

**ESTIMATION OF COST OVERRUN RISK IN
INTERNATIONAL PROJECTS BY USING FUZZY SET THEORY**

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ABSTRACT

ESTIMATION OF COST OVERRUN RISK IN INTERNATIONAL PROJECTS BY USING FUZZY SET THEORY

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In the global construction market, most construction companies are willing to undertake international projects in order to maximise their profitability by taking advantage of attractive emerging markets and minimise dependence on unfavorable domestic market conditions. In order to be awarded a contract in highly competitive global construction market, companies should excel in choosing the most attractive markets and prepare winning bids for the selected construction projects in those markets. While preparing bids, the major concern of companies is to offer an optimum price that will enable them to earn enough profits and win the contract at the same time, where profit making ability is strongly correlated with proper estimation of a risk premium that is added onto the estimated cost of the project. Due to the nature of construction works, there are lots of uncertainties associated with the project, market and country conditions. Therefore, how the profitability of the project changes with

occurrence of various risk events, in other words, the sensitivity of project costs to risk events, should be estimated by bidders realistically.

In this study, fuzzy set theory is used to estimate cost overrun risk in international projects at the bidding stage. The objective is to propose a methodology which can be used by bidders to quantify cost overrun risk so that a realistic risk premium may be determined. A fuzzy risk rating approach is proposed to quantify cost overrun risk rating, which takes into account of risks characterised in international construction projects. For this purpose, risk sources have been identified and a risk model is put forward by using influence diagramming method. Based on this risk model, a fuzzy risk rating algorithm has been defined and software has been developed to conduct fuzzy risk rating calculations easily. After a decision-maker inserts the necessary inputs related with project and country risk factors, the output of the software is a rating that takes into account of all factors that may affect cost overrun risk in international construction projects. The reliability of the algorithm and developed software have been tested by an application on a real construction project. The proposed methodology and decision support tool have been proved to be reliable for the estimation of cost overrun risk while giving bidding decisions in international markets.

Keywords : International Construction, Risk Management, Bidding, Cost Overrun Risk, Fuzzy Set Theory.

ÖZ

BULANIK KÜME TEORİSİNİ KULLANARAK ULUSLARARASI PROJELERDEKİ MALİYET AŞIMI RİSKİNİN HESAPLANMASI

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Global inşaat piyasasında, çoğu inşaat firması, cazip nitelikteki yeni pazarlardan yararlanarak, karlılıklarını en üst seviyeye çıkarmak ve elverişsiz yurtiçi pazar koşullarına bağımlılığı en alt seviyede tutabilmek amacıyla uluslararası projelere girmeyi istemektedirler. Çok yüksek bir rekabetin yaşandığı global inşaat piyasasında, şirketler en cazip pazarları belirleyerek ve bu pazarlardaki seçilmiş inşaat projelerini kazanabilmek için teklif hazırlama aşamasında olası tüm belirsizlikleri değerlendirmek zorundadırlar. Teklifleri hazırlarken, şirketlerin en önemli kaygısı yeterli bir kar elde etmesine ve aynı zamanda sözleşmeyi kazanabilmesine imkan verecek en üst fiyatı teklif etmektir. Bu durumda kar elde etme yeterliliği, projenin tahmini maliyeti üstüne eklenecek makul bir risk prim hesabı ile büyük oranda bağlantılıdır. İnşaat işlerinin doğası gereği, projeye, pazar ve ülke şartlarıyla ilişkili olan birçok belirsizlik vardır. Bu yüzden projenin karlılığının çeşitli riskli olayların meydana gelmesiyle değişeceği, bir başka deyişle, proje maliyetlerinin riskli

olaylara duyarlılığı, teklif verenler tarafından gerçekçi bir biçimde hesaplanmalıdır.

Bu çalışmada, teklif verme aşamasında, uluslararası projelerdeki maliyet aşımı riskini hesaplamak için “bulanık küme teorisi” kullanılmıştır. Çalışmanın amacı, gerçekçi bir risk priminin belirlenebilmesi için teklif verenler tarafından maliyet aşımı riskini saptamayı sağlayacak kullanabilir bir metodoloji önermektir. Bulanık risk oranı yaklaşımı, uluslararası inşaat projelerinin karakteristik risklerini hesaba katarak, belirlenen maliyet aşımı risk oranının saptanması için önerilmiştir. Bu amaçla, riskin kaynakları tanımlanmış ve bir risk modeli, etki şekillendirme metodu kullanılarak ileri sürülmüştür. Bu risk modeline dayanarak bulanık risk ölçme algoritması tanımlanmış ve bulanık risk ölçme hesaplamalarını kolaylıkla uygulamak için bir bilgisayar programı geliştirilmiştir. Bir karar vericinin proje ve ülkeyle ilgili risk faktörlerini belirlemesinden sonra, programın çıktısı, uluslararası projelerdeki maliyet aşımı riskini etkileyecek bütün faktörleri göz önüne alarak bir oran vermektedir. Algoritmanın ve geliştirilmiş bilgisayar programının güvenilirliği gerçek bir inşaat projesine uygulanarak test edilmiştir. Önerilen metodoloji ve karar destekleme aracının, uluslararası piyasalarda teklif verme aşamasında maliyet aşımı riskinin hesaplanması konusunda güvenilirliği kanıtlanmıştır.

Anahtar Kelimeler : Uluslararası İnşaat, Risk Yönetimi, Teklif Verme, Maliyet Aşımı, Bulanık Küme Teorisi

To My Family

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LIST OF SYMBOLS

| | |
|-----------|-------------------------------|
| MCS | Monte Carlo Simulation |
| FLC | Fuzzy Logic Control |
| FST | Fuzzy Set Theory |
| HDM | Height Defuzzification Method |
| USD | United States Dollar |
| ATS | Austria Shilling |
| \cap | Intersection |
| \cup | Union |
| μ | Membership function |
| U | Universe |
| min | Minimum |
| max | Maximum |
| \in | Belongs to |
| \subset | Proper subset of |
| CO | Control output |
| D | Deviation |
| L | Low |
| M | Middle |
| MO | Moderate |
| H | High |
| N | Not |
| S | Somewhat |
| V | Very |

CHAPTER I

INTRODUCTION

1.1 Introduction

In the world, as well as in Turkey, as a result of the globalisation trend, most construction companies are willing to enter into international markets in order to maximise their revenues and growth potential. While bidding for these projects, they have to take into account of their companies' strategies, strengths, weaknesses and risks which they will face. Bid preparation is among the most important critical success factors for companies willing to carry out international construction projects.

The major objective of construction companies is profit maximisation. Although profit maximisation is not the sole criteria while giving bid/no-bid decisions and objectives such as gaining experience, reputation etc. are also considered while preparing bids, companies can not survive without money. Thus, while preparing bids, the major concern of companies is to offer an optimum price that will enable them to earn enough profits and win the contract at the same time, where profit making ability is strongly correlated with proper estimation of a risk premium that is added onto the estimated cost of the project. Due to the nature of construction works, there are lots of uncertainties associated with the project, market and country conditions. Therefore, how the profitability of the project changes with occurrence of

various risk events, in other words, the sensitivity of project costs to risk events, should be estimated by bidders realistically. For this purpose, risks should be identified, impact of risk events should be quantified, necessary risk response strategies should be developed so that overall risk level of the project can be minimised and finally, a risk premium that takes into account of the risk level of the project should be determined. Poor quantification of this risk premium may lead to significant problems for contractors. If it is lower than the required level, it may lead to significant monetary losses whereas if it is higher than the required level, a company may face the risk of loosing the job because of poor competitiveness.

