to other cause-group risks in the system.

4.3.3 Trade-Off Between Project Objectives

At the lowest level of Figure 7, where the most negative Q values are observed, project objectives are significantly influenced by risks with higher or more positive influence values (i.e., risks with higher Q values). In this region, Financial Risks (FR), which refer to finance-related uncertainties, are positioned at the bottom right of the diagram. This placement indicates that while FR risks have the least influence on other risks, they are among the most impacted by others. Therefore, although they hold lower strategic importance in terms of influence, they demand considerable attention due to their vulnerability. Targeted strategies are essential to address the factors contributing to these financial risks and to develop effective mitigation measures. Conversely, Health, Safety, and Environmental (HSE) risks exhibit the most negative influence value, suggesting they are the least influential and may be receiving insufficient prioritization in the broader risk landscape.

In the diagram, the Cost Objective (represented by cost-related uncertainties) is positioned below the Time Objective (time-related uncertainties). This vertical arrangement implies that project stakeholders, particularly owners, place a higher priority on meeting deadlines, potentially at the expense of strict cost control. Meanwhile, the Quality Objective (Quality Uncertainties or QU) is situated near the horizontal axis. Although it has a relatively high weight (W), indicating its perceived importance, its lower influence value (Q) suggests that it is less central in driving other project outcomes. This may signal a risk of quality being compromised in favor of time and cost priorities, highlighting a potential imbalance in project goal management.

5. Conclusion and Recommendation

5.1 Conclusion

After reviewing the concepts of uncertainty, risk, and fuzzy logic, the Fuzzy-DEMATEL concept authors referenced in this research concluded that the reasoning underpinning risk assessment is neither purely absolute nor strictly probabilistic instead, it is fundamentally interrelated and interdependent as in the fuzzy set theory establishments. It is strongly believed that traditional decision-making methods commonly applied in risk assessment can be significantly improved by adopting fuzzy logic-based approaches.

With the advent of integrated project delivery methods and the evolving understanding of the construction project lifecycle, construction projects are no longer viewed as a series of isolated phases. Instead, they are recognized as complex, interconnected systems. This shift is especially relevant given the increasing number of megaprojects, particularly in our country, where the project environment is becoming more dynamic and multifaceted.

In these complex and integrated environments, the number of risks as well as the interdependencies among them has grown substantially. This has created a pressing need for a systematic and integrated approach to risk assessment. Such an approach naturally leads to the adoption of structured, group decision-making methods, which in turn facilitate the development of risk hierarchies and networks of interrelated risks.

Because human reasoning tends to involve trade-offs between significance and precision, the values provided by risk management team members during the risk assessment process are inherently imprecise. Fuzzy logic, which reflects this human mode of thinking, has therefore been increasingly accepted based on recent research and discussion as a foundational theory for systematic risk analysis.

In this study, the fuzzy DEMATEL method was employed to distinguish the most prominent categories of risk, yielding logical and actionable results. Forty-five (45) major risks were identified, grouped into twenty-one (21) categories, and analyzed within a systematic, hierarchical framework. The findings confirm that Procurement Risks, Economy-Related Uncertainties, Time

Uncertainties/Risks, and Technological Uncertainties are the most critical risks impacting the achievement of project goals.

During the risk analysis process, trade-offs between competing project objectives must be considered, typically through pairwise comparison methods. It is important to account for the causal relationships between project objectives, as each goal can be influenced directly by specific risks and indirectly through their effects on other objectives.

In summary, the application of the fuzzy DEMATEL method is highly recommended for risk assessment throughout the project lifecycle, especially during the implementation phase, due to its ability to handle complexity, uncertainty, and interdependencies among risks.

5.2 - Recommendations for Further Research

- One potential avenue for future research is evaluating the validity of the final hierarchical model developed in this study. This can be done via trying to implement the findings on pilot road projects in Addis Ababa.
- This evaluation could be conducted using neural network models as a possible methodological approach.
- Additionally, further research could focus on defining fuzzy functions for the project objectives and exploring their relationships with project risks.
- Another important direction would be to investigate the reverse influence how project goals might impact associated risks through complementary studies building on this work.

