CONSTRUCTION PROJECT RISK MANAGEMENT WITH LINGUISTIC DATA: A CASE OF A CONSTRUCTION PROJECT IN KUNMING, THE PEOPLE’S REPUBLIC OF CHINA

By

Miss Ziting GUO

A Thesis Submitted in Partial Fulfillment of the Requirements
for Master of Engineering ENGINEERING MANAGEMENT
Department of INDUSTRIAL ENGINEERING AND MANAGEMENT
Silpakorn University
Academic Year 2023

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Title	Construction Project Risk Management with Linguistic Data: A Case of a Construction Project in Kunming, the People's Republic of China
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Miss Ziting GUO : Construction Project Risk Management with Linguistic Data: A Case of a Construction Project in Kunming, the People's Republic of China Thesis advisor : Noppakun Sangkhiew, Ph.D.

Most risk assessment tools are cumbersome, especially for a complex system like a construction project. They need skilled staff and experienced management in construction projects to determine. However, in practice, the risk management team is scarce. This study proposes a practical risk assessment tool available for mid-level management. Accordingly, it can be deployed without a doubt.

Furthermore, the proposed risk assessment tool includes linguistic data determined by triangular fuzzy numbers. It allows an assessor to make a decision barely. A sample construction project in Kunming shows that financing investment risk is the most critical, with RPN = 0.275. The second one is construction phase risk, with RPN = 0.253. Management must focus on supervision in the construction phase and be aware of the economic instability in China.

The proposed risk assessment procedure also proposed a logic of selecting risk mitigation strategies by deploying Pareto rule and the sample construction project disclosed some risk mitigation scheme in this report.

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Ziting GUO

TABLE OF CONTENTS

Page

List of Tables

Page

List of Figures

Page

CHAPTER 1
INTRODUCTION

1.1 Background

The construction sector is becoming increasingly complicated, which introduces a great deal of unpredictability and risk into building projects. Risk is defined as an unknown occurrence or circumstance that, if it occurs, affects at least one project objective (Mohammadi & Tavakolan, 2013). This definition comes from the Project Management Body of Knowledge.

Other definitions of risk can be found in the relevant literature, such as the "likelihood of a detrimental event occurring to the project" (Balodi & Price, 2003), "a measure of the probability, severity, and exposure of all the activity hazards" (Jannadi & Almishari, 2003). Any event that may affect project objectives, regardless of whether it has a positive or negative impact, will be considered a risk.

In construction projects, there are many potential sources of risk, and several strategies have been proposed as potential methods for locating, categorizing, and evaluating these risks. On the issue of risk management procedures, a significant number of scholars have offered a variety of various processes, and the ultimate objective of any technique is to achieve successful risk management (Iqbal et al., 2015).

The effective management of risks is a crucial component of effective project management. The goal of risk management is to understand the risks involved and then either eliminate or reduce them. The team in charge of project management needs to take into account every potential risk in order to devise corrective steps at the appropriate moment, which will allow them to capitalize on chances and steer clear of potential dangers (Liu et al., 2007).

Nevertheless, the risk assessment is much more complicated than before. There are several risk sources, and some of them can not be quantified. Thus, a risk assessment tool must be able to consider crisp data and is simple to figure out in practice. In this study, the researcher will propose a practical risk assessment procedure that manageable the linguistic variables by using fuzzy set theory and failure mode and effective analysis model. The primary intention is to find a pack of risk assessment tool is located.

1.2 Research Objectives

1. To propose a practical state-of-the art risk assessment tool in construction industry.

2. To apply the proposed tool to identify and manage the risk in a construction project in Kunming, the People's Republic of China.

1.3 Research Contributions

1. A novel tool that is customized for the construction industry is proposed.

2. An application to a case study can illustrate as a referenced case model to construction projects about risk assessment and management in case of crisp data is involved.

3. This study shows how to apply a mathematical theory in practical engineering management, which is helpful for other solving engineering problems.

1.4 Scopes and Limitations

1. This study is a combination of survey research and quantitative research; however, the primary one is the quantitative research that attempts to propose a practical tool and the case is about collecting data from the case study.

2. The survey research has a specific manner. Thus, the result from the case study cannot guarantee other cases in general.

3. The data is collected between December 2023 to January 2024

4. This study neglects uncertainty of variables.

1.5 Abbreviations

AEC	Architech, Engineering, and Construction
ANP	Analytic Network Process
BOT	Build-Operate-Transfer
CFPR	Consistent Fuzzy Preference Relation
COG	Cebter of Gravity
D-S Theory	Dempster-Shafer Theory
FMEA	Failure Mode and Effects Analysis
FST	Fuzzy Set Theory
GM	Geometric Mean
MADM	Multi-attribute Decision-making
MCDM	Multi-criteria Decision-making
O-S-D	Occurance-Severity-Detection
OWA	Ordered Weighted Averaging
RPN	Risk Priority Number
TRM	Total Risk Management

CHAPTER 2
LITERATURE REVIEW

The risk management is described in this chapter, section 2.1. It is the paramount factor in successful project management. Time, cost, quality, and safety are attributes in construction projects. Fuzzy set theory is reviewed in section 2.2. A well-known analysis tool is examined in section 2.3. Various literature in the last decade deployed failure mode and effects analysis (FMEA) to assess the risks. The advantages and disadvantages of this tool is unfolded. Fuzzy FMEA is probed in section 2.4. Finally, related literature is reexamined in section 2.5.

2.1 Risk Management

2.1.1 System engineering and risk management

It is necessary for effective management of technical as well as non-technological systems to take into account the holistic character of the system, taking into account its hierarchical structure, organizational makeup, and basic decision-making structure. Also to be taken into consideration are the numerous non-commensurate objectives, sub-objectives, and sub-sub objectives, as well as the many different time horizons, the numerous decision-makers, constituencies, power brokers, stakeholders, and users of the system, as well as a host of other institutional legal and socioeconomic conditions. Therefore, there are a number of basic philosophical and methodological concerns that are raised by risk management (Haimes, 2015).

Engineering systems are virtually always planned, produced, integrated, and operated under conditions of risk and uncertainty that cannot be avoided. They are sometimes required to accomplish numerous objectives that are in direct opposition to one another. It should not be a separate, cosmetic afterthought but rather an inherent and explicit component of the whole process of management decision-making that involves identifying, measuring, assessing, and trading off risks, rewards, and costs. This should take place before making any decisions. The corpus of knowledge in risk assessment and management has received a substantial amount of attention over the past three decades (particularly after the assault on the United States on September 11, 2001); it includes a wide range of disciplines and incorporates empirical, quantitative, as well as normative and judgmental components of decision-making (Szymański, 2017). Does this entail the creation of a brand-new field that stands on its own, such as systems engineering or systems analysis? Or do the terms "systems engineering" and "systems analysis" require a more specific and restrictive definition? Has it been appropriately perceived that the body of knowledge known as risk assessment and management significantly fills a critical void that supplements and complements the theories and methodologies of systems engineering and systems analysis when risk and uncertainty are addressed within a practical decision-making framework? If so, this would indicate that this perception is accurate. It is not enough to be just motivated by intellectual curiosity to ponder these and other concerns of a similar sort regarding the nature, role, and location of risk assessment and management in the management of technology and nontechnological systems, as well as in the broader process of managerial decision-making. Rather than that, exploring such problems ought to give a means of bridging the gaps and removing some of the obstacles that now exist across the many fields of study (Algahtany et al., 2016).

2.1.2 System failure and risk assessment

When it comes to the management of technical systems, a system's failure can be attributed to a number of different factors, including the hardware, the software, the organization, or the persons that were involved. Naturally, natural disasters, acts of terrorism, or other tragedies might potentially serve as the starting point for the chain of events.

The definition of the term "management" might shift depending on the specific domain in question as well as the surrounding circumstances. A common definition of risk is a measurement of the likelihood and intensity of negative impacts that may occur. Even while some people use the word risk management to refer to the full process of risk assessment and management, most people separate risk management from risk assessment. In risk assessment, the analyst will often attempt to answer the following set of triplet questions (Moosa, 2007).

- What could possibly go wrong?
- What are the chances that something may go wrong with it?
- What are the repercussions of this decision?

• It brings us to our fourth question: What exactly is meant by the time domain?

The responses to these questions provide analysts with information that helps them identify, measure, quantify, and assess risks as well as the repercussions and impacts of those risks. The risk management process seeks solutions to a second set of three questions to expand on the risk assessment findings (Moosa, 2017).

• What can be done, and what different alternatives are there to choose from?

• What are the trade-offs involved in terms of all of the applicable costs, benefits, and other factors?

• How will the actions made by the present management affect the choices available in the future?

The evaluation and management of risk is fundamentally composed of a synthesis and amalgamation of empirical and normative evidence, quantitative and qualitative analysis, as well as objective and subjective labor. Is it possible to attain total risk management (TRM) when these problems are handled in the larger context of management, where all possibilities and the related trade-offs are examined within the hierarchical organizational structure? (The word TRM will be defined in a more official capacity at a later time.) In point of fact, it is not possible to intelligently and truly evaluate the whole trade-offs among all essential and relative system objectives in terms of costs, benefits, and risks in isolation from the modeling of the system and the more general resource allocation views of the entire organization (Algahtany et al., 2016).

Therefore, effective management has to embrace risk management and treat it within a holistic and all-encompassing framework that also combines and tackles all pertinent resource allocation and other management concerns relating to the business. The following four potential failure causes must be addressed by an approach to total risk management designed to synchronize risk management with the management of the system as a whole, see Fig. 2.1.