The aim of this study is estimation of cost overrun risk in international projects by using fuzzy set theory at the bidding stage. The objective is to propose a methodology which can be used by bidders to quantify cost overrun risk so that a realistic risk premium may be determined. It should be noted that, this study is not about quantification of risk premium as a percentage of the total cost of the project but it is about determination of a risk rating that may further be used by decision makers to estimate the required risk premium. The cost overrun risk rating takes into account of risks characterised in international construction projects. Within this context, influence diagramming method is proposed as the risk identification tool and fuzzy risk rating technique is utilized as the risk analysis method.

For this purpose, the basic concept of risk management will be explained in Chapter 2. Tools of risk identification, analysis and management will be briefly introduced as well as their various applications in the construction industry.

In Chapter 3, introductory information about fuzzy set theory will be presented together with the steps of fuzzy risk assessment. Advantages and disadvantages of fuzzy rating technique for risk assessment will be discussed. Moreover,

applications of fuzzy risk assessment procedure within the construction management literature will be covered.

In Chapter 4, the proposed fuzzy risk rating methodology will be introduced. The steps of the fuzzy risk rating approach and the associated tool developed to carry out these steps will be explained. Finally, application of the proposed tool/methodology will be demonstrated by a case study.

Finally, in Chapter 5, findings of this study will be presented as well as conclusions about benefits and shortcomings of the proposed fuzzy risk rating approach. How the proposed tool may be further refined to reflect the realities of construction business will be discussed.

CHAPTER II

RISK AND RISK MANAGEMENT

2.1 Risk

There is not a unique definition of risk in the literature. Some definitions are given as follows:

Oxford Advanced Learner's Dictionary (1995 ed.) defines risk as the "chance of failure or the possibility of meeting danger or of suffering harm or loss."

Risk in its most basic form, is the uncertainty associated with any outcome [1].

Risk implies the effects of events which may or may not occur [2].

There are many reasons about why the construction industry is subject to more risk than other industries. One of the reasons is the physical nature of products. It involves large size, technical complexity, high capital requirement, and wide geographical range. It is made specifically according to the needs of each customer. Most parts are produced elsewhere. Another reason of high risk in construction projects is involvement of a high number of parties. Many parties are involved in this industry such as subcontractors, joint venture partners, consultants, designers and client. Structure of the industry is another reason. In the construction industry, there are many

contractors of various sizes. Also, most widely used selection procedure by the clients is competitive bidding where selection criteria mostly depends on cost factors. Demand conditions constitute another source of risk in the construction industry. Unlike the other sectors, price should be estimated before production. Then, uncertainty about factors that may increase project cost is higher. Another reason of higher risk in construction projects is the vulnerability of project success to environmental factors such as weather conditions and legal, political, economical factors etc.

One of the dimensions of risk is “uncertainty”. Uncertainty can be defined as “implication that there is a known likelihood of variation in an event, which will occur and some degree of knowledge of the range” [2]. Sometimes source of uncertainty is not having enough information or vagueness about definitions. In other words, risk exists when a decision is expressed in terms of a range of possible outcomes and when known probabilities can be attached to the outcomes. Probability can be defined as the ratio of occurrence to the number of equally likely cases. On the other hand, uncertainty exists when there are many different outcomes of a course of action, but probability of each possible outcome is unknown. Moreover, the risk does not mean always negative results. Sometimes the risk shows the probability of opportunities. That is, risk can be in positive or negative direction. In a symbolic way, risk can be expressed as;

Risk = f (uncertainty of an event, potential loss/gain from event) [3].

Risks existing in construction projects are classified under different categories. Risks can be categorized into 3 levels. These levels are macro environment, project environment and project specific environment. Examples of these categories are specified as follows:

Macro environment: Force major, economical, political, market, weather conditions.

Project environment: Client risk, design risk, sub contractor risk, contract risk.

Project specific environment: Construction risk, material risk, labour risk, equipment risk.

From the bidding phase to the end of construction, construction firms are exposed to many risks such as those above mentioned [4].

Alternatively, risks are categorised according to their level of controllability. Risks can be categorised as controllable risks and uncontrollable risks. For the controllable risk, the causes of these risks must be dealt with. On the other hand, for uncontrollable risks, the effects of these risks must be dealt with.

According to their “expectability” and “availability of information for their estimation”, three risk categories are defined:

Known Risk: They occur frequently, impacts are expectable.

Known Unknowns: Either their occurrence or likely effects is known.

Unknown Unknowns: Probability and impact are not foreseeable by even the most experienced staff [4].

Proper definition and classification of risk is necessary for successful management of risk.

2.2 Construction Risk Management

The major idea behind risk management is “Once a risk is identified and analysed, it is no longer a risk and becomes a management problem” [4].

Risk management is the identification, measurement and control at most economic cost of the risks which can threaten life, property and the assets and earnings of an organisation [5].

Risk management is the art and science of identifying, assessing and responding to project risk throughout the life of a project and in the best interests of its objectives [6].

In the context of project management, risk management is defined as “A formal orderly process for systematically identifying, analysing and responding the risk event throughout the life of a project to obtain the opt to acceptable degree of risk elimination or control [3].

Aim of risk management is to assist manager to tackle right risks and to decrease the negative impacts of risk. There are a lot of risk management approaches. Cooper and Chapman (1987), and Chapman and Ward (1997) identified their approaches as a multiphase “risk analysis” which covers identification, evaluation, control and management of risks [7, 8]. Hertz and Thomas (1983) view it as a logical sequence of steps consisting of risk identification, risk measurement, risk evaluation and re-evaluation [9]. Moreover, they claim that risk management is related with strategic planning and management. In a similar way, Hayes’s (1987), definition of risk management is risk identification, risk analysis and risk response [10]. On the other hand, Charrette (1989) considers risk analysis and risk management separately [11].

There is no guarantee that risk management activities are always successful, there are some critical success factors that should be applied in construction projects. For example, risk management should be carried out by all parties involved in the project (client, contractor, financial agents, consultant etc.) and at each stage of construction (pre-feasibility, feasibility, design, contract, procurement, construction and operation) so that overall project success can be ensured.

Moreover, there are some misperceptions about risk management. For instance, risk management does not mean insurance and it does not embrace management of all risks to which a businesses exposed. In addition, it does not mean that, after implementation of risk management principles, risk are controlled and secured, and success is certain. Furthermore, it does not necessarily mean application of advanced mathematics.

In the forthcoming parts, Hayes's (1987) definition of risk management, which consists of three stages, called as risk identification, analysis, response, will be explained. For systematic management of risk, different methods should be utilised to conduct identification, analysis and response management activities.

2.3 Risk Identification

Since the most influential decisions are made early in the life of projects, all the potential risk and uncertainties should be identified as early as possible. Risk identification and classification involves a process of systematically and continuously identifying, categorising and assessing the initial significance of the risk associated with a project. Then, sources of risk are defined and grouped so as to construct taxonomy and develop responses according to each category.

Aim of risk identification is not perfect prediction of the future. It is rather recognition of potential sources of risk that may have a high impact on the project and high profitability of occurrence. In case of bad definition of risk, it will cause further risk. There are different tools for risk identification:

- Brainstorming with the project team and workshops,
- Preparation of a standard checklist of risk compiled from previous experience,
- Developing a hierarchical risk breakdown structure (Fig. 2.1),
- Interviewing with key project participants.