REFERENCE

(AfDB), A. D. (2020). *Africa Development Bank*. Retrieved June 17, 2020, from African Economic Outlook 2020, Africa Development Bank: https://www.afdb.org/en/documents/ african-economic-outlook-2020

(AfDB), A. D. (2020). *Africa Development Bank Group*. Retrieved June 17, 2020, from Ethiopia Economic Outlook 2020, Africa Development Bank Group: https://www.afdb.org/en/countries/east-africa/ethiopia/ethiopia-economic-outlook

Alfredo Federico Serpella, X. F. (2014). Risk management in construction projects: a knowledge-based approach. *Procedia - Social and Behavioral Sciences, No. 119*, 653-662.

AMA, A. M. (2011). *The AMA Handbook of Project Management* (3rd Edition ed.). (P. C. Cabanis-Brewin, Ed.) New York, NY 10019., USA: AMACOM Books.

Amin Vafadarnikjoo, M. M. (2015). An Integrated Gray-Fuzzy Cause and Effect Approach to Determine the Most Significant Categories of Project Risks. *Proceedings of the 2015 Industrial and Systems Engineering Research Conference* (pp. 1-11). Nashville, Tennessee: University of East Anglia.

Ashely, D. L. (1979). *A Qualitative method for Analyzing the Allocation of Risks in Transportation Construction* . Washington DC, U.S.A: Massachusetts Institute of Technology, U.S. Department of Transportation .

Bank, T. W. (2023, March 26). *The World Bank Group*. Retrieved March 26, 2023, from The World Bank Group Web Site: https://www.worldbank.org/en/country/ethiopia/overview

Bowers, Rodrigues, Alexandre, & John. (1996). System Dynamics in Project Management: a comparative analysis with traditional methods. *System Dynamics Review, Vol-12*(2), 121-138.

Celik, E. A. (2015, November). A fuzzy DEMATEL method to evaluate critical operational hazards during gas freeing process in crude oil tankers. *Journal of Loss Prevention in the Process Industries, Vol-38*, 243-253.

David B, A. J. (2006). *Guide to Risk Assessment and Allocation for Highway Construction Management.* Washington DC, U.S.A: U.S. Department of Transportation, Federal Highway Administration.

Debela, G. Y. (2014). *The Practice of Construction Risks Management Through Insurance in the Ethiopian Federal Road Projects.* Addis Ababa, Ethiopia: Addis Ababa University .

Doraid Dalalah, M. H. (2011, July). A fuzzy multi-criteria decision making model for supplier selection. *Expert Systems with Applications, Vol-38*(7), 8384-8391.

EEA, E. E. (2006/07). *Report on the Ethiopia Economy, The Current State of the Construction Industry.* Addis Ababa, Ethiopia: Ethiopian Economic Association (EEA).

Ethiopian Investment Commission, E. (2015). *Invest In Ethiopia* . Addis Ababa, Ethiopia: Ethiopian Investment Commission.

Garbolino, Emmanuel, Chery, Jean-Pierre, Guarnieri, & Franck. (2016). A Simplified Approach to Risk Assessment Based on System Dynamics: An Industrial Case Study. *Risk Analysis, No. 36*(No. 01), 16-29.

Hagos, M. (2016). *Decision Support Mechanism for Risk Allocation in Private Real Estate Purchase Agreements.* Addis Ababa, Ethiopia: Addis Ababa University .

Hassen, E. (2017). *A Study on Development of a Conceptual Risk Management Framework: A Case Study on Addis Ababa City Roads Authority.* Addis Ababa, Ethiopia: Addis Ababa University .

Islam, D. M. (2019). Fuzzy-Decision making trial and evaluation laboratory (DEMATEL).

Jiunn-I Shieh, H.-H. W.-K. (2010, April). A DEMATEL method in identifying key success factors of hospital service quality. *Knowledge-Based Systems, Vol-23*(3), 277-282.

Liu, J. W. (2014). A System Dynamics Model for Risk Analysis during Project Construction Process. *Open Journal of Social Sciences, No. 02*, 451-454.

Ltd, A. P. (2004). *Project Risk Analysis and Management Guide.* High Wycombe: APM Publishing Ltd.

Mesfin, A. (2014). *A Study on Construction Contract Risk Management Practices in Ethiopian Building Construction Projects.* Addis Ababa, Ethiopia : Addis Ababa University .

Ministry of Finance and Economic Development, M. (2010). *Growth and Transformation Plan (GTP) 2010/11-2014/15.* Addis Ababa, The Federal Democratic Republic of Ethiopia: Ministry of Finance and Economic Development, MoFED.