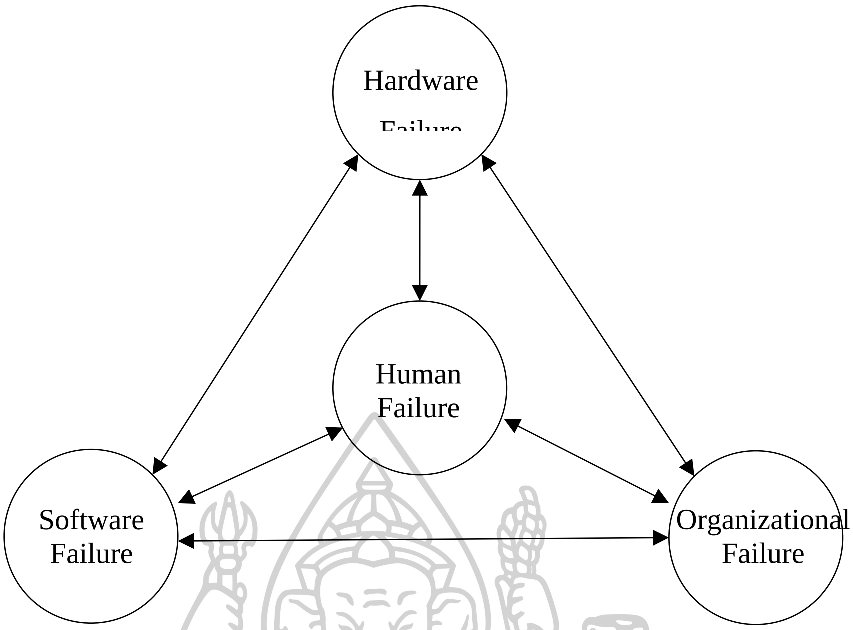

Figure 2.1 System failure.

Source: Algahtany et al. (2016)

- Human failure
- Hardware failure
- Software failure
- Organizational failure

The above list of potential failure points is meant to be all-encompassing with regard to the system's internal environment (i.e., all-encompassing inside the system itself). However, it's important to note that these four components aren't always operating in isolation from one another. The line between software and hardware is not always easy to draw, and it is sometimes challenging to differentiate between the effects of human error and those of organizational failings. In spite of this, the combination of these four categories produces a significant basis for a framework for overall risk management. Edwards & Edwards (1995), the authors of the definitive book on quality control, argue that "the three building blocks of business are hardware, software, and humanware." In addition to this, they argue that total quality control "means that quality control effects must involve people, organization, hardware, and software." As was previously said, efficient information management within an organization plays a significant role in lowering the incidence rates of these many causes of failure.

2.1.3 Total risk management

The term "*total risk management*," abbreviated as "TRM," refers to a methodical, comprehensive, and statistically based procedure. It is built on quantitative risk modeling, assessment, and management (Haimes, 2005). Within a hierarchical-multiobjective framework, it covers four different sources of failure and provides answers to the two sets of risk assessment and management questions introduced earlier. The TRM paradigm is illustrated in Fig. 2.2.

In the context of TRM, the phrase "hierarchical-multiobjective framework" may be described in further detail. The structure of most companies, if not all of them, is hierarchical, which is reflected in how decisions are made inside the organizations. In addition, the decision-making process at each level of the organizational hierarchy is driven by many incompatible objectives, which compete with one another and cannot be compared. The "optimal" distribution of an organization's resources across its many hierarchical levels and subsystems is at the core of all sound management choices. When we talk about the "optimal" allocation, we are referring to it in the sense of the Pareto optimum allocation, which is when the trade-offs among all of the costs, rewards, and risks are assessed in terms of hierarchical objectives (and sub-objectives) and their temporal consequences on future alternatives (Haimes, 2005).

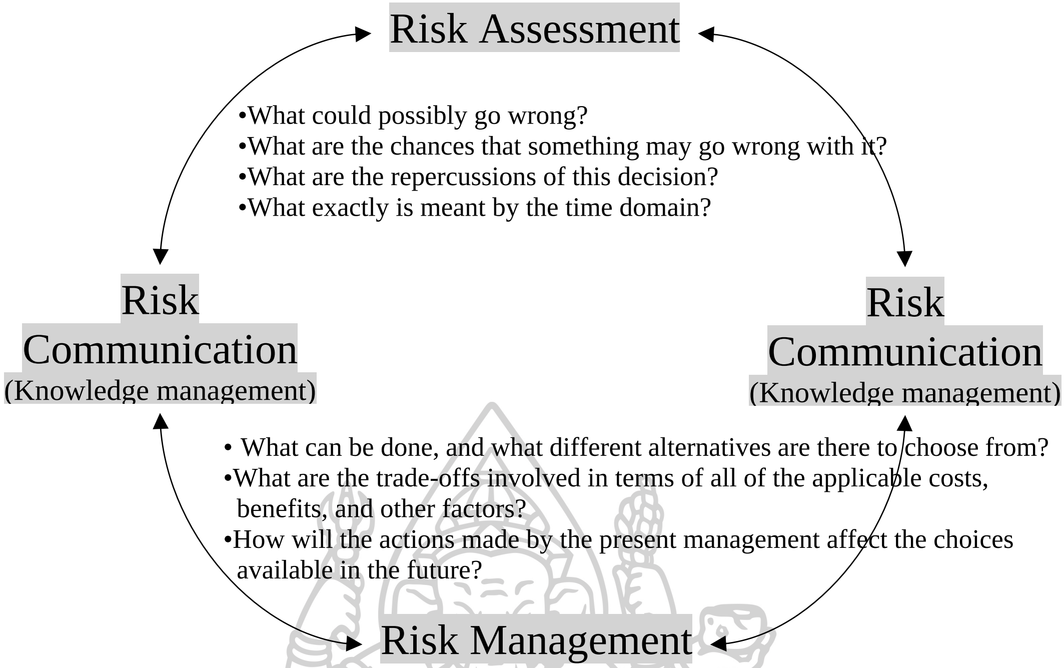

Figure 2.2 Total risk management.

Source: Haimes (2005)

2.1.4 Risk management in construction industry

The AEC (Architecture, Engineering, and Construction) industry has witnessed rapid development all around the world, especially in developing countries, over the course of the last few decades – large-scale projects have become widespread and international, and new project delivery methodologies are being adopted, design theory and tools are constantly improving, and innovative and new approaches, methods, and materials of construction are being introduced (Zou et al., 2017). AEC projects, which include buildings, infrastructure systems, and plants, are included in the purview of urban spatial planning and design. These projects have an immediate influence on the accommodation of land use for the future expansion of cities, as well as a direct relation to one another. Urban spatial planning and design are interdisciplinary fields. Nevertheless, the AEC business has a terrible reputation as a result of its high accident rates and dangerous practices, which also endanger the industry's future ability to innovate and advance. The extent of the risk is expansive, and it includes things like the destruction or collapse of structures, the sustaining of injuries or the loss of life, going over budget, and falling behind schedule. These things can be brought on by a variety of factors, including flaws in the design, faulty materials, incompetent workers, and ineffective management. For example, in the United States, there were 503 bridge collapses documented between the years 1989 and 2000 (Wardhana & Hadipriono, 2003). Furthermore, according to government statistics, more than 26,000 construction workers lost their life on the job between the years 1989 and 2013 (Zhang et al., 2013). According to estimates provided by the International Labor Organization in 2005, over 60,000 fatal incidents occurring on-site occur each year across the world. Even though the number of construction monitoring businesses expanded in China from 52 in 1989 to 5123 in 2000 (Liu et al., 2004), unwelcome risks in relation to safety, time, and cost have been noticed often as a result of poor risk management.

Planning and design are the first steps of an AEC project, which is then followed by a building phase that might continue for months or even years. At some point in the future, the construction project will enter its operation phase, which might endure for decades before being demolished. At each point of the product or project lifecycle, there is the potential for a unique set of hazards to be present. There is a diverse set of potential hazards that might be caused by risks. In recent years, as a result of the fast growth of society, risks have been steadily developing. This is due to the increasing structural complexity and project size, as well as the adoption of new and complicated building technologies (Shim et al., 2012). In order to lessen the likelihood that these dangers will materialize and to increase the likelihood that project goals will be successfully accomplished, there is an increased requirement for efficient risk management throughout the life cycle of a project. Nevertheless, physical labor is still required to carry out the application of traditional risk management. The evaluation is primarily weighted toward practical experience as well as analytical mathematics.

Both the construction industry as a whole and individual building projects must contend with a number of different types of dangers termed hazards. In construction projects, risk assessment has been utilized in a variety of unique ways from project to project (making use of a wide variety of risk assessment models) in order to analyze the risk involved in distinct project activities. Nevertheless, the socioeconomic complexity that is involved in building events makes them more prone to risk, which means that there may be detrimental impacts on the project's potential to be sustainable (Chatterjee et al., 2018). The construction business is very diversified and heterogeneous as a result of a variety of complicated elements. Additionally, the sector is undergoing a significant amount of dynamic change as a result of global sourcing and increased price rivalry (Van et al., 2019).

In the past, contractors have typically relied on large markups as a method of mitigating these risks; however, this strategy is no longer viable due to the fact that their margins have shrunk (Forteza et al., 2016). As a result of advances in technology and increased demand from stakeholders, the stages of building projects have gotten significantly more complicated in recent decades. They are distinguished by a great number of uncertainties, which have a detrimental impact on the initiatives. In light of the fact that risk-free building projects simply cannot be carried out in the real world, it is necessary to implement a controlled risk assessment approach in order to manage the numerous hazards associated with a project (Razia et al., 2019).