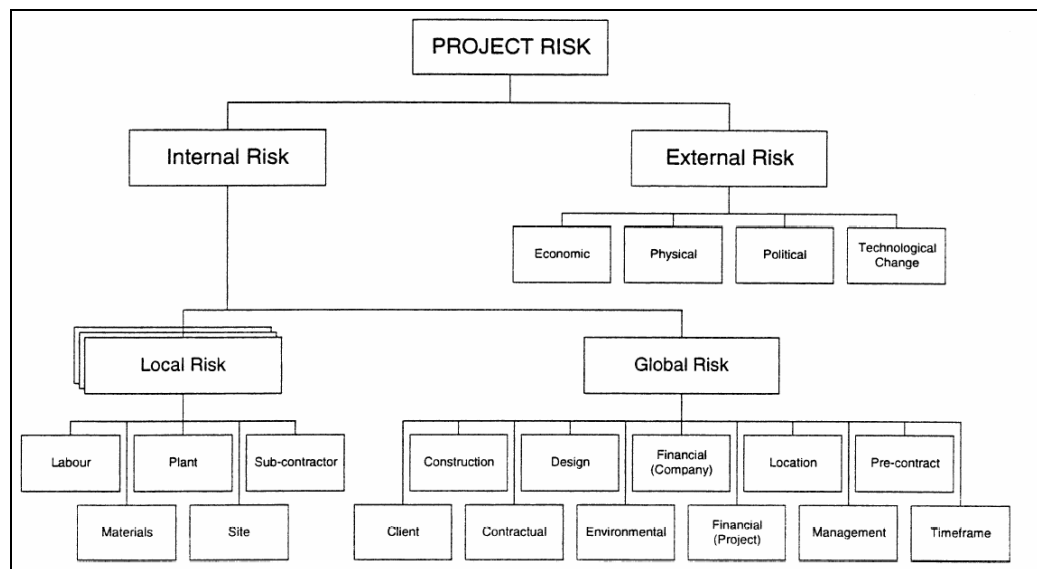


Figure 2.1: Hierarchical Risk Breakdown [12]

2.4 Risk Analysis

Risk analysis means quantification of risk impacts on the project success criteria. There are various risk analysis techniques proposed by different

researchers. Probabilistic approach is the most common approach. Al-Bahar and Crandall [3] defines risk analysis as a process, which incorporates uncertainty in a quantitative manner using probability theory to evaluate the potential impact of risks.

However, there are some stages before risk analysis techniques are applied. Collection of data relevant to risk exposure is the first stage of the risk analysis. Historical data performed in the past is collected. Mostly, these data can not be obtained, so these data are derived as a result of experienced people and our intuition feelings. After data is collected, these data are applied into a number of systematic models used in quantitative risk analysis stage. These tools/techniques are influence diagrams, probability/impact matrix, risk mapping, risk rating, decision matrices and trees, sensitive testing, Monte Carlo Simulation, fuzzy set decision theory.

2.4.1 Influence Diagrams

An influence diagram is simply a diagram, which consists of nodes reflecting “variables” and “decisions”, and arrows reflect “influence”. They make it easier to formulate the problem and capture expert opinion. Relatively complex relationships can be formulated by influence diagrams. It acts as a convenient way of expressing the nature of the problem to others and aids general understanding of the factors, risks and decision affecting the “outcomes”. The influence diagramming method is a very flexible way of building the risk model. Influence diagrams are the first step in a quantitative risk analysis. They are usually used with other analysis techniques such as Monte Carlo simulation.

Influence Diagramming Notation is shown in Fig. 2.2.

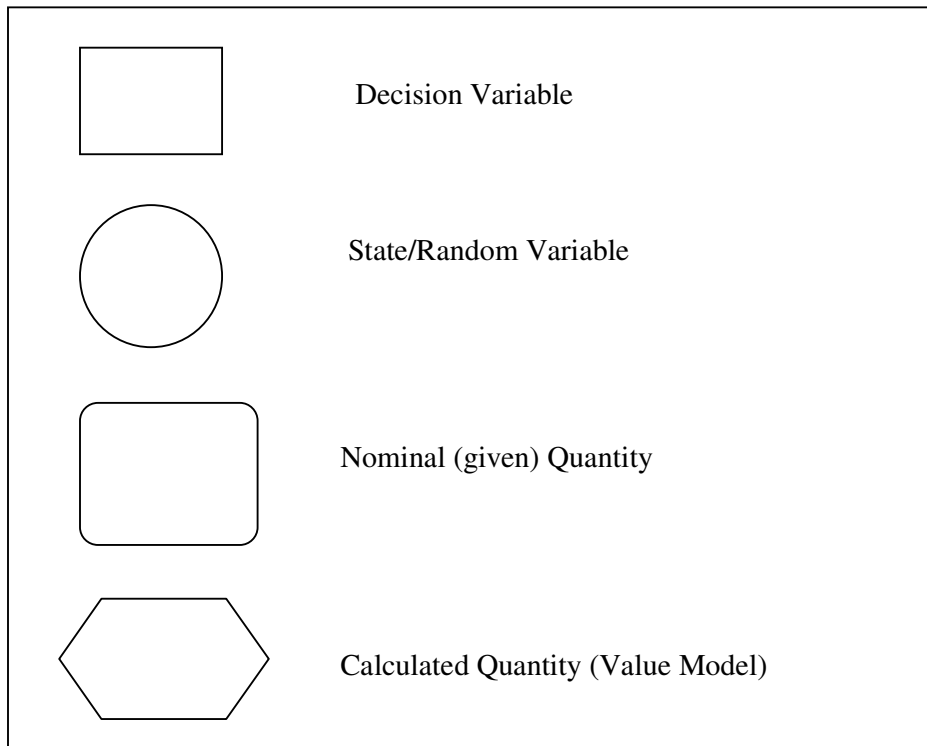
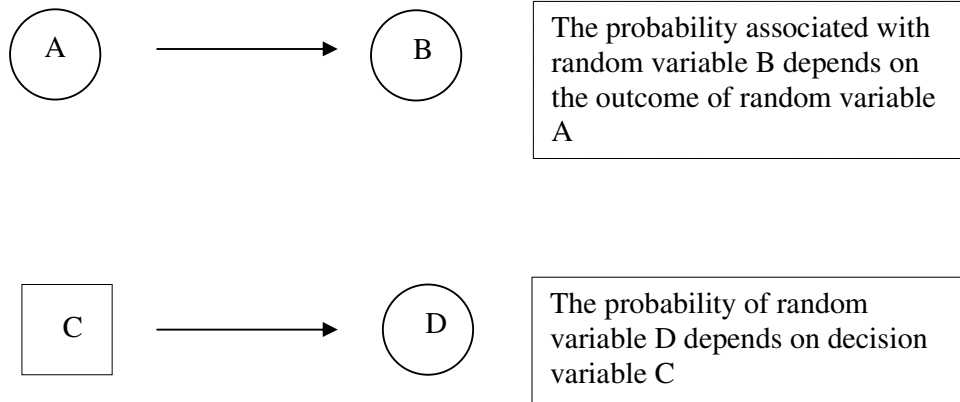
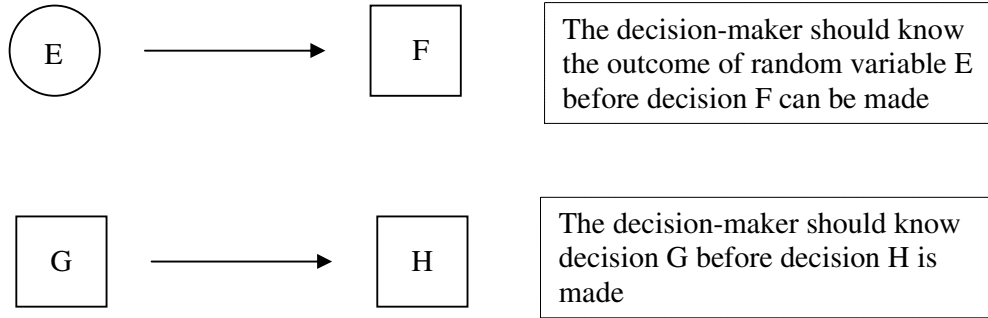


Figure 2.2: The Notations of Influence Diagrams

Influence Diagramming Relationship

This relationship is shown as follows:





In this thesis, influence diagramming method is used to construct the risk model.