Ministry of Finance and Economic Development, M. (2015). *Second Growth and Transformation Plan (GTP II) 2015-2020 Draft.* Addis Ababa, The Federal Democratic Republic of Ethiopia: Ministry of Finance and Economic Development, MoFED.

Mohamed Sayed Bassiony, A. A.-K.-A. (2017). Identification and assessment of risk factors affecting Construction Projects. *Housing and Building National Research Center*, 202-216.

Muhammad Nazir Muhammad, N. C. (2017). Fuzzy DEMATEL method for identifying LMS evaluation criteria. *9th International Conference on Theory and Application of Soft Computing, Computing with Words and Perception, ICSCCW 2017* (pp. 742-749). Budapest, Hungary: Procedia Computer Science.

Naderikia, A. N. (2017, October). A new fuzzy approach to identify the critical risk factors in maintenance management. *International Journal of Advanced Manufacturing Technology, Vol-92*, 3749-3783.

Nair, G. K. (2013). Dynamics of Financial System: A System Dynamics Approach. *International Journal of Economics and Financial Issues, Vol. 3*(1), 14-26.

Nasirzadeh, F., Afshar, A., & Khanzadi, M. (2008). System dynamics approach for construction risk analysis. *International Journal of Civil Engineerng, No. 06*(No. 02), 120-131.

Nasirzadeh, F., Rouhparvar, M., Zadeh, H. M., & Rezaie, M. (2015). Integrating system dynamics and fuzzy bargaining for quantitative risk allocation in construction projects. *Scientia Iranica, No. 22*(No. 03), 668-678.

Nathan A. Minami, S. M. (2008). A Systems Approach to Risk Management. *American Society For Engineering Management Conference Proceedings* (pp. 12-15). Massachusetts Institute of Technology, Cambridge, MA 02142: Composite Information Systems Laboratory (CISL).

Nega, F. (2008). *Causes and Effects of Cost Overrun on Public Building Construction Projects in Ethiopia.* Addis Ababa, Ethiopia: Addis Ababa University .

Office, E. N. (2015). *Economic Data.* Addis Ababa, Ethiopia: Ethiopia National Statistics Office .

P.E.D. Love, G. H. (2002). Using systems dynamics to better understand change and rework in construction project management systems. *International Journal of Project Management, 20,* 425-436.

Pennock, M. a. (2001). *Principles and Giudlines for Project Risk Management.* Systems Engineering.

PMI. (2008). *A Guide to The Project Management Body of Knowledge* (4th Edition ed.). Pennsylvania, , USA: Project Management Institute, Inc.

PMI. (2013). *A Guide to the Project Management Body of Knowledge* (5th Edition ed.). Newtown Square, Pennsylvania 19073-3299 , USA: Project Management Institute, Inc.

PMI, Project Management Institute, Inc. (2003). *Construction Extension to A Guide to the Project Management Body of Knowledge* (2000 Edition ed.). Pennsylvania, USA: Project Management Institute, Inc.

Prince Boateng, Z. C. (2012). A system dynamics approach to risks description in megaprojects development. *Technical and Research Paper,* 593- 603.

PRINCE2, C. O. (2009). *Managing Successful Projects with PRINCE2.* Norwich, UK: The Stationery Office.

PRINCE2, Commerce, Office of Government. (2009). *Managing Successful Projects with PRINCE2.* Norwich, UK: The Stationery Office.

Raftery, J. (2003). *Risk Analysis in Project Management* . London EC4P 4EE, UK.: Taylor & Francis e-Library.

Railan, R. (2001). *Risk Management Survey: Analysis of Responses and Recommendations.* Washington DC, U.S.A: U.S. Department of Energy, Office of Environmental Management.

Review, W. P. (2023). *World Population Review*. Retrieved March 26, 2023, from World Population Review: https://worldpopulationreview.com/

Route One Publishing Ltd. (n.d.). *WorldHighways*. Retrieved May 19, 2023, from WorldHighways: https://www.worldhighways.com/wh10/news/ethiopian-capital-addis-ababas-road-development

Serpella, A., Ferrada, X., Rubio, L., & Arauzo, S. (2015). Evaluating risk management practices in construction organizations. *Procedia - Social and Behavioral Sciences, No. 194,* 201-210.