The process of identifying the risks that a project faces, analyzing those risks, and deciding what steps should be taken to mitigate those risks is what we mean when we talk about risk management (Mhetre et al., 2016). Dealing with potential dangers throughout the execution of a project calls for incorporating the entirety of the stages involved in risk management. Risk management is an essential step in the construction industry because of the unpredictable nature of the work. The following are some broad categories that may be used to classify the dangers linked with the building industry:

1) Technical risks

The risks referred to as "technical" include those related to an incomplete design, an inadequate specification, an inadequate site assessment, a change in scope, construction processes, and insufficient availability of resources.

2) Construciton risks

These hazards consist of labor productivity, disagreements, the state of the site, failed equipment, design revisions, excessively high-quality requirements, and emerging technologies.

3) Physical risks

The risks associated with damage to the building and equipment, injuries to workers, loss of equipment and materials due to theft or fire, and other similar events are referred to as physical hazards.

4) Organizational risks

The organizational risks may be broken down into five categories: contractual connections, the experience of the Contractor, the attitudes of participants, inexperienced staff, and communication.

5) Financial risks

Increased material costs, decreased market demand, fluctuating exchange rates, payment delays, and incorrect tax calculations all contribute to the possibility of a negative financial outcome.

6) Socio-political risks

Socio-political hazards include alterations to existing laws and regulations, new regulations on pollution and safety, bribery and corruption, language and cultural barriers, law and order, civil war and unrest, and the need for permits and approval of those permits.

7) Environmental risks

Environmental hazards include but are not limited to, natural disasters and weather implications.

Mhetre et al. (2016) concluded that risk management has three primary steps: identification, assessment, and response. The brief literature on each step is recited below.

Risk identification: It can be done by one or a combination of theses methods.

1) Brainstorming: It is rapidly becoming one of the most often used methods. In most cases, it is employed to produce ideas, and it is beneficial in identifying potential risks. Everyone important in connection with the project comes together in one location. One of the facilitators talks to the attendees about the various components, then writes down the variables. Before bringing it to a close, the facilitator will review the criteria and cross off those that are not required.

2) Delphi Method: It is a process that is very similar to brainstorming; however, with this method, the participants are required to learn from one another and to be in the exact location. They will determine the elements independently without

seeking input from the other participants. The facilitator will, much as in brainstorming, summarize the variables found.

3) Interviews with Subject Matter Experts: Subject matter experts or individuals with sufficient expertise in a project may be of tremendous assistance in preventing or resolving problems that have occurred in the past. It is possible to conduct interviews with all people involved in the project who are relevant to investigating the variables impacting risk.

4) Previous Experience: Experience gained from the same project allows an analogy to be built, which can then be used to identify the components. When comparing the features of different projects, one may get insight into the things common to them.

5) Checklists: They are straightforward but handy preset lists of potential elements for the project. Checklists may be found online. The checklist, which includes a list of the risks discovered in projects carried out in the past and the answers to those risks, offers a head start in risk identification by providing a list of the risks detected in projects carried out in the past.

Risk assessment: It can be divided into main categories: qualitative methods and quantitative methods. Their details are as follows:

1) Qualitative methods: They are based on descriptive scales, and they are employed for the purpose of describing the possibility of a risk as well as its potential impact. When a rapid evaluation is necessary for projects of a smaller or medium scale, these procedures, which are very straightforward, might be applied. In addition, this approach is frequently employed when numerical data are insufficient, limited, or unavailable, as well as when time and financial resources are in short supply. The following is a listing of them:

1.1) Risk assessment is based on its likelihood of occurring and its potential consequences. It may be done by employing a technique known as risk assessment based on its likelihood of occurring and potential consequences. In addition, the influence that risk has on a project's objectives is evaluated in terms of its positive impacts on opportunities and its adverse effects on threats. For this evaluation, the probability and the effect should each be specified and adapted to a specific project. It indicates that explicit definitions of scale ought to be drafted, and the project's nature, criteria, and goals should determine the breadth of the scale's application. The Project Management Institute (PMI) establishes a sample probability range that goes from "very unlikely" to "almost certain," although the accompanying numerical evaluation can still be used. On the impact scale, values range from very low to very high.

1.2) Risk evaluation matrix based on probability and impact: The probability and influence of the event, which was evaluated in the stage before this one, serve as the foundation for quantitative analysis. Because of this, the evaluation results are ranked in order of importance by employing various approaches to computation that may be discovered in the relevant body of research. The priority score is determined by taking the average likelihood and the impact in Westland's algorithm. The importance of each danger is represented by its range of priority scores, ratings, and color, respectively. Threats that have a high effect and a high possibility are considered high-risk, and a reaction to them may be required immediately. In contrast, threats with a low priority score can be observed, and action can be taken if or when necessary.

1.3) Risk Assessment Based on Its Urgency and Risk Categorization: Classifying risks is a method for organizing a project's risks.

2) Quantitative methods.

2.1) Sensitivity analysis: It aims to determine which aspects of a project are unknown. As a result, it will have the most significant influence on the project's final product. After a risk model has been developed, a sensitivity analysis is carried out to examine the impact that various model features have on the project's final results. In order to carry these out, the values of one variable at a time are altered, and the effect that each of these alterations has on the project is then evaluated.

2.2) Scenario analysis: An investigation of alternative scenarios for a project, or the impact of distinct hazards if they coincide, is referred to as a scenario analysis. After conducting this analysis, a reasonable choice may be made; the alternative that results in a lower risk of experiencing a loss of some kind may be selected.

2.3) A probabilistic analysis: It also known as a Monte Carlo simulation, is when a model is used in a project simulation to demonstrate the possible influence that varying degrees of uncertainty might have on the project's goals. In most cases, the Monte Carlo Simulation method is employed for this investigation. It can estimate the influence that uncertainties and risks have on the schedule and budget of the project. It runs through several simulation iterations, randomly selecting a value to represent each element based on the probability distribution associated with that factor. When managing time, this method employs three-point estimations, such as the most likely, worst-case, and best-case durations for each activity.

2.4) Decision Trees: A decision tree diagram was used to carry out this investigation. Both parties can benefit from using decision trees.

Risk response: This step identifies the activities that should be launched toward the identified risks and menaces. A chosen response or its combination depends on the type of risk and available resources.

1) Risk avoidance: The best way to avoid risk is to eliminate the factors that may lead to it happening in the first place. One way to do this is to steer the project on a new path while still working toward achieving the project's goals. Modify the strategy for the management of the project so that a threat may be removed, project objectives can be shielded from the impact of the risk, or the project objective that is in danger of being lost can be made less important by, for example, extending the timeline or narrowing the scope.

2) Risk transfer: Finding a third party that is prepared to assume responsibility for the risk's management and who is willing to bear the financial burden of the risk in the event that it materializes is required in order to successfully transfer risk. Transferring a threat does not eradicate it; the threat continues to exist; rather, it now belongs to another party who is responsible for managing it. The successful management of financial risk exposure can sometimes include the transfer of risk to another party. The goal is to make certain that the risk is owned and managed by the entity that is in the greatest position to successfully deal with it.

3) Risk Mitigation and Reduction: Risk mitigation is the process of reducing the chance of a negative risk occurrence or its impact to a level that is

acceptable. It is typically more beneficial to take preventative measures early on to lessen the likelihood of a risk's occurrence or its effects than it is to try to restore the harm after the risk has already passed.

4) Ris exploitation: It is a tactic that aims to reduce the amount of uncertainty that is connected to a particular positive risk by making the most of the opportunity that presents itself when the risk is realized. Reduce or do away with the uncertainty that is connected with a Particular Upside Risk. An opportunity may be a risk event that, should it come to pass, will have a beneficial effect on the accomplishment of the project's goals.

5) Risk share: It is when one party allows the risk ownership of an opportunity to another party in the hopes that the other party will be able to raise the possible advantages should the opportunity really materialize. A third party is utilized in both the process of transferring threats and sharing opportunities. Those to whom the threats are passed take on the liability, and those to whom opportunities are assigned should also be permitted to partake in the possible advantages of the opportunity.

6) Increase the Risk: The purpose of this strategy is to change the "size" of the potential benefit. The opportunity is improved by raising either its likelihood or its effect, which in turn helps to ensure that the advantages obtained from the project are maximized. It aims to promote or bolster the cause of the opportunity, as well as proactively target and enhance the factors that trigger it.

7) Acceptance of Risk: In the end, it is only feasible to partially remove all potential dangers or fully capitalize on all available possibilities. We are able to document them and, at the very least, bring consciousness to the fact that these have been identified and exist. When it is impossible to respond to the risk using the other techniques or when the grandness of the danger does not warrant a response, this strategy is used. When the management of the project and the team decide to accept a risk, they make a pact to deal with it if and when it really occurs.

8) Contingency strategy: In the event that a danger materializes, following a contingency-plan entails reverting to an alternate strategy. Additionally, contingencies can occasionally be maintained in reserve to deal with unknown

hazards or in the form of charges to deal with unknown risks. Both of these strategies can be used.

Iqbal et al. (2015) illustratted risk modeling in construction industry that related to Build-Operate-Transfer (BOT) which consider on the effects of the construction project activities and system, see Fig. 2.3.