2.4.2 Probability Impact Matrix

In this technique, probability and impacts of each risk are assessed against defined scales, and risk factors are placed in appropriate boxes as shown in Figure 2.3. Position on the matrix represents significance of the risk.

| | | Impact | | |
|-------------|--------|--------|--------|-----|
| | | High | Medium | Low |
| Probability | High | | | |
| | Medium | | | |
| | Low | | | |

Figure 2.3: Probability Impact Matrix

2.4.3 Risk Rating

When the probability of occurrence and impact can not be determined analytically, following procedure can be applied:

1. Decide on the components of the risk factor (attributes),
2. Decide on the alternative importance of the attributes,
3. Estimate the risk ratings of attributes for each alternative
4. Aggregation (summation of all weighted risk ratings).

This procedure can be used to quantify the level of risks which can not be quantified by objective measures such as quality risk, political risk, security risk etc.

2.4.4 Risk Mapping

In this technique, a graph of two dimension or scales is recommended to build the risk map. In the first dimension, risk will be estimated according to its potential impact. In the second dimension, uncertainty will be assessed according to the probability of occurrence. Such a two dimensional graph is considered as an important graphical illustration and will facilitate project manager to evaluate the relative importance of a potential risk disclosed in an early stage. As previously mentioned, risk is a function of interaction of uncertainty and potential gain/loss, the suggested mapping function shows Iso-Risk curves where each curve corresponds to equivalent risk but differences in uncertainty and gain/loss. When the curve is further from the origin, the risk is greater. Figure 2.4 shows the risk mapping [3].

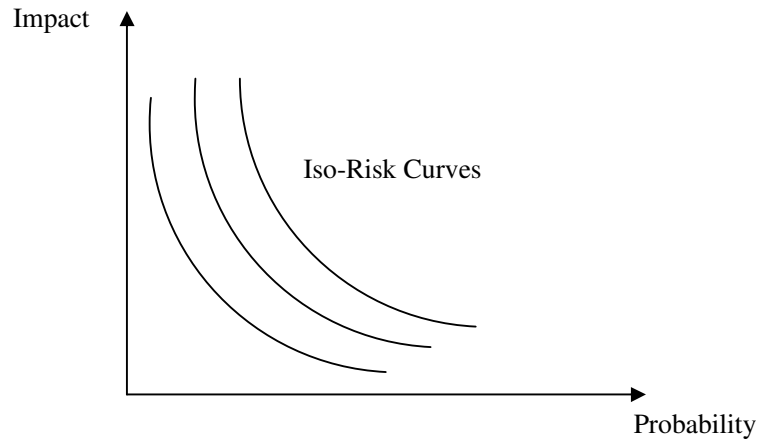


Fig.2.4: Risk Mapping Concept

2.4.5 Decision Trees

Decision trees are commonly used to study impact of alternatives and the effects of different choices on project outcomes [13]. It is a means of setting out problems that are characterized by a series of “either/or” decisions. It shows a sequence of decision and the expected outcomes under each possible set of circumstances. A measure of value for each possible outcome of each different route is required, thus, probabilities should be attached to each particular outcome occurrence.

2.4.6 Sensitivity Analysis

It is a modeling technique used to test the impact of change in the value of an independent variable on the dependent variable.

Dependent variable (like cost, time etc.) = X

Independent variables (like useful life, cost and duration of each activity etc.) = a, b, c

$$X = f(a, b, c)$$

Aim of sensitivity testing is to find out the impact of a change in a single risky variable (independent variable) on the project performance (dependent criteria). Each time by changing the value of a single variable and keeping the others constant, change in the dependent variable is monitored and “spider diagrams” are drawn to find out the risky parameters that affect the project performance most. Advantages of sensitivity analysis are specified as follows:

- It shows management that there are various possible outcomes of a project.
- It shows which components of project have the greatest impact upon the project outcomes.
- It shows critical factor for further analysis. It narrows down the main parameters and leads to savings in information requirements.
- Sensitivity analysis helps comparison of alternatives in all conditions under which the ranking of alternatives may change.

2.4.7 Monte Carlo Simulation (MCS)

Monte Carlo method is simulation by means of random number generation. The method is conceptually straightforward and very powerful. The basic steps of this method are:

1. Assess the range for the variables being considered, and determine the probability distribution most suited to that variable.
2. Select a value for each variable within its specified range; this value should be randomly chosen and must take into account of the probability distribution for the occurrence of the variable. This is usually achieved by generating the cumulative frequency curve for the variable and choosing a value from a random number table.

3. Run a deterministic analysis using the combination of values selected for each one of the variables.
4. Repeat a number of times to obtain the probability distribution of the result. The number of iterations required depends on the number of variables and the degree of confidence required, but typically between 1000 and 10000 [14].

There are also problems in Monte Carlo Simulation. One of the problems is level of disaggregation. In the case of high level of disaggregation, it is high reliable due to more details. In the case of low level of disaggregation, correlation may be eliminated. Correlation is another problem and difficult to detect. Pouliquen [15] proposes 3 ways to cope with problem of calculations:

1. Form groups according to sources of uncertainty to eliminate correlation between groups sensitive to similar risks.
2. Assume complete the dependency (pessimistic) and independency (optimistic). Check if the results change considerably.
3. Collect more data in order to be able to calculate correlation statistically.

Probability distribution is another problem. Results don't change considerably if a triangular distribution is used instead of normal and trapezoidal distributions within the same range. Results are not very sensitive to the shape of the distribution but very sensitive to correlation. On the other hand, there are also benefits of using MCS. These benefits are following:

- MCS permits the use of a great deal of information which would otherwise be lost
- It enables us to handle uncertainty not only about the viability of a marginal project but also about the most appropriate design, phasing or size of a project

- It provides a highly efficient medium of communication and a focus for evaluation and discussion
- It does not replace skilled judgement. Its reliability depends on input data and judgements.

2.4.8 Fuzzy Set Theory

There is always subjectivity while giving decisions involving risk. Risk analysis using fuzzy set theory is based on quantification of fuzziness rather than probability which will be explained in detail in Chapter 3.

2.5 Risk Response

This is the action phase of the Risk Management System [1]. After the identification of the risk, contractor is able to formulate suitable risk management strategies in advance of the problem occurring [3, 16]. The objectives of these strategies are removing as much as possible the potential impact and increasing control of risk. There are two approaches to management of risk. One of them is called as risk finance; the other one is called as risk control [3]. Through this ambition, there are five alternative policies:

- Risk avoidance
- Risk reduction
- Risk retention
- Risk transfer
- Insurance

2.5.1 Risk avoidance

The aim is to remove risk from project. Risk avoidance methods for the contractors are not bidding on the project, tendering a very high bid, placing conditions on the bid, not bidding on the high-risk parts of the contract. For the client, the solution is not proceeding with project.

2.5.2 Risk reduction and risk prevention

For the contractor, there are two ways of reducing risk and preventing risk. These ways are 1- reducing the probability of a risk and 2 - reducing the financial risk if it does happen.

Risk reduction and prevention falls into four basic categories:

- Education and training the alert the staff potential risk
- Physical protection to reduce likelihood of loss
- Systems to ensure consistency and make people ask the “what if” questions.
- Physical protection to protect people and property [1, 17].

2.5.3 Risk retention

There are two types of retention. Risk retention can be planned or not planned. Planned risk retention is taken by the contractor for identified and known risks. In the case of plan, there are many ways to retain the risk. These ways depend on the philosophy, the particular needs and financial capabilities of the contractor. On the other hand, unplanned risk retention is the result of not

identification and not recognition of existence of risk. In this case, the loss will occur.

2.5.4 Risk transfer

Transferring risk does not mean to reduce the effect of resource of risk, it just removes it to another party [17]. Decision about allocation of risk is realized either through the provision in contracts or through insurance [6, 13].