Shahbodaghlou, B. A. (2012, December). A Fuzzy Systematic Approach to Construction Risk Analysis. *Journal of Risk Analysis and Crisis Response, Vol. 02*(No. 04), 275-284.

SHEN, L. Y. (1996). DYNAMIC APPROACH FOR CONSTRUCTION PROJECT MANAGEMENT. *CIB W89 BEIJING INTERNATIONAL CONFERENCE* (pp. 21-24). BEIJING: CIB.

Sukran Seker, a. E. (2017). Application of Fuzzy DEMATEL Method for Analyzing Occupational Risks on Construction Sites. *Sustainability*, 1-19.

Tegabu, T. (2015). *Right of Way Risk Management of Road Construction Projects in Urban Areas, A Case Study of Addis Ababa.* Addis Ababa, Ethiopia: Addis Ababa University .

Tsegaye, G. (2009). *Design Risk Management in Ethiopian Federal Road Projects* . Addis Ababa, Ethiopia: Addis Ababa University .

U.S. Department of Energy, O. o. (2003). *Project Management Practices: Risk Management.* Washington DC, U.S.A: U.S. Department of Energy, Office of Management.

Wideman, R. (1992). *Project and Program Risk Management, A Guide to Managing Project Risks* . Newton Square, PA: Project Management Institute.

Xu, G. a. (2006). The Method of System Dynamics: Principle, Characteristics and New Development. *Journal of Harbin, 8*, 72-77.

Zadeh, L. (1965, June). Fuzzy Sets. *Information and Control, Vol-8*(3), 338-353.

Zhu, Y. (2011). The Basis and Method for Engineering Project Risk Identification. *Modern Enterprise*, *9*, 24-25.

ANNEX-1: RESEARCH SURVEY (QUESTIONNAIRE)

Dear Expert and Scholars,

I would first like to thank you for sharing your time to take part in this questionnaire survey. The purpose of this research is to discuss "**A FUZZY DEMATEL SYSTEMATIC APPROACH FOR RISK ANALYSIS IN THE CASE OF ADDIS ABABA'S ROAD CONSTRUCTION PROJECTS".** This questionnaire survey developed to gather the necessary data for fulfillment of master's thesis.

Professionals and academia in the Construction Industry aim to find out the factors affecting the road construction industry. Through literature review, twenty-one (21) evaluation aspects and fifty-five (55) evaluation criteria are gathered. The research results will be helpful for use the development of a decision support tool for Risk Management and Analysis.

Please be informed that this survey will STRICTLY be used for academic purposes ONLY to explore the prominent categories and types of risks in the Addis Ababa's road construction industry, and therefore, your responses will be kept confidential.

Moreover, your genuine response will play a crucial role towards attaining a precise output in identifying risk categories those with high impact on the project and to get better understanding on the construction practices in relation to Risk Management.

To this end, your support will be the key to the success of this research. We sincerely invite you to give us your insights as a reference for this research. Thank you again for your patience to help fill out the answers and your generous advice. If you have any questions about the content of the questionnaire, Please feel free to contact us by phone, telegram or email.

Thank You for Your Assistance!

Enyew Lemma

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I. Instructions for filling out the Questionnaire

The Questionnaire of this research is divided into four parts:

I. Questionnaire Filling Instructions,
II. Explanation of the connotation of the dimension criterion
III. General Profile
IV. Basic Information
V. Ranking of Risk Factors
VI. Questionnaire

II. Explanation of the connotation of the dimension criterion

Through the review of relevant literature, this research summarizes twenty-one (21) evaluation aspects and fifty-five (55) evaluation criteria. Each name and definitions are described on the last pages of this questionnaire.

Part III. General Profile

Please place a "✓" mark to all your responses in the box provided besides each statement.

1. Gender

☐ Male ☐ Female

2. What Type of Degree do you have?

☐ Master's degree or above in Construction Technology and Management
☐ Master's degree or above in Road and Transport
☐ Master's degree or above in Project Management
☐ Bachelor's Degree in Civil Engineering
☐ Bachelor's Degree in Construction Technology and Management
☐ Other related fields

3. Which of the following best describes your role in the construction Industry?

☐ Project Manager ☐ Construction/Site Engineer ☐ Contract Admin/Office Engineer
☐ Material/Pavement Engineer ☐ Others

4. How many years of working experience do you have? ________________________

Part IV. This part of the questionnaire covers the Risk Management schemes followed by your company, existing Risk management practices and factors leading to poor construction Risk Management.