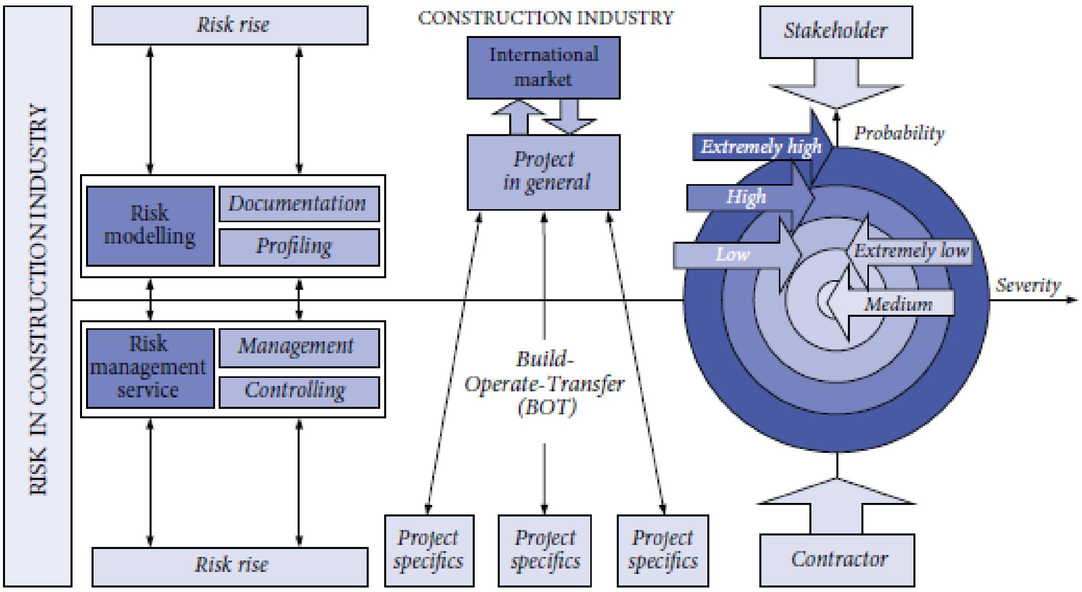

Figure 2.3 Risk model in construction project.

Source: Iqbal et al. (2015)

2.2 Fuzzy Set Theory

2.2.1 Fuzzy set

The fuzzy set has emerged as an essential method in the field of artificial intelligence because it makes it possible to simulate the unpredictability of human behavior on a computer while maintaining definite performance (Zadeh, 1978). The use of fuzzy sets has made significant progress in the field of intelligent computing research and practice applications. The support of fuzzy set theory is essential to the speedy development of fuzzy control and cannot be separated from it. According to Dubois (1980), the fuzzy set theory offers new scientific logic and methodologies for the fields of information science and cognitive science, as well as an efficient way for the development of intelligent information processing technology. Since that time, several scholars have devoted a significant amount of time and energy to examining fuzzy numbers. The use of fuzzy numbers in mathematical modeling is a valuable technique that may be used for modeling uncertainty and processing information that is hazy or subjective. Their future areas of growth are broad, and they have been utilized to solve a wide range of real-world issues, including fuzzy optimization, fuzzy transportation problems, and fuzzy differential equations (Ebrahimnejad, 2016).

2.2.2 Membership functions

The concept of binary membership is extended by Zadeh (1965) to account for multiple 'degrees of membership' on the actual continuous interval [0,1]. The endpoints of 0 and 1 correspond to no membership and complete membership, respectively, in Fig. 2.4 (a). The indicator function works for discrete sets; however, an endless number of values might indicate varying degrees of membership for an element X in a set anywhere in the universe. It is the case even though the function works for discrete sets. The sets that exist in universe X are what Zadeh refers to as fuzzy sets. A membership function, which can be seen depicted in Fig. 2.4 (b), is what makes up fuzzy sets. The membership function is a critical distinction between crisp sets and fuzzy sets. A crisp set has a single membership function, but a fuzzy set might have endless membership functions to describe it. Modifying the membership function of fuzzy sets is possible, which means their increased adaptability can compensate for their lack of uniqueness. Fuzzy sets are helpful for a variety of different applications.

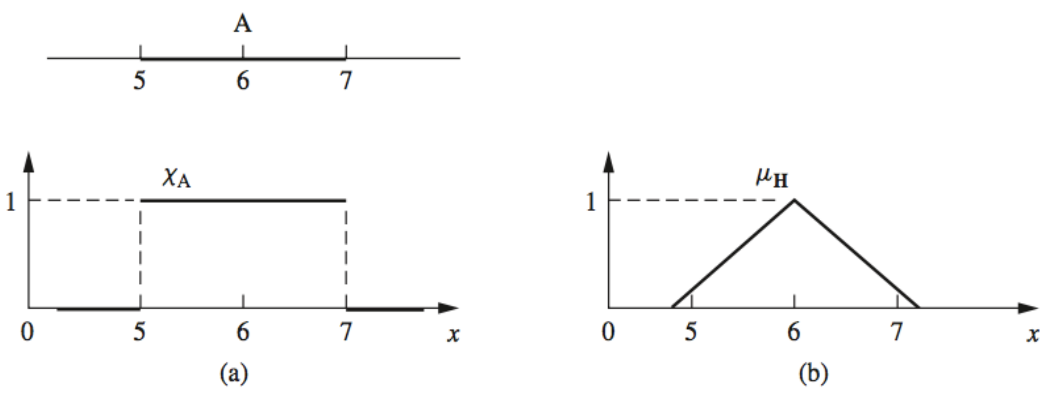

Figure 2.4 Height membership functions for (a) a crisp set A, (b) a fuzzy set H.
Source: Jomthong (2023)

The triangular function, the Gaussian function, the trapezoidal function, the generalized bell function, the sigmoid function, and the Left–Right (LR) membership function are the essential functions that are used to construct fuzzy logic (Jomthong, 2023). However, this review briefly describes the triangular, gaussian, and trapezoidal membership functions.

1) Triangular membership function

Straight lines are used to generate the membership functions that are the simplest to understand. The triangle membership function, sometimes known as TRIMF because of its function name, is the simplest one. There is nothing more to it than the collection of three points forming a triangle together. Mandal et al. (2012) presents us with a graphical depiction of the triangle membership function that may be found in Fig. 2.5.

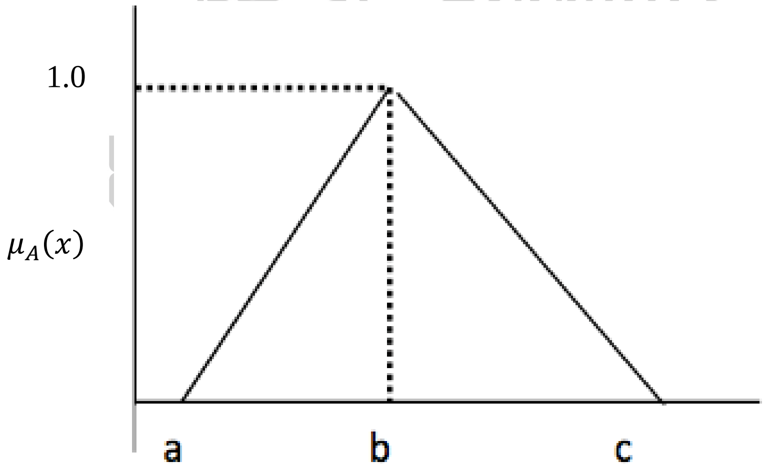

Figure 2.5 Triangular membership function.
Source: Mandal et al. (2012)

$$\mu(x) = \begin{cases} \dfrac{x-a}{b-a} & if\ a \le x \le b \\ \dfrac{c-x}{c-b} & if\ b \le x \le c \\ 0 & if\ x \le a\ or\ x \ge c \end{cases} \quad (2.1)$$

2) Gaussian membership function

According to Jomthong (2023), the Gaussian membership function is often shown as the expression Gaussian ($x: c, s$), in which c and s stand for the mean and standard deviation, respectively. See Fig. 2.6.

Figure 2.6 Gaussian membership function.

Souce: Jomthong (2023)

$$\mu(x, c, s, m) = exp\left[-\frac{1}{2}\left|\frac{x-c}{s}\right|^{m}\right] \quad (2.2)$$

3) Trapezodial membership function

The trapezoidal membership function is characterized by a lower limit of value a, an upper limit of value d, a lower support limit of value b, and an upper support limit of value c (Jomthong, 2023), see Fig. 2.7.

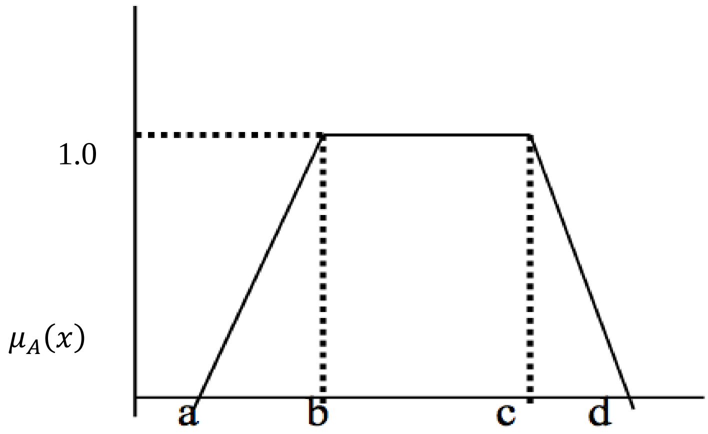

Figure 2.7 Trapzoidal membership function.