In the contracts, responsibilities and duties of the parties in the construction project are defined. Specific terms and conditions of the contract give the details about risk allocation, which party is responsible for which risk under various conditions, which party should carry the risk if it cannot be controlled and what is the cost of risk transferring.

Usually the routes for the transfer of risk in construction projects and contracts are [18]:

- Client to contractor,
- Contractor to sub-contractor,
- Clients, contractor, sub-contractor, to insurer,
- Contactor or sub-contractor to surety or guarantor.

2.5.5 Insurance

Insurance is generally a used method of tackling with the risk by contractor. In many contractors' view, risk management is insurance management. Specific insurance company as an allocation strategy is responsible for specific risk under specific conditional for a price [1]. Many contractors purchase insurance

policy with certain deductibles against severe loss exposures. Owing to being too expensive, insurance policy should be applied as a last alternative. And also, it is a complicated and inefficient method of borrowing money, the essence of which is that you payback the loan before you get the money [5].

2.6 Conclusion

Risk management is a vital aspect of project management. The success of a project depends on identification of possible risks, an effective risk analysis and correct response strategies. In systematic risk management expressed in this chapter, firstly, risks are identified, then these risk are quantified by various techniques and tools described above. Once the risks are identified and analysed, appropriate actions to mitigate risks are determined. However, it must be reminded that eliminating of all risks is impossible. Yet, preparing a risk management strategy to mitigate and minimize the project' exposure to those risks is possible and vital.

In this thesis, the risk identification and analysis parts of risk management in international construction projects will be covered. In the forthcoming chapter, fuzzy set theory which is proposed as an effective risk analysis technique in construction projects will be explained.

CHAPTER III

FUZZY SET THEORY

3.1 Fuzzy Sets

This part of the thesis begins with a brief review of classical sets so as to make the introduction of fuzzy sets easier. Then, a basic knowledge about fuzzy sets and fuzzy relations will be given. Fuzzy numbers are described as a particular case of fuzzy sets.

3.1.1 Classical Sets: Relations and Factions

Classical sets

The concepts of set are commonly used in our daily life. For example, all workers in a factory, all students in class. There is a main property that enables us to consider the objects as a whole. The objects in a set are called elements or members of the set. We point out these elements by small letters a, b, c, \dots etc. and the sets by capital letters A, B, C, \dots etc. Sets are also called ordinary or crisp in order to be separated from a fuzzy set.

The basic notion in set theory is membership. If an object x is a member of the set A , it is written as $x \in A$; if x is not a member of A , $x \notin A$ is written. In other words, for each object there are only two choices; either x is a member of A or not. Basic fundamental notations of classical sets are specified as follows [19]:

Intersection

The intersection of the sets A and B, denoted by $A \cap B$ is defined by

$$A \cap B = \{x \mid x \in A \text{ and } x \in B\}; \quad (3.1.1)$$

$A \cap B$ is a set whose elements are common to A and B [19].

Union

The union of A and B, denoted by $A \cup B$, is defined by

$$A \cup B = \{x \mid x \in A \text{ or } x \in B\}; \quad (3.1.2)$$

$A \cup B$ is a set whose elements are in A or B, including any element that belongs to both A and B [19].

Characteristic Function

The membership rule characterizing the elements (numbers) of a set $A \subset U$ can be established by the concept of characteristic function (or membership function) $\mu_A(x)$ taking only two values, 1 and 0, showing that $x \in U$ is a member of A or not.

$$\mu_A(x) = \begin{cases} 1 & \text{for } x \in A \\ 0 & \text{for } x \notin A \end{cases} \quad (3.1.3)$$

The formal development of set theory resumed in latest time of 19th century - with the work of George Cantor (1845-1915)- is one of the most original mathematicians in history. Set theory has been used to establish the foundations of mathematics and modern methods of mathematical proof. Cantor's sets are crisp. Each element under consideration is either a member of

a set or not. As a consequence, there is a boundary between the elements of the set and those which are not [19].

Example 3.1.1:

In this example, it is tried to use crisp sets to describe tall men. It is assumed that man is tall if his height is 185 cm. or greater. If his height is below 185 cm, he is not tall (see Fig. 3.1). The characteristic function of the set A= {tall men} then is

$$\mu_A(x) = \begin{cases} 1 & \text{for } 185 \leq x \leq 210 \\ 0 & \text{for } 155 \leq x \leq 185 \end{cases}$$

Universe is $U = \{x \mid 155 \leq x \leq 210\}$

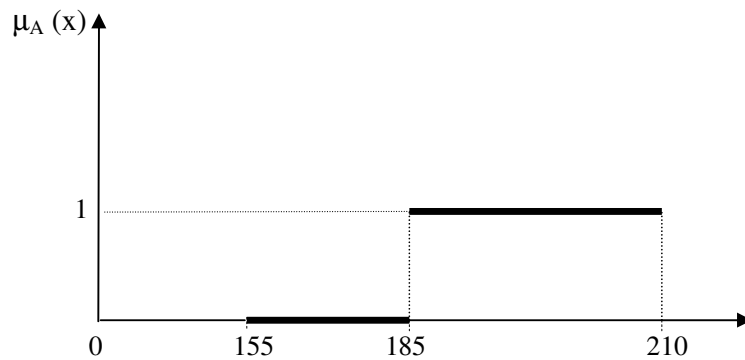


Figure 3.1: Membership Function of the Set Tall Men

As seen in the graph, this description of the set of tall men is not good enough because it doesn't allow graduation. The word tall is vague. For instance, a person whose height is 184 cm is not as short as a person whose height is 155 cm. On the other hand, a person whose height is 185 cm is tall and so is a

person with height 210 cm. Moreover, the definition above shows a severe difference between heights of 184 cm and 185 cm, thus fails to describe borderline cases. This paradox is coming from ancient Greece; it resulted in serious problems for logicians and mathematicians [19].

The concept of characteristic function introduced here will make the understanding of the fuzzy set concept easily which is the subject of following section.

3.1.2 Definition of Fuzzy Sets

The first definition of fuzziness was introduced in the form of fuzzy sets by Zadeh [20]. According to dictionaries and also use in daily language, the words fuzzy, vague, ambiguous, uncertain, imprecise and their adverbs have more or less relationship with themselves in terms of meaning. According to Oxford English Dictionary, this statement is supported by the following brief explanations [21].

Fuzzy: not clear in shape or sound; confused and not expressed clearly.

Vague: not having or giving enough information or details about something; not having a clear shape.

Ambiguous: that can be understood in more than one way; having different meanings; not clearly stated or defined (synonym: vague).

Uncertain: not sure; not definite or decided; likely to change, especially in a negative or unpleasant way.

Imprecise: not precise, inexact, vague.

There are various opinions on the meaning of these words and sometimes they are misused in common language. According to Poper [22] “One should never quarrel about words and never get involved in questions of terminology. One should always keep away from discussing concepts. What we are really interested in, our real problems, are factual problems or in other words, problems of theories and their truth”.

Membership of an object to a set is a precise concept; the object is either a member to a set or not. As a consequence membership value takes either 1 or 0. The set tall man example shows that the describing capabilities of classical sets must be increased while words are dealt with.

Consider a classic set A of the universe U . A fuzzy set A is defined by a set or ordered pairs, binary relation.

$$A = \{(x, \mu_A(x)) \mid x \in A, \mu_A(x) \in [0, 1]\} \quad (3.1.4)$$

Where $\mu_A(x)$ is a function called membership function; $\mu_A(x)$ exactly states the grade or degree to which any element x in A is a member of the fuzzy set A . Definition (3.1.4) combines each element x in A with $\mu_A(x)$ in the interval $[0, 1]$ which is assigned to x . Larger values of $\mu_A(x)$ indicate higher degrees of membership [19].