A. Risk Management Schemes

1. Does your company have Risk Management as a guiding document? Or are you aware of any Risk management system that is developed by your organization?

☐ Yes ☐ No

2. If yes, is this Risk Management Methods implemented on site?

☐ Yes ☐ No

3. Does your company track risks and mitigate before damages occurs?

☐ Yes ☐ No

If your response to question 3 is "YES", how frequent is this?

____

4. Are you familiar with Risk management tools and techniques?

☐ Yes ☐ No

5. If your answer to question 5 is "YES", do you use any of these Risk management tools and techniques in your company?

☐ Yes ☐ No

B. Existing Risk Management Practices

6. Do you think companies assign qualified experts on the required positions?

☐ Yes ☐ No

7. Does the company provide the staff with trainings regarding Risk management?

☐ Yes ☐ No

8. If your answer to question 7 is "YES", please state how frequent this training is.

____

9. Does the company has or is aiming to acquire any International Certifications in Risk Management?

☐ Yes ☐ No

If your answer to question 9 is "YES", please state which certification that is.

10. Do you think that the current Ethiopian road construction industry's risk management practice is poor?

☐ Yes ☐ No

11. Do you think that the current Ethiopian road construction industry's practice needs a raise in awareness regarding Risk management and mitigation measures?

☐ Yes ☐ No

12. Do you think that proper Risk management is one of the key critical success indicators within a firm?

☐ Yes ☐ No

13. Do you believe that avoiding or minimizing risks leads to the company's long-term higher productivity and success?

☐ Yes ☐ No

14. If your answer to question 13 is "NO", please state the reason.

____

____

Part V. This part of the questionnaire covers the type of Risks and Risk Categories identified through literature review and focus group discussions. The concept first tries to rank the identified risk in their severity of their impact on the projects goals and then proceed to the interdependence of their impact on one another. For instance: the effect of Management Risk on Procurement Risks. This will be done by Experts of the construction industry.

15. Please rank the under listed risk categories and their factors in the order of their criticality or influence/impact on the project goals.

Rank	Risk Category	Remark
1st		
2nd		
3rd		
4th		
5th		
6th		
7th		
8th		
9th		
10th		
11th		
12th		
13th		
14th		
15th		
16th		
17th		
18th		
19th		
20th		
21st		

RISK CATEGORIES AND THEIR FACTORS

1. **<u>Project-Related Uncertainties (Abbr.: PRU)</u>**: Those are the uncertain areas about a project itself, such as:

- ✓ Uncertain location conditions,
- ✓ Uncertainties in contract (i.e. contract conditions formulation…)
- ✓ Uncertain duration for individual activities (i.e. activities planning…)
- ✓ Uncertain costs of resources,
- ✓ Uncertain complexity of technical requirements, and
- ✓ Uncertain resources availability or limitations.

2. **<u>Management Risks: Organization-related uncertainties (Abbr.: MR)</u>:** Risks associated with ineffective, destructive or underperforming management, which affects project goals are called management risks. Moreover, management risks refer to the risks of the circumstance in which project parties would have been better off without the choices made by management.

- ✓ Frequent replacement of project managers/Personnel Turnovers
- ✓ Poor Organization management
- ✓ Ineffective and insufficient project planning and budgeting
- ✓ Delay in choosing sub-contractors

3. **<u>Financial Risks: Finance-related uncertainties (Abbr.: FR)</u>**: Company's financial capability/policies can be changed due to the changes in economic conditions. The changed financial status from any party within the construction project team can affect or even jeopardize the construction of a project. Financial risks are associated with any form of financing and reflect the uncertainty of whether the return on an investment will be less than that required for the repayment of lending.

- ✓ Insufficient economic justification
- ✓ Weakness of banking systems
- ✓ Absence of foreign banks

4. **<u>Interest/Demand-Related Conflicts (Abbr.: IRC)</u>**: Although all parties involved in a construction project want to get a project completed as specified quality, on schedule and within project budget, their different constraints and interests will often cause

conflicts between them. This will hinder the cooperation in dealing with changes, thus affect the management performance.