Souce: Jomthong (2023)

$$\mu(x) = \begin{cases} 0, & (x < a)\ or\ (x > d) \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \frac{d-x}{d-c}, & c \leq x \leq d \end{cases} \tag{2.3}$$

2.3 Failure Mode and Effects Analysis

2.3.1 FMEA and risk management

Analysis of Failure Mode and Effects, or FMEA for short, is a method that involves determining all of the different failure modes that exist inside a system, doing an investigation into the underlying causes of those failure modes, determining the impact those failure modes have, and making plans for how to fix the problems (Mohammadi & Tabakolan, 2013). Risk Priority Numbers (RPNs) are used in traditional FMEA to identify the risk priority of the failure modes that are identified. The RPN has a range from 1 to 1,000 and may be calculated by multiplying the scores of risk variables such as the incidence (O), severity (S), and detection (D).

$$RPN = O \times S \times D \tag{2.4}$$

where O is the failure probability, S is the failure severity, and D is the power of detection.

Several studies have recommended The FMEA methodology for use in risk management. Carbone & Tippett (2004) presented the use of FMEA that applies to the overall project risk management scope. They used the PRN number as a calculation tool to determine the most severe dangers. An exemplary case study from the paper sector was used by Sharma et al. (2005) to demonstrate the application of FMEA and fuzzy logic to risk assessment. They evaluated the ratings for the risk factors by making use of language variables, which were then represented as fuzzy numbers. Their findings demonstrated that fuzzy linguistic modeling was an effective solution to the uncertainty inherent in conventional evaluation. The conventional FMEA does, however, suffer from a few drawbacks. Accurately determining the probability of failure occurrences in FMEA can be challenging or even impossible in some cases (Yang & Wang, 2015). At the same time, a significant amount of the information in the FMEA is conveyed by using language such as 'likely' and 'Very high.' Multiple sets of O, S, and D can generate the same value in RPN analysis, but the risk implication can be quite different from one case to the next. Consider, for example, two distinct occurrences, one with the value $O = 3$, $S = 5$, $D = 3$, and the other with the values $O = 9$, $S = 5$, and $D = 1$, respectively. Even though the total RPN value of these two occurrences will be the same, which is sixty, the risk implications of these two events will not necessarily be the same. After much study, Liu et al. (2012) compiled an exhaustive list of FMEA flaws. They point out that the relative relevance of O, S, and D is not taken into consideration, and instead, it is believed that all three components have the same level of significance.

2.3.2 Traditional FMEA

Detection is capacity to recognize the risk event in enough of time to make preparations for a contingency and take appropriate action on the risk. The values of these three elements might range anywhere from "1" to "10". Components of the system that have a high RPN are presumed to have a higher level of criticality than those that have lower values (Gavrysh & Melnykova, 2019). It has been demonstrated that the classic FMEA is one of the most critical tools for minimizing the possibility of mistakes and failures occurring inside the system. On the other hand, the traditional RPN technique has received a lot of backlash in the academic literature for a variety of different reasons (Yang et al., 2015). Basically, the severity, occurance, and detection are scaled in the traditional FMEA as shown in Table 2.1 to 2.3.

Table 2.1 Severity scaling.

Effect	Criteria: severity of effect	Rank
Hazardous	Failure is dangerous and might take place without any prior notice. It prevents the system from operating normally and/or results in violations of laws and regulations imposed by the government.	10
Serious	Failure may be defined as the occurrence of dangerous consequences or the violation of government norms or standards.	9
Extreme	The product is unable to be used and has lost its primary function. The system is completely ineffective.	8
Major	Product performance is drastically compromised, although it continues to function normally. It's possible that the system won't work.	7
Significant	The functionality of the product is deteriorating. It's possible that the functions of comfort or convince won't work.	6
Moderate	Impact on product performance that is just moderate. It is necessary to fix the product.	5
Low	Very little impact on the overall performance of the product. The item does not need to be repaired in any way.	4
Miner	A barely noticeable impact on the overall functioning of the product or system.	3
Very Miner	Very little impact on the overall performance of the product or system.	2
None	No effect.	1

Source: Nuchpho et al. (2014)

Table 2.2 Occurrence scaling.

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

Source: Nuchpho et al. (2014)

Table 2.3 Detection scaling.

Detection	Criteria: likehood of detection by design control	Rank
Absolute uncertainty	Either the design control does not identify a possible failure mode or subsequent cause of failure, or there is no design control.	10
Very remote	There is a very little possibility that the design control may identify a probable failure mode or a future failure cause.	9
Remote	There is a small possibility that the design control may identify a probable failure mode or a future failure cause.	8
Very low	Very little likelihood that the design control will identify a probable failure cause or later failure mode.	7

Table 2.3 (continued)

Low	There is a low probability that the design control will identify a probable failure mode or a future failure cause.	6
Moderate	There is a good likelihood that the design control will be able to identify a prospective failure mode or a subsequent failure cause.	5
Moderately high	There is a fair probability that the design control will identify a probable failure mode or a future failure cause.	4
High	There is a good likelihood that the design control will be able to identify a prospective failure mode or a subsequent failure cause.	3
Very high	Extremely high probability that the design control will identify a probable failure cause or later failure mode.	2
Almost certain	When properly implemented, design control will almost likely be able to identify a prospective failure mode or a future failure cause.	1

Source: Nuchpho et al. (2014)

Figure 2.8 illustrates the example of FMEA analysis table.

Project Phase	Project Risks	Potential Cause	Probability	Impact	Risk	Action	Due Date	Responsible	Completed	New Probability of Occurrence	Status
Analyze	Resource commitment too low	Resource have 'operational' activities	3	2	6	Ensure project is in performance objectives of all resources on project	08. Feb 08	Steering Committee	Yes	1	2
Improve	Plans are unrealistic for Improve	Making estimates after Define too early because solutions are not yet known	3	2	6	Update Steering Committee as plans become more firm	15. Mar 08	BB	No		6
Control	Project close without being able to prove objectives met	Long lead time before "post-improvement" data can be collected	3	1	3	Monitoring phase by Office of Process Excellence	End Improve	MBB	No		3
Control	Not enough resources in process owner department to roll-out solution to broad audience	Huge organization to reach with small organization	3	2	6	Plan additional resources for rollout	End Improve	BB	No		6
General	Redundant process improve-ment work going on in different organizations	Process improve-ment initiatives in other organiza-tions with similar scope	1	2	2	SC should drive awareness in their organizations and put project team in touch with people in their organization carrying out similar tasks	16-Feb-08 and ongoing	Steering Committee	No		2

Figure 2.8 An example of FMEA analysis.

Source: Buthmann (2010)

2.4 Related Works

Liu et al. (2007) investigated the primary factors in Chinese's construction industry risk. The target population were construction project managers, supervisors, contractors, insurers, insurance brokers, financial consultants, surveyors, and universitys' professors. It was found that the knowledge about the risk of contractors was very important in risk management. However, the results were suspected since the sample size was 41 respondents. However, it was inevitable to quote that education about risk management is really substantial.

Mohammadi & Tavakolan (2013) combined FMEA and fuzzy to examine the failure modes to assess their impacts and issue countermeasures. Linguistic variables were used to assess the ratings of occurrence, severity, and detection. The study used seven membership functions with 343 rules for fuzzy system. Additionally, the researchers also used the analytical hierarchy process (AHP) to calculate the weights of risk impact on time, cost, quality, and safety.

Chanamool & Naenna (2016) investigated the risks of emergency departments in a hospital. They used fuzzy FMEA to rank and evaluate of emergency department's failure. The researchers concluded the restrictions of the traditional FMEA. Firstly, the importance of criteria giving different weights; it does not consider the relative importance of opportunity, severity, and detection. Secondly, the exact value may come from various combinations of chance, severity, and detection. However, the hidden risks are different. Thirdly, the value of RPN plays an essential role in other effects. Thus, the calculation of it is crucial. Finally, the traditional FMEA cannot deal with linguistic data. In their study, the authors claimed the proposed method could help management choose corrective actions sagely.

Hayati & Abroshan (2017) used fuzzy FMEA to assess the risks of a subway tunneling construction project in Tehran. Based on the experts' opinion of the project, many risk factors can be cumbersome due to ambiguity and qualitative and subjective judgments. The authors proposed two computational fuzzy logic approaches for analyzing undefined values. The case study showed that the fuzzy number method's left and right ratings yielded different risk ordering with the triangular fuzzy number method. Nevertheless, the triangular fuzzy number method gave the exact risk ordering as the traditional method. In conclusion, even using fuzzy FMEA, the fuzzy number method is the decisive factor.

Gavrysh & Melnykova (2019) examined five construction projects in Ukrain during 2010 and 2018 using fuzzy set theory. The group of experts in construction industry were internviewed to identify, evaluate, and alleviate the risks. Seven phases includes 1) identifying risk, a term-set of value, lingustistic meaning, and semantic rule; 2) calculating a set of individual project risk factors; 3) comparing the determined significant risk factors; 4) developing a classifier of index values to normalize the qualitative and quantitative luves; 5) determining a matrix of membership levels for the bearer of significant project risk factors; 6) estimating the current values of risk components by using membership of fuzzy subsets; and 7) accumulating the projects’ risks usng the aggregate project risks. The study’s result showed that the fuzzy set theory has various advantages to construction project risk assessment.

CHAPTER 3
RESEARCH METHODOLOGY

This study uses the FMEA and fuzzy set theory to assess a construction project risk with linguistic input data. It is a case of a construction site in Kunming, the People’s Republic of China. Accordingly, the research procedure is proposed in this chapter. Section 3.1 explained the steps of using the fuuzy FMEA tool in this study. The experts and the theory used are explained in this section. Section 3.2 shows the research procedure chart.

3.1 Application of fuzzy FMEA

The factors are listed from literature. Based on a content analysis of the relevant literature. Structured interviews will be conducted to explore the rational of the factors.