Example 3.1.2:

Consider the fuzzy set

$$A = \{(x_1, 0.1), (x_2, 0.4), (x_3, 0.5)\}$$

The membership function $\mu_A(x)$ of A takes the following values on $[0, 1]$:

$$\mu_A(x_1) = 0.1 \quad \mu_A(x_2) = 0.4 \quad \mu_A(x_3) = 0.5$$

Example 3.1.3:

It is seen that, in example (3.1.1), the description of tall men by classical sets is not adequate. Now, for the same aim, the fuzzy T= {x, $\mu_T(x)$ }, where x measured in cm belongs to the interval [155,210] and μ_T is defined by (see Fig. 3.2).

$$\mu_T(x) = \begin{cases} 1/[2*40^2]*(x-130)^2 & \text{for } 155 \leq x \leq 170 \\ -1/[2*40^2]*(x-210)^2+1 & \text{for } 170 \leq x \leq 210 \end{cases}$$

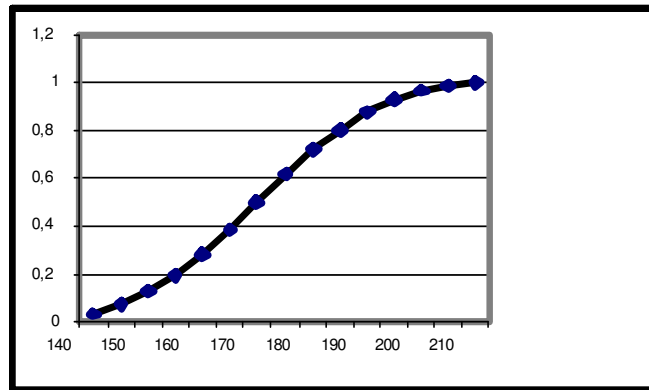


Figure 3.2: Description of Tall Men by Fuzzy Sets

Moreover, the notion of fuzzy set is sometimes thought as a type of probability. Although there are many similarities and bonds between fuzzy sets and probability, there are also great differences. For instance, a grade or degree of membership is not a probabilistic concept. In example (3.1.3), a man who is 185 cm tall has a degree of membership 0.804 in the set tall men. It is possible to say that this person is 80.4% tall (almost tall), but it can't be said that there is a probability of 80.4% that he is tall [19].

3.1.3. Basic Operations on Fuzzy Sets

Consider the fuzzy sets A and B in the universe U,

$$A = \{(x, \mu_A(x))\}, \quad \mu_A(x) \in [0, 1],$$

$$B = \{(x, \mu_B(x))\}, \quad \mu_B(x) \in [0, 1],$$

The operations with A and B are done by means of operating on their membership functions $\mu_A(x)$ and $\mu_B(x)$.

Intersection

The operation intersection of A and B denoted as $A \cap B$ is defined by

$$\mu_{A \cap B}(x) = \min(\mu_A(x), \mu_B(x)), \quad x \in U \quad (3.1.5)$$

If $a_1 < a_2$, $\min(a_1, a_2) = a_1$. For instance $\min(0.5, 0.6) = 0.5$ [19].

Union

The operation union of A and B denoted as $A \cup B$ is defined by

$$\mu_{A \cup B}(x) = \max(\mu_A(x), \mu_B(x)), \quad x \in U \quad (3.1.6)$$

If $a_1 < a_2$, $\max(a_1, a_2) = a_2$. For instance $\max(0.5, 0.6) = 0.6$ [19].

Example 3.1.4:

Consider the universe $U = \{x_1, x_2, x_3, x_4\}$ and the fuzzy sets A and B defined by the table [19].

| x | x_1 | x_2 | x_3 | x_4 |
|------------|-------|-------|-------|-------|
| $\mu_A(x)$ | 0.2 | 0.7 | 1 | 0 |
| $\mu_B(x)$ | 0.5 | 0.3 | 1 | 0.1 |

Equation (3.1.5) and (3.1.6) give

| X | x ₁ | x ₂ | x ₃ | x ₄ |
|---------------------|----------------|----------------|----------------|----------------|
| $\mu_{A \cap B}(x)$ | 0.2 | 0.3 | 1 | 0 |
| $\mu_{A \cup B}(x)$ | 0.5 | 0.7 | 1 | 0.1 |

3.1.4. Fuzzy Numbers

The concept of fuzzy number was introduced after that of fuzzy set. Significant contributions to fuzzy numbers were made by Nahmias [23], Dubois and Prade [24], and Kaufmann and Gupta [25].

In many applications, either fuzzy number or fuzzy sets are preferred although presentations with fuzzy numbers are simpler. For general studies and also for making fuzzy logic easier, fuzzy set theory is a usable tool.

Fuzzy numbers are denoted by bold capital letters A, B, C.... and their membership functions by μ_A, μ_B, μ_C ...Examples of fuzzy numbers are specified as follows [19]:

3.1.5 Triangular Fuzzy Numbers

A triangular fuzzy number with membership function $\mu_A(x)$ is defined by

$$\mu_A(x) = \begin{cases} (x-a)/(b-a) & \text{for } a \leq x \leq b, \\ (x-c)/(b-c) & \text{for } b \leq x \leq c, \\ 0 & \text{otherwise,} \end{cases} \quad (3.1.7)$$

Where $[a_1, a_2]$ is the supporting interval and the point $(b, 1)$ is the peak (see Fig. 3.3). The third line in (3.1.7) can be dropped [19].

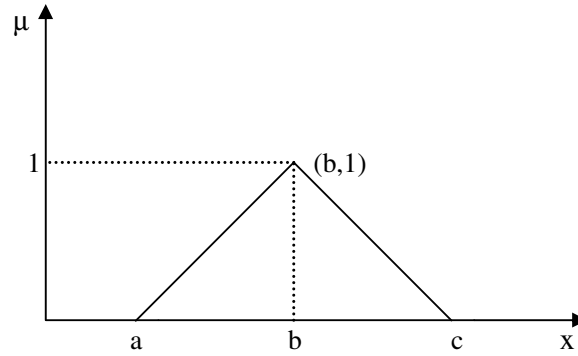


Figure 3.3: Triangular Fuzzy Number

3.1.6 Trapezoidal Fuzzy Numbers

A trapezoidal fuzzy number A (see Fig. 3.4) is defined by

$$\mu_A(x) = \begin{cases} (x-a)/(b_1-a) & \text{for } a \leq x \leq b_1, \\ 1 & \text{for } b_1 \leq x \leq b_2, \\ (x-c)/(b_2-c) & \text{for } b_2 \leq x \leq c, \\ 0 & \text{otherwise,} \end{cases} \quad (3.1.8)$$

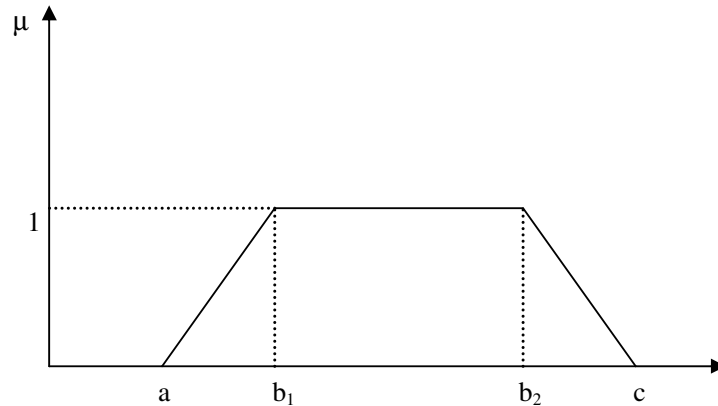


Figure 3.4: Trapezoidal Fuzzy Number [19]

3.2 Fuzzy Logic

In this section, the important concepts of linguistic variables and linguistic modifiers will be expressed. By means of these concepts, modeling complex systems in words and sentences will be achieved.