5. **Human capital risks: Human-related uncertainties (Abbr. HRC)**: people and situations need to be treated on their merits – a contingency approach is needed. The effectiveness of human resources is affected by personal characteristics, personal social background, personal religion, customs, life style, education level, work conditions, etc. This dynamic nature causes a major concern in the management of complex projects.

- ✓ Lack of professionals and developed manpower
- ✓ Low level motivation and efficiency of existing manpower
- ✓ Low efficiency of training programs
- ✓ Ineffective in hiring professionals

6. **Companies' Capabilities Risks (Abbr.: CCR)**: The success of a project depends on the capabilities of its participant companies, the project's executive system, and the existing infrastructure, inclusive of legal, informative, cultural, and educational infrastructures. Company's capability is defined by parameters such as: strategy, policy, cash flow, organizational structure, management systems, and Information Technology infrastructure. It also requires leadership, skills and proficiency, personnel motivation and organizational culture.

- ✓ Low level capability of contractors
- ✓ Lack of powerful project's executive system

7. **Insurance Risks (Abbr.: IR)**: Insurance risks reflect the uncertainty of insurance and bonding.

- ✓ Incapability of insurance companies in the construction industry
- ✓ Absence of foreign insurance companies

8. **Procurement Risks (Abbr.: PR)**: Risks originating from procurement activities are known as procurement risks. In huge projects, 40% to 60% of budget is assigned to procurement activities. Thus, risks associated with procurement activities have huge impacts on project primary goals.

- ✓ Low quality of construction materials product (i.e. failure to fulfill Specific requirement)
- ✓ Manufacturers ineffectiveness in manufacturing of some project equipment
- ✓ Obstacles on abroad procurement (i.e. Foreign Currency Account, LC)

- ✓ Impediments of Planning and Design Software purchasing

9. **Design, Construction, Operation and Maintenance risks (Abbr.: DCM)**: This category of risks is all about risks arisen during the project implementation. These types of risks are very typical so that they can be identified in all construction projects.

- ✓ Lack of experience in the type of project
- ✓ Design risks
- ✓ Change orders
- ✓ Force Majeure
- ✓ Operational risks
- ✓ Maintenance risks

10. **Country Risks (Abbr.: CR):** it is a particularly a general term, which refers to risks affecting all companies operating within a particular country. Primarily, it refers to the risk of investing in a country due to international sanctions, instability and etc.

- ✓ Multinational Sanctions
- ✓ Possibility of war or conflicts
- ✓ Political instability of the government
- ✓ Recession
- ✓ Corruption
- ✓ Slow process of governmental permits issuance
- ✓ Slow and costly customs process
- ✓ Insufficient and Incapable infrastructures

11. **Social Uncertainties (Abbr.: SU)**: Social influence is mainly from the public acceptability to the activities in a project and the impact of a project to the society. For example, the recruitment of overseas construction workers is restricted by the resistance from community. On the other hand, the construction of a building may have adverse social consequences due to its special nature and location. This can cause very strong resistance from society, thus affect the whole construction process for a project. The changes in social background will also affect individual staff's behavior to large extent, and affect the industrial relations within a project.

12. **Technological Uncertainties: New Construction Trends (Abbr.: TC)**: The project technology consists of the physical or mental processes. The physical aspects of the technology range from materials used to equipment used. The human participation is

knowledge and skills of project managers, architects, engineers, and other consultants. New technology can directly influence the design and construction works in a project. Technological uncertainties include all those possible changes in using materials, techniques, labors, facilities, machines, etc. The impacts of changes on the technology can result in redesign, use of new/alternative materials. The development of new materials or machines, or new staff with better skills or education can normally help improve management efficiency and effectiveness in planning, scheduling, organizing, cost control, quality management, coordinating, and other decision-making areas.

13. **Institutional Influences (Abbr.: II)**: Interference from professional institutions can affect the conduct of construction professionals through conditions of engagement, etc. The rules of conduct of professionals and education regulations can affect the project organization structure and decision-making process.
14. **Health, Safety and Environmental risks (Abbr.: HSE)**: Similar to all construction projects, health, safety and environmental (HSE) risks are highlighted in projects. Lack of health and safety culture within construction industry makes the situation worse. Because of unique environment of site location, environmental risks are highly required to be taken into consideration.