3.1.1 Study the risk factors of a sample construction project

The experts are defined in this step. The sample construction project will be studied carefully. The researcher and experts review all risk factors related to the project’s success. Unstructured interview questions and questionnaires will be prepared if necessary. Ten experts were used in this study. Five experts were engineers in the sample construction project. Five experts were at the middle-management level and had at least three years of experience.

3.1.2 Determine potential failure modes

The data were collected in the first step. Then, potential failure modes are determined not only its effects but also its current control. The linguistic data will be identified in this step too.

3.1.3 Assess S, O, and D

The assessment will be conducted with experts and engineers to receive confident input that this analysis can respond to the construction project's stakeholders. A focus group meeting was conducted in the site. The score must be only one number with the concensus of the expert team.

3.1.4 Caculate RPN using fuzzy set theory

The first thing that has to be done in order to build a membership function for input variables is to specify a scale of score for each factor. The generation of the membership function for the output variable is the second stage in the process. Determining the rules that will be used to regulate output is the final phase, see Fig. 3.1.

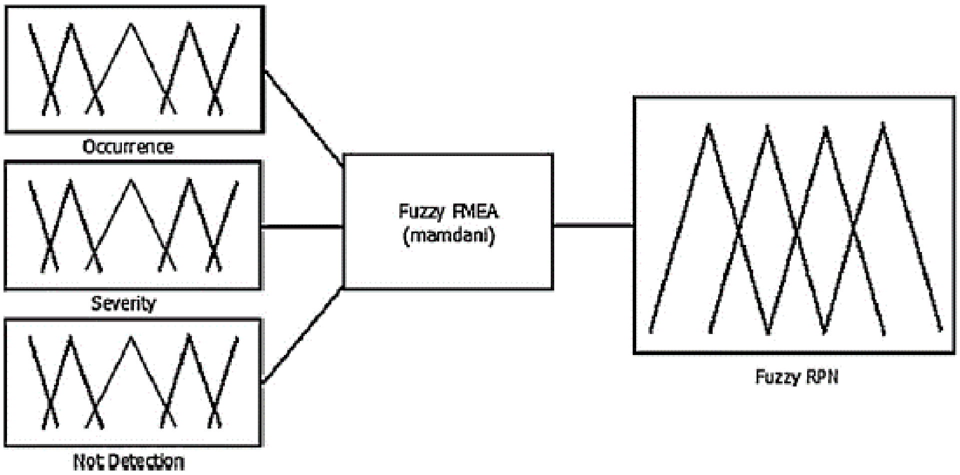

Figure 3.1 Fuzzy FMEA model.
Source: Chanamool & Naenna (2016)

Define the severity, occurrence, and detection scales of the criteria that are utilized for the evaluation of fuzzy. Before the execution of these criteria, the construction project management is required to give their approval along with the score decrease. As seen in Fig. 3.2, the membership function of the S, O, and D factors was generated by dividing scores ranging from 1 to 10 in each factor into a total of five levels. The following definitions apply to the numbers 1 through 10: 1 equals nearly none, 2–3 equals low, 4–6 equals medium, 7–8 equals high, and 9–10 equals exceptionally high. The S, O, and D input variables are converted to fuzzy inputs using this approach, which is part of the fuzzification process.

The membership function for the risk should be generated. In Fig. 3.3, the specified output used to build a member of a way function looks very much like the input. In the output part, the importance of hazards associated with the problem was rated on a scale from one to ten, with one being "none," two being "very low," three being "low," four being "high low," five being "low medium," six being "medium," seven being "high medium," and ten being "very high." Because the rules were employed for fuzzy inference to govern the receiving output value, these things had to be according to the rule of defining. The defuzzification process involves carrying out this operation to convert fuzzy outputs to FRPN, which stands for "risk of each failure."

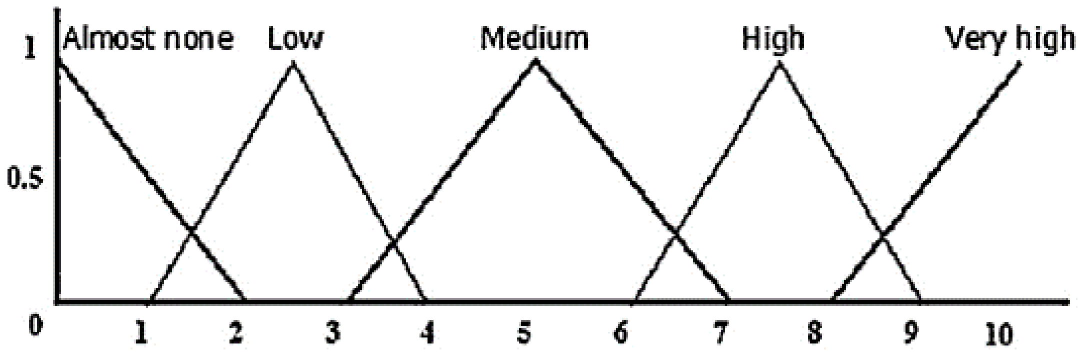

Figure 3.2 Membership function for input variable.
Source: Chanamool & Naenna (2016)

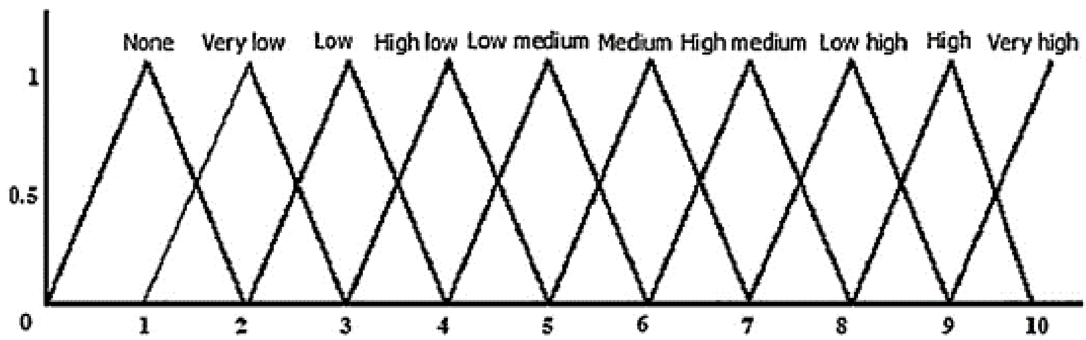

Figure 3.3 Membership function for output variable.
Source: Chanamool & Naenna (2016)

The rules can be defined by users who are thoroughly familiar with the system or by industry professionals. It is possible to calculate the total number of fuzzy rules by using the formula "Membership function No. of Severity; Membership function No. of Occurrence; Membership function No. of no Detection = Rules No. of Fuzzy."

3.1.5 Fuzzy RPN ordering

The findings of the fuzzy analysis serve as the basis for evaluating the results of the defuzzification process. It pointed to the possibility of not taking appropriate remedial action in accordance with the priorities.

3.1.6 Risk mitigation proposing

The researcher proposes the risk countermeasure in the supervision of the sample construction project manager.

3.2 Research Procedure

Figure 3.4 shows the steps of this research project.

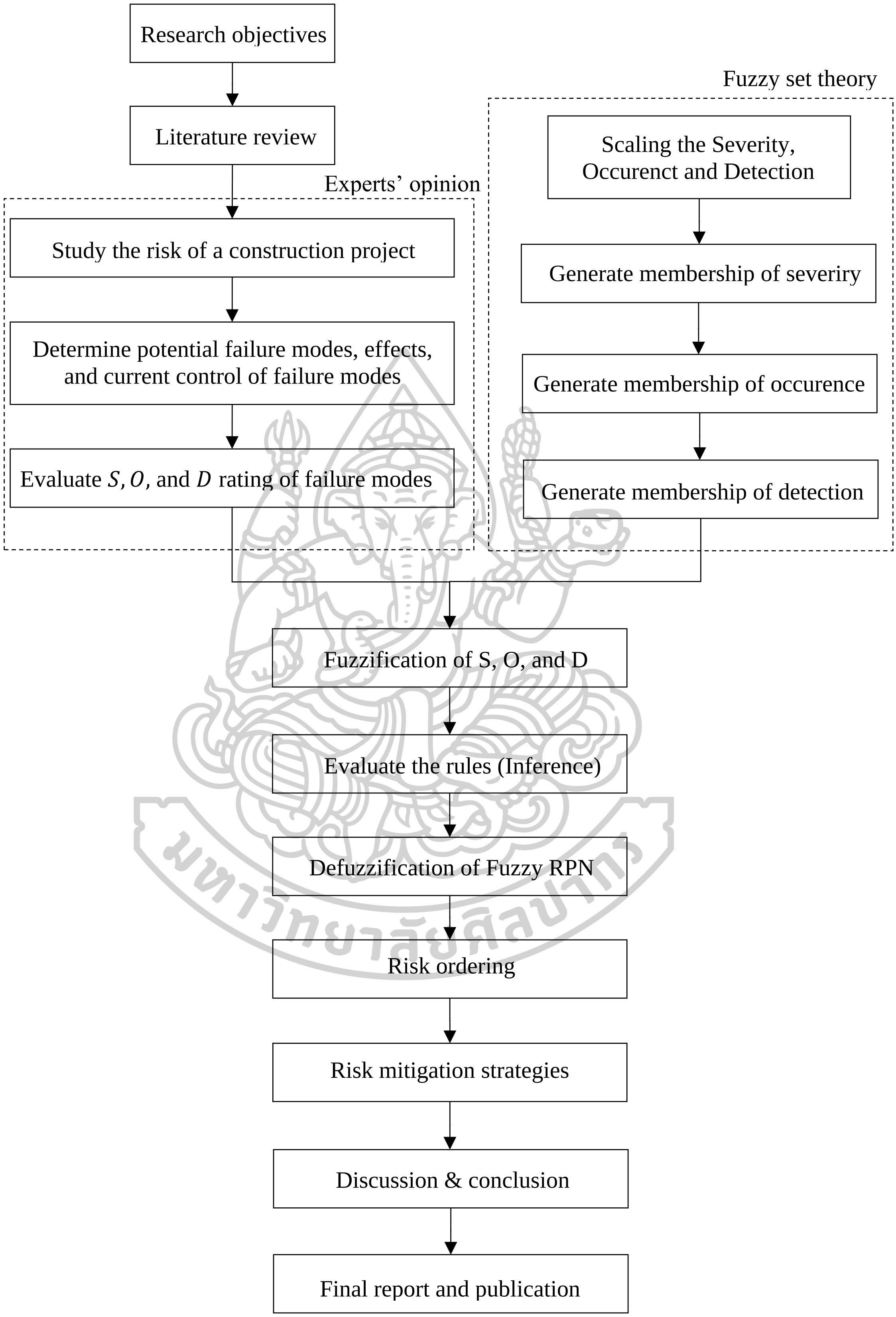

Figure 3.4 Research process flowchart.