3.2.1 What is Fuzzy Logic?

The founder of fuzzy logic is Lotfi Zadeh [20]. He made valuable contributions to the establishment of fuzzy logic as scientific discipline.

There is not a unique system of knowledge called fuzzy logic; however, there are various methodologies suggesting valid consideration of imperfect and vague knowledge. Some topics are under the research. There are still discussions and debates going on about these topics .

Fuzzy logic uses fuzzy set theory. Fuzzy logic focuses on linguistic variables in daily language and tries to provide foundations for approximate reasoning with imprecise propositions. It reflects both the rightness and vagueness of natural language in common sense reasoning.

Major parts of fuzzy logic deal with linguistic variable and linguistic modifiers, propositional fuzzy logic, inferential rules, and approximate reasoning [19].

3.2.2 Linguistic Variables

It is called those linguistic variables of which values are words or sentences in natural language or man-made languages.

To illustrate the concept of linguistic variable, one should think about the word “age” in its daily usage. Age is a linguistic variable whose values are words like very, young, middle age, old, very old. They are called the terms of the linguistic variable “age” and are demonstrated by fuzzy sets on universal set U [19].

Example 3.2.1:

Assume the linguistic variable age on the universal set $U = [0, 100]$. Age in years is represented by triangular and trapezoidal numbers that specify the terms very young, young, middle age, old and very old (see Fig. 3.5).

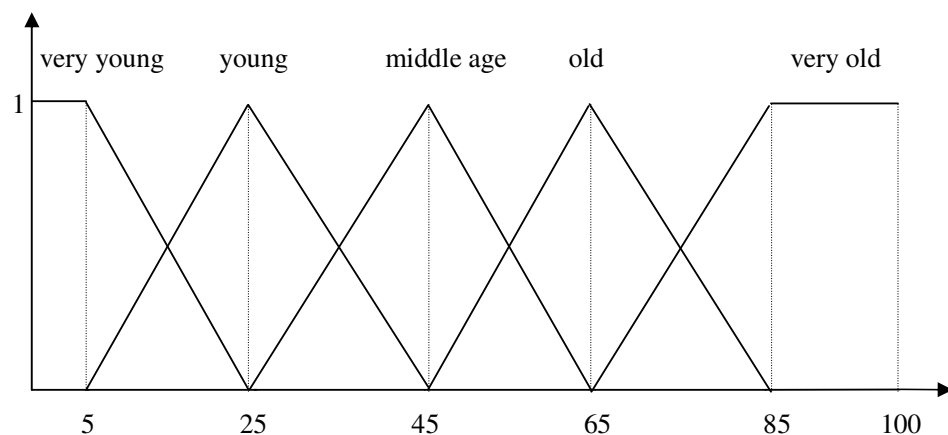


Figure 3.5: Terms of the Linguistic Variable Age

$$\mu_{\text{very young}}(x) = \begin{cases} 1 & \text{for } 0 \leq x \leq 5 \\ (25-x)/20 & \text{for } 5 \leq x \leq 25 \end{cases}$$

$$\mu_{\text{young}}(x) = \begin{cases} (x-5)/20 & \text{for } 5 \leq x \leq 25 \\ (45-x)/20 & \text{for } 25 \leq x \leq 45 \end{cases}$$

$$\mu_{\text{middle age}}(x) = \begin{cases} (x-25)/20 & \text{for } 25 \leq x \leq 45 \\ (65-x)/20 & \text{for } 45 \leq x \leq 65 \end{cases}$$

$$\mu_{\text{old}}(x) = \begin{cases} (x-45)/20 & \text{for } 45 \leq x \leq 65 \\ (85-x)/20 & \text{for } 65 \leq x \leq 85 \end{cases}$$

$$\mu_{\text{very old}}(x) = \begin{cases} (x-65)/20 & \text{for } 65 \leq x \leq 85 \\ 1 & \text{for } 85 \leq x \leq 100 \end{cases}$$

Linguistic variables are applied in particularly financial and management systems. For example, profit, inflation, risk, investment, etc. can be understood easily by application of linguistic variable [19].

3.3 Fuzzy Logic Control Model

This section will show how decisions can be made by using and aggregating if... then inferential rules. The presented methodology creates fuzzy logic

models reflecting a given situation in reality and provides solution leading to suggestion for action.

A block diagram for control processes is shown in Fig. 3.6. The meaning of each block is explained in the parts of this section.

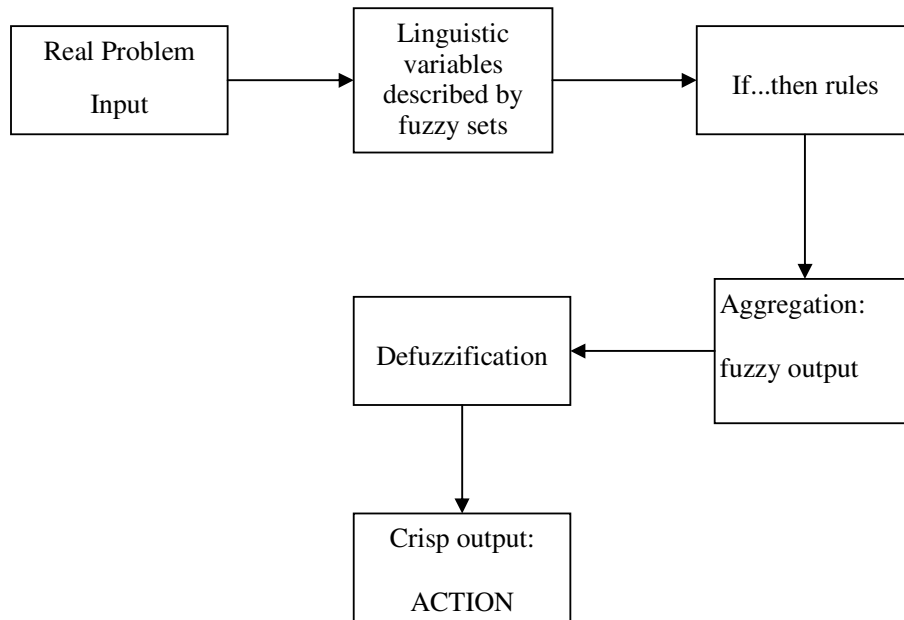


Figure 3.6: Block Diagram for Fuzzy Logic Control Process [19]

3.3.1 Modelling the Control Variables

There are inputs and outputs in the control problems and they are considered as linguistic variables.

Example 3.3.1:

Suppose the financial experts agree to describe the input variables annual income and total net worth and the output variable risk tolerance by the sets.

The terms of linguistic variables of annual income, total net worth and risk tolerance described by triangular and part of trapezoidal numbers formally have the same membership functions presented analytically below (see Fig. 3.7, 3.8, 3.9)[19].