- ✓ Insufficiency in provision of health and safety equipment and ignorance of environmental regulations.
- ✓ High risk project in terms of health, safety and environmental risks

15. **Site Condition Risks (Abbr.: SCR)** Differing site conditions has always been an issue in construction contracts. Hence, risks arisen from site condition should be taken into account in terms of risk assessment. Externally physical conditions for implementing project management include infrastructure /transportation, capacity and degree of saturation, district development plans, access to the site for material and labor transportation, etc. The uncertain availability and adequacy of these conditions can bring either a big loss or a big saving to project management.

- ✓ Geotechnical risks
- ✓ Earthquake-prone area
- ✓ Hydrological risks/Unforeseen Weather Condition
- ✓ Mangrove forests
- ✓ Large Volume of Traffic

- ✓ Distance from primary sources and materials
- ✓ Distance from major manufacturers which are concentrated in central states

16. **Late Removal of Right of Way Obstructions (Abbr.: ROW)** Right-of-way (ROW) clearance is defined as those instances where there is an interest in land acquired and includes all necessary procedures to acquire the property. In some cases land and interests in land must be acquired outside existing ROW for or by the utility. ROW removal or acquisition and utility adjustment are always on the critical path of a road infrastructure project. It is important to identify and focus on all parcels within the ROW, but especially those that might cause delay, such as those that may require eminent domain acquisition or have other inherent problem.

17. **Government-Intervention Related Uncertainties (Abbr.: GIU)**: Changes in governmental policies or government's interventions can bring a big change in project management. Furthermore, changes in government policies about taxation and investment, which are commonly adjusted to control the level of economic activity, can affect the project planning at the initial decision stage. The changes in legislation directly affect a project client's objectives through the implementation of such as new safety law, new planning law, new building regulations, etc. These changes will particularly affect the construction operational procedure, construction programme, thus change the total costs of a construction project. Legislation changes also influence the contractual relationships between different parties within a project through implementing new contract law.

18. **Economy-Related Uncertainties (Abbr.: ERU)**: Uncertain inflation rate, uncertain interest rate, unstableness in currency exchange rate, etc. under economy environment will affect the implementation of a construction project in term of cash flow, costs of materials, costs of salaries, etc. Changes in economy conditions will also affect the state of competition, the effect of monopolistic phenomena, the availability of finance, materials and labor, etc. For example, high economic activity can produce high level of demand on the construction industry, resulting in shortages of materials, which may delay the project. The changes in economic conditions may also affect the project suppliers' financial situation. Project suppliers include a wide range of professions such as: those providing finance, labor input, distribution of concrete, rebar, brick, and hardware, and etc. The shortage in supplying resources will directly affect the project program and the engagement of all parties for undertaking project works.

19. **Time Uncertainties/Risks (Abbr.: TU)**:

20. **Quality Uncertainties/Risks (Abbr. QU)**:

21. **Cost Uncertainties/Risks (Abbr.:CU)**

Part VI. Rating Scale Questions: Identified Risks and their Inter-relationship among each other.

A. Existing Risk Management Schemes

To show their Inter-Relationship among each other, please put the respective the abbreviation of extent of influence you feel is appropriate on the space provided for the following risk factors.

Scale Rating Description:

Linguistic Terms/ Extent of Influence	Abbreviation	Explanation
Very High Influence	VH	Represents a very high degree of correlation between the two evaluation aspects/criteria.
High Influence	H	Represents a high degree of correlation between the two evaluation aspects/criteria
Low Influence	L	Represents a moderate correlation between the two evaluation aspects/criteria.
Very Low Influence	VL	Represents a low correlation between the two evaluation aspects/criteria.
No Influence	NI	Represents that the two evaluation aspects/criteria are not related to each other.

3. Fill in the questionnaire, as shown in the table below:

(1) Based on your expertise, if you believe that A has a "No Influence" on C, please fill in "NI" in the box.
(2) Based on your expertise, if you believe that C has a "Very High Influence" on D, please fill in "VH" in the box.

Affected by (effect) / The Main influence (Cause)	A (for example: CU)	B (for example: TU)	C (for example: QU)	D (for example: ERU)
A (for example: CU)	The effect of A on A does not need to be filled in.	VL	NI	VH
B (for example: TU)	LI	The effect of A on A does not need to be filled in.	LI	LI
C (for example: QU)	NI		The effect of A on A does not need to be filled in.	VH
D (for example: ERU)	HI	HI	LI	The effect of A on A does not need to be filled in.