CHAPTER 4
RESULT AND ANALYSIS

This study assesses the risks and proposes a new risk evaluation procedure. The case of linguistic data or an assessor hardly designates risk numbers. The proposed method is based on failure mode and practical analysis technique but can accept fuzzy numbers.

As a result, this chapter is divided into four sections based on a sample construction project. However, due to privacy and business reasons, I cannot disclose the details of this construction project. Section 1 shows the logic of risk divisions based on the risk-assessing team. Section 2 describes triangular fuzzy numbers (TFNs) used in this study. The fuzzy FMEA analysis of the sample construction project is proposed in Section 4.3. Finally, the risk mitigation is drawn in Section 4.4.

4.1 Risk Divisions

The risks were grouped into five main groups based on phases: preliminary study, tender, detailed design, construction, and financing the investment (Szymanski, 2017). The preliminary study risk is that the losses from project implementation expenses could occur if the project is rejected. It is the outcome of the various risks that the business must inescapably take. The project can begin once the tender has been completed (Serpella et al., 2014). This fact establishes the necessity of a particular strategy for this building process phase. These are the dangers associated with the tender stage. A detailed design phase that serves as the foundation for the finished project. The construction phase forms the project that is put into action. Investment financing is the highest risk in construction projects (Banaitiene & Banaitis, 2012). The contents of five groups are defined in Table 4.1.

Table 4.1 Risk divisions.

No.	Group	Contents
R1	Preliminary design	R1-1 Risk of underappreciated competition, R1-2 Risk of underappreciated investor preferences, R1-3 Risk of low self-esteem, R1-4 Risk of overestimating project costs (beyond investor capacities).
R2	Tender	R2-1 Risk of corruption, R2-1 Risk of a canceled tender, R2-3 Risk of a poor bid for the project (i.e., setting the boundaries of profitability), R2-4 Risk of competitors adopting predatory pricing, R2-5 Danger of paying too much (or too little) for lobbying and marketing, R2-6 Risk to the client's dependability
R3	Detailed design	R3-1 Risk of choosing the wrong design team, R3-2 Risk of overspending on the project, R3-3 Risk of a decline in aesthetic quality R3-4 Risk of choosing the wrong technology (materials, construction style).
R4	Construction	R4-1 Possibility of protests (from locals, ecologists, etc.), R4-2 Danger of an improperly identified soil formation, R4-3 Danger of an unfavorable work schedule, R4-4 Risks associated with equipment failure and employee absences (strikes, illness), R4-5 Risk associated with employees' qualifications (performance), R4-6 The possibility of inadequate handling of workers, commodities, and material resources, R4-7 Danger of a timely supply of building supplies, R4-8 Danger of the quality of the building materials,

Table 4.1 Risk divisions. (continued)

No.	Group	Contents
		R4-9 The danger of upholding norms, R4-10 Danger of inadequate supervision, R4-11 Risk of expanding the job scope and risk of inadequate work organization.
R5	Investment financing	R5-1 Danger of the nation's political instability, R5-2 Risk of its economic instability, R5-3 Risks associated with inflation, R5-4 An inadequate cost strategy, R5-5 Industry-wide recession risk, R5-6 The danger of a client's credibility, R5-7 One potential risk associated with contracts is the possibility of inaccurate or vague scope definitions, changes in project goals midway through, and issues with commissioning. R5-8 Another potential risk is the possibility of legal compliance and enforcement issues.

Source: Szymanski (2017)

4.2 Triangular Fuzzy Numbers

As we know, quantifying risk is complex. It may need a group of experts who have both risk assessment skills and the construction industry. On the other hand, most of them are not in the construction industry, or they are scarce. The problem is how to simplify the risk assessment, which can be quantified by middle management or high-operational level staff. As a result, fuzzy theory is exploited. A sample construction company defined the levels and linguistic variables in Table 4.2.

Nevertheless, unequal levels among the three risk variables were the staff's decision. They had a solid reason to propose more levels of unconfident variables and fewer levels of high-confident variables. As a result, there were seven levels of failure probability risk variable, five levels of severity risk variable, and four levels of detection variables.

Table 4.2 Linguistic variables of risk attributes and triangular fuzzy numbers.

Risk variables	Linguistic variables	Fuzzy memberships
Failure	Very low (O_1)	$(0, 3, 4)$
probability (O)	Low (O_2)	$(3, 4, 5)$
	Reasonable low (O_3)	$(4, 5, 6)$
	Average (O_4)	$(5, 6, 7)$
	Reasonably frequent (O_5)	$(6.5, 7, 9.5)$
	Frequent (O_6)	$(7, 9, 9.5)$
	Very frequent (O_7)	$(9, 9.5, 10)$
Severity (S)	Negligible (S_1)	$(0, 0, 1)$
	Marginal (S_2)	$(1.5, 2.5, 3.5)$
	Moderate (S_3)	$(4, 5, 6)$
	Critical (S_4)	$(6.5, 7.5, 8.5)$
	Catastrophic (S_5)	$(9, 10, 10)$
Detection (D)	Good (D_1)	$(0, 2, 4)$
	Average (D_2)	$(2.5, 4.5, 6.5)$
	Fair (D_3)	$(5.5, 7.5, 9.5)$
	Poor (D_4)	$(8, 10, 10)$

A group of managers of a sample construction project conducted a brainstorming meeting to assign the level of each risk variable. The members of the management groups included construction, finance and accounting, engineering, project management, and human resource departments.

4.3 Fuzzy FMEA Analysis

Risk priority numbers (RPNs) were calculated based on the levels of each risk variable. Equation (4.1) shows the RPN calculation.

$$RPN = O \times S \times D \tag{4.1}$$

where O is the failure probability score, S is the severity score, and D is the detection score. Nevertheless, the score used in this study is a triangular fuzzy number (TFN). Thus, we need to use fuzzy arithmetic operations as shown below. Let $C = (c_1, c_2, c_3)$ and $D = (d_1, d_2, d_3)$ then the multiplication formula is,

$$CD = [\min(c_1d_1, c_1d_3, c_3d_1, c_3d_3), c_2d_2, \max(c_1d_1, c_1d_3, c_3d_1, c_3d_3)] \quad (4.2)$$

The defuzzification method used in this study was the center of gravity (COG) method. Let $A = (l, m, u)$ is the fuzzy numbers. Then, the crisp value of a risk variable is,

$$\tilde{A} = \frac{(u-l)+(u-m)}{3} + l \quad (4.3)$$

We, then, rank the risk variables descendent.

Table 4.3 shows the score of failure probability (O), severity (S), and detection (D) that the management of the sample construction project assigned. The risk priority numbers (RPN) informed of triangular fuzzy numbers (TFN) were calculated using (4.1) and (4.2). The RPN (crisp value) was calculated by using (4.3).

Table 4.3 Expert judgement on risk variables.

Group	Risk variable	*O*	*S*	*D*	RPN (TFN)	RPN (Crisp value)	Rank
Preliminary design	R1-1	2	3	1	(0.000, 0.040, 0.120)	0.053	14
	R1-2	2	4	2	(0.049, 0.135, 0.276)	0.153	12
	R1-3	2	2	1	(0.000, 0.020, 0.070)	0.030	15
	R1-4	3	4	3	(0.143, 0.281, 0.485)	0.303	6
Tender	R2-1	4	4	2	(0.081, 0.203, 0.387)	0.224	9
	R2-2	3	5	2	(0.090, 0.225, 0.390)	0.235	8
	R2-3	3	4	2	(0.065, 0.169, 0.332)	0.188	12
	R2-4	5	3	2	(0.065, 0.158, 0.371)	0.198	11
	R2-5	5	3	2	(0.065, 0.158, 0.371)	0.198	11
	R2-6	6	3	2	(0.070, 0.203, 0.371)	0.214	10

Table 4.3 (continued)