EX1	PRU	MR	FR	IRC	HCR	CCR	IR	PR	DCM	CR	SU	TC	II	HSE	SCR	ROW	GIU	ER	TU	QU	CU
PRU	1																				
MR		1																			
FR			1																		
IRC				1																	
HCR					1																
CCR						1															
IR							1														
PR								1													
DCM									1												
CR										1											
SU											1										
TC												1									
II													1								
HSE														1							
SCR															1						
ROW																1					
GIU																	1				
ER																		1			
TU																			1		
QU																				1	
CU																					1

EX1	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21
A1	1	I	VL	VL	VL	I	VL	NI	I	VL	I	I	I	HI	VL	I	NI	VL	VL	VL	I
A2	HI	1	I	VL	NI	I	I	VL	I	I	HI	VHI	VHI	VHI	VHI	VHI	HI	HI	HI	VHI	HI
A3	NI	I	1	VHI	VHI	VL	HI	I	NI	NI	NI	NI	VL	VL	NI	NI	I	NI	NI	VL	HI
A4	NI	VL	HI	1	VHI	VL	HI	VL	NI	NI	NI	NI	VL	VL	NI	NI	NI	NI	NI	VL	HI
A5	NI	VL	VHI	VHI	1	NI	VL	NI	NI	NI	NI	NI	NI	VL	NI	NI	NI	NI	VL	VL	I
A6	I	HI	NI	I	VL	1	VHI	I	I	I	I	VL	HI	HI	I	HI	I	HI	VHI	I	I
A7	I	VHI	I	VL	NI	VHI	1	HI	NI	VL	VL	VL	I	VHI	I	VHI	I	VL	VHI	VL	VHI
A8	NI	HI	HI	NI	VL	I	I	1	VL	VL	NI	NI	VL	VHI	VL	VL	VL	NI	I	VL	HI
A9	VL	VHI	VL	VL	VL	HI	I	NI	1	VHI	VL	VL	I	VHI	HI	HI	HI	VL	I	HI	HI
A10	VL	VHI	VL	NI	NI	HI	I	NI	VHI	1	NI	VL	VL	VHI	HI	HI	HI	VL	I	HI	I
A11	VL	VHI	NI	NI	NI	VL	VL	NI	VL	VL	1	VHI	HI	HI	I	VL	VL	NI	VL	VL	HI
A12	HI	HI	NI	NI	NI	VL	VL	NI	VL	VL	VHI	1	VHI	HI	HI	NI	VL	NI	VL	VL	I
A13	VL	HI	VL	VL	NI	VL	VHI	NI	VL	VL	HI	VHI	1	VHI	I	VL	HI	NI	VL	VL	VHI
A14	HI	VHI	VL	NI	VL	I	VHI	I	VHI	HI	VHI	VHI	VHI	1	VHI	I	VHI	I	I	VHI	HI
A15	VHI	VHI	VL	VL	I	I	I	VL	HI	HI	VHI	HI	I	VHI	1	I	I	I	I	VL	I
A16	VL	VL	NI	NI	NI	VHI	VL	VL	VL	VL	VL	I	NI	VL	NI	1	NI	VL	VL	NI	VL
A17	I	I	VL	I	I	HI	I	I	VL	I	VL	NI	VL	I	VL	NI	1	NI	NI	VL	VL
A18	HI	I	VL	VL	I	VL	I	VL	I	I	HI	VHI	VHI	HI	VHI	VL	VL	1	VL	I	VL
A19	VL	VL	NI	VL	VL	HI	NI	NI	VL	NI	VL	NI	NI	VL	VL	VL	NI	VL	1	NI	I
A20	NI	I	I	HI	HI	VHI	VHI	VHI	HI	I	NI	NI	VL	VHI	NI	VL	I	NI	I	1	HI
A21	HI	HI	I	I	I	VL	VHI	I	HI	HI	I	HI	I	HI	I	HI	I	VL	I	I	1

Example:

Thank You for your time.

ANNEX-2: SAMPLE MATLAB CODING TO ANALYZE THE DATA AND GENERATE THE CAUSAL RELATIONSHIP DIAGRAM.

(Reference: https://cran.r-project.org/web/packages/dematel/vignettes/dematel.html)

ANNEX-3: RESPONDENTS RESPONSE DATA

ANNEX-4: DATA ANALYSIS