Group	Risk variable	*O*	*S*	*D*	RPN (TFN)	RPN (Crisp value)	Rank
Detailed design	R3-1	3	5	1	(0.000, 0.100, 0.240)	0.113	13
	R3-2	4	4	3	(0.179, 0.338, 0.565)	0.361	3
	R3-3	5	3	2	(0.065, 0.158, 0.371)	0.198	11
	R3-4	6	4	2	(0.114, 0.304, 0.525)	0.314	5
Construction	R4-1	6	4	2	(0.114, 0.304, 0.525)	0.314	5
	R4-2	3	5	1	(0.000, 0.100, 0.240)	0.113	13
	R4-3	6	3	2	(0.070, 0.203, 0.371)	0.214	10
	R4-4	5	3	2	(0.065, 0.158, 0.371)	0.198	11
	R4-5	5	4	2	(0.106, 0.236, 0.525)	0.289	7
	R4-6	5	3	3	(0.143, 0.263, 0.542)	0.316	4
	R4-7	6	3	2	(0.070, 0.203, 0.371)	0.214	10
	R4-8	6	4	2	(0.114, 0.304, 0.525)	0.314	5
	R4-9	5	3	2	(0.065, 0.158, 0.371)	0.198	11
	R4-10	5	4	3	(0.232, 0.394, 0.767)	0.464	1
	R4-11	4	3	2	(0.050, 0.135, 0.273)	0.153	12
Investment financing	R5-1	5	4	2	(0.106, 0.236, 0.525)	0.289	7
	R5-2	6	5	2	(0.158, 0.405, 0.618)	0.393	2
	R5-3	6	4	2	(0.114, 0.304, 0.525)	0.314	5
	R5-4	5	4	2	(0.106, 0.236, 0.525)	0.289	7
	R5-6	5	4	2	(0.106, 0.236, 0.525)	0.289	7
	R5-7	4	3	2	(0.050, 0.135, 0.273)	0.153	12
	R5-8	5	3	2	(0.065, 0.158, 0.371)	0.198	11

Figure 4.1 illustrates the top five risk priority numbers from Table 3. ‘Danger of inadequate supervision’ (R4-10) is the critical variable in the sample construction project with RPN = 0.464. ‘Risk of its economic instability’ (R5-2) is the second rank with RPN = 0.393. ‘Risk of overspending on the project’ (R3-2) is the third rank with RPN = 0.361. This result recommends that the management conduct risk mitigation

wisely. Table 4.4 ranks the risk variable as a group attribute. It shows that the most critical risk of this sample construction project is investment financing, and the second critical risk is the construction phase, which needs to be looked after.

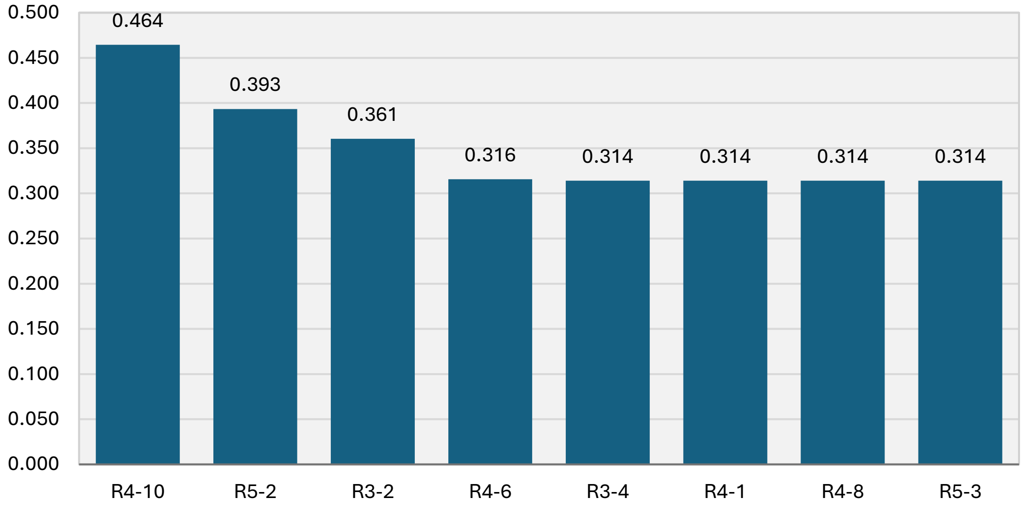

Figure 4.1 Top five risk priority numbers.

Table 4.4 Risk priority numbers by risk groups.

Group	RPN	Rank
Preliminary design	0.135	5
Tender	0.209	4
Detailed design	0.246	3
Construction	0.253	2
Investment financing	0.275	1

4.4 Risk Mitigation

The risk assessment team of the sample construction project proposes risk mitigation strategies. They are not implementing risk mitigation for all risk factors because the project cost will be high. Accordingly, they deployed the Pareto rule (80-20) to select the risk factors. Figure 4.2 shows a Pareto chart that orders risk priority numbers. The red dot line divides risk factors according to the 80-20 rule. Twenty-one risk factors need to be designed in the risk mitigation strategies.

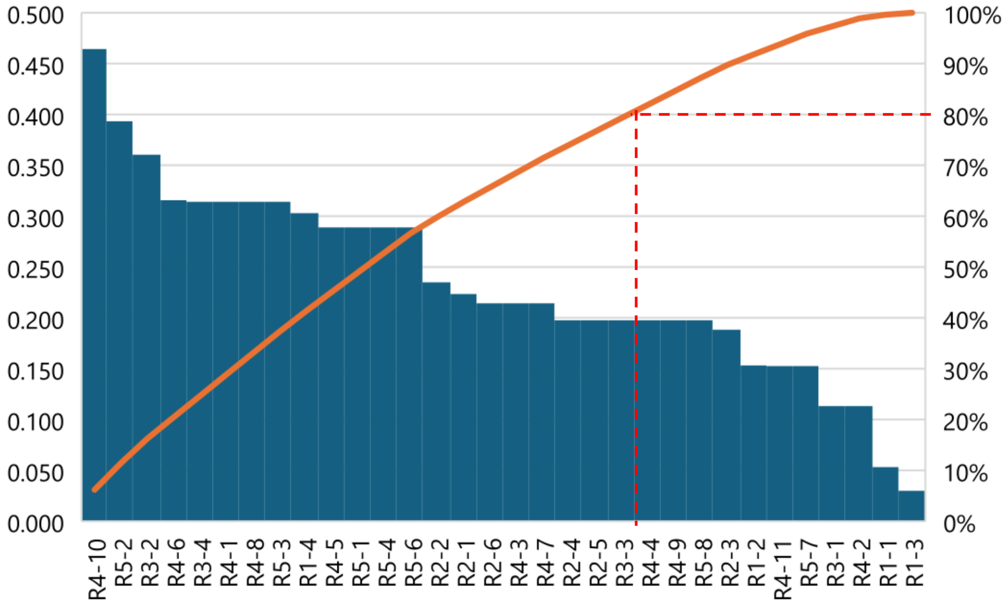

Figure 4.2 Pareto chart of risk priority numbers.

However, the first three risk factors are roughly described in this report area, as shown in Table 4.5. The mitigation strategies were formulated by the group of experts who conducted the risk factor determination. A focus group meeting was conducted under the supervision of the project manager.

Table 4.5 Risk mitigation strategies.

No.	Risk contents	RPN	Risk mitigation	In charge
R4-10	Danger of inadequate supervision,	0.464	• Improve organization structure for empowering of the supervision function.	Management
R5-2	Risk of its economic instability	0.393	• Form an operational team to monitor the economic situation and proprosing dynamic tactic to cope with the economic instability.	Management (Finance, Accounting, General management, etc.)
R3-2	Risk of overspending on the project	0.361	• Improve cost accounting and cost control for the construction project.	Accounting and cost control
R4-6	The possibility of inadequate handling of workers, commodities, and material resources	0.316	• Improve workforce control, material control, and other building material control functions.	Management, Human resource

Table 4.5 (continued)

No.	Risk contents	RPN	Risk mitigation	In charge
R3-4	Risk of choosing the wrong technology (materials, construction style).	0.314	• Hire a consulting firm for new construction technology implement and development.	Management
R4-1	Possibility of protests (from locals, ecologists, etc.),	0.314	• Improve sustainable construction pratices. • Improve public communication and relationship. • Form a new department that dynamically monitoring health, safety, and environment.	Management
R4-8	Danger of the quality of the building materials	0.314	• Form a new department for incoming material quality inspection.	Management

Table 4.5 (continued)

No.	Risk contents	RPN	Risk mitigation	In charge
R5-3	Risks associated with inflation	0.314	• Use financial tools for controlling risk such as future material buying, flexible pricing strategy, and insurance, etc.	Finance and accounting
R1-4	Risk of overestimating project costs (beyond investor capacities)	0.303	• Review budgeting of the previous projects and invent new mechanism for project cost analysis.	Management, Project cost analysis
R4-5	Risk associated with employees' qualifications (performance)	0.289	• Improve human resource capability and competency, especially with new construction technologies.	Human resource

The sample risk mitigation strategies are proposed in Table 4.5. Furthermore, the persons/departments in charge are also defined. However, some strategies require cooperation from more than one department. As a result, management must be involved in the strategies and charge of operations.

CHAPTER 5
CONCLUSION

5.1 Conclusion

Risk identification and risk determination are the most crucial operations in risk management. The fuzzy risk priority numbers were proposed based on the failure and mode practical analysis (FMEA) technique. It was modified by using triangular fuzzy numbers for linguistic data. The sample construction in Kunming experimented with this new risk assessment tool. The result shows that investment financing was the most critical risk. They must consider economic stability, inflation, and political and industry-wide recession. If we look at the details, the management must pay attention to operation supervision.

The proposed risk assessment procedure also selects risk factors using the 80-20 rule of Pareto. Sample risk mitigation strategies show logic in risk management. This new tool is acceptable and practical in the construction industry.

5.2 Future Research

It is interesting to select risk mitigation by using economic data. The return on investment and the cost-benefit ratio are suitable for implementing risk mitigation strategies. As a result, future research must improve this mechanism to fill this knowledge gap.

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