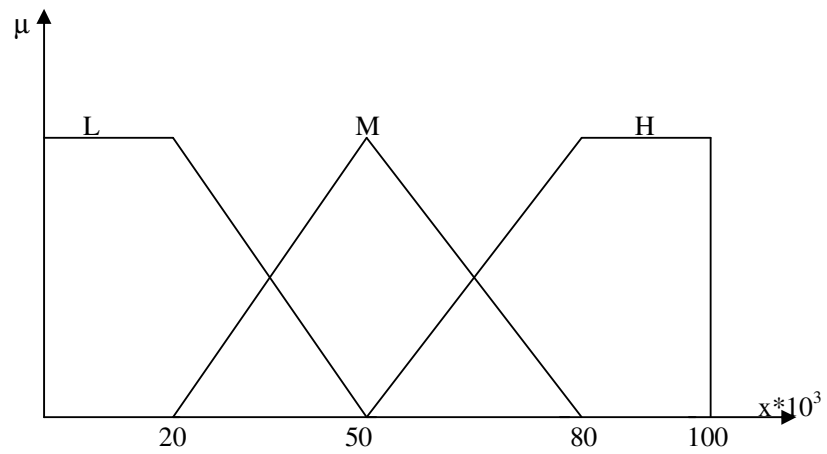


Figure 3.7: Terms of the *Annual Income*

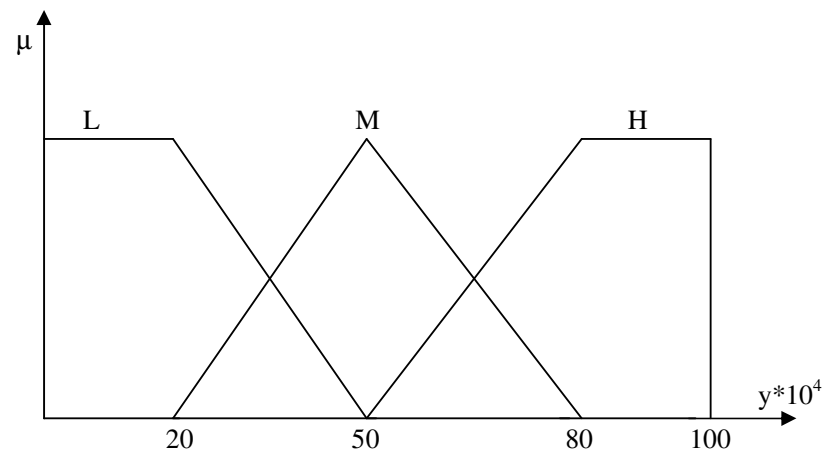


Figure 3.8: Terms of the *Total Net Worth*

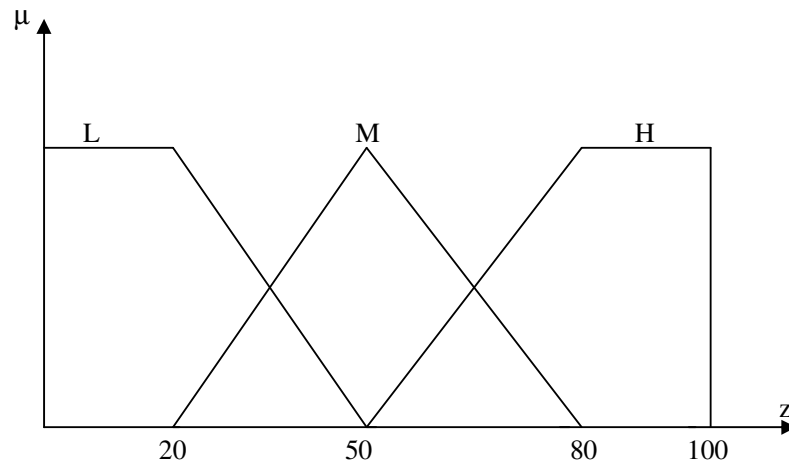


Figure 3.9: Terms of the *Output Risk Tolerance*

3.3.2 If... and... then Rules

The actual meaning of the if... and... then rules is

$$\text{If } x \text{ is } A_i \text{ and } y \text{ is } B_j \text{ then } z \text{ is } C_k \quad (3.3.1)$$

It can be denoted in fuzzy relation with membership function

$$p_i \cap q_j = \min(\mu_{A_i}(x), \mu_{B_j}(y)), \quad (x, y) \in A \times B \subset U_1 \times U_2 \quad [19]. \quad (3.3.2)$$

3.3.3 Aggregation (Conflict Resolution)

Aggregation or conflict resolution is the methodology used in order to decide what control action should be taken as result of the firing of several rules.

The process of conflict resolution can be illustrated by using those four rules numbered for convenience. For instance,

Rule 1: If x is $A_i^{(0)}$ and y is $B_j^{(0)}$ then z is C_{ij} ,

Rule 2: If x is $A_i^{(0)}$ and y is $B_{j+1}^{(0)}$ then z is $C_{i,j+1}$,

Rule 3: If x is $A_{i+1}^{(0)}$ and y is $B_j^{(0)}$ then z is $C_{i+1,j}$,

Rule 4: If x is $A_{i+1}^{(0)}$ and y is $B_{j+1}^{(0)}$ then z is $C_{i+1, j+1}$,

The “and” part of each rule, ie. the precondition, called here strength of the rule or level of firing is denoted by

$$\begin{aligned}\alpha_{ij} &= \mu_{A_i}(x_0) \cap \mu_{B_j}(y_0) = \min(\mu_{A_i}(x_0), \mu_{B_j}(y_0)), \\ \alpha_{i, j+1} &= \mu_{A_i}(x_0) \cap \mu_{B_{j+1}}(y_0) = \min(\mu_{A_i}(x_0), \mu_{B_{j+1}}(y_0)), \\ \alpha_{i+1, j} &= \mu_{A_{i+1}}(x_0) \cap \mu_{B_j}(y_0) = \min(\mu_{A_{i+1}}(x_0), \mu_{B_j}(y_0)), \\ \alpha_{i+1, j+1} &= \mu_{A_{i+1}}(x_0) \cap \mu_{B_{j+1}}(y_0) = \min(\mu_{A_{i+1}}(x_0), \mu_{B_{j+1}}(y_0)),\end{aligned}\tag{3.3.3}$$

Control output (CO) of each rule is defined by operation conjunction applied on its strength and conclusion is as follows:

$$\begin{aligned}\text{CO of rule 1: } & \alpha_{ij} \cap \mu_{C_{ij}}(z) = \min(\alpha_{ij}, \mu_{C_{ij}}(z)), \\ \text{CO of rule 2: } & \alpha_{i, j+1} \cap \mu_{C_{i, j+1}}(z) = \min(\alpha_{i, j+1}, \mu_{C_{i, j+1}}(z)), \\ \text{CO of rule 3: } & \alpha_{i+1, j} \cap \mu_{C_{i+1, j}}(z) = \min(\alpha_{i+1, j}, \mu_{C_{i+1, j}}(z)), \\ \text{CO of rule 4: } & \alpha_{i+1, j+1} \cap \mu_{C_{i+1, j+1}}(z) = \min(\alpha_{i+1, j+1}, \mu_{C_{ij}}(z)),\end{aligned}\tag{3.3.4}$$

The outputs of the four rules (3.3.4) have to be combined or aggregated in order to produce one control output with membership function $\mu_{\text{agg}}(z)$. Aggregation is denoted by the operator \cup or expressed by max:

$$\begin{aligned}\mu_{\text{agg}}(z) &= \{(\alpha_{ij} \cap \mu_{C_{ij}}(z)) \cup (\alpha_{i, j+1} \cap \mu_{C_{i, j+1}}(z)) \cup (\alpha_{i+1, j} \cap \mu_{C_{i+1, j}}(z)) \\ &\quad \cup (\alpha_{i+1, j+1} \cap \mu_{C_{i+1, j+1}}(z))\} \\ &= \max \{(\alpha_{ij} \cap \mu_{C_{ij}}(z)), (\alpha_{i, j+1} \cap \mu_{C_{i, j+1}}(z)), (\alpha_{i+1, j} \cap \mu_{C_{i+1, j}}(z)), \\ &\quad (\alpha_{i+1, j+1} \cap \mu_{C_{i+1, j+1}}(z))\}\end{aligned}\tag{3.3.5}$$

After real number α and the fuzzy set C with membership function $\mu_C(z)$ are obtained. Then

$$\mu_{\alpha \cap \mu_C}(z) = \alpha \cap \mu_C(z) = \min(\mu_\alpha(z) = \alpha, \mu_C(z))\tag{3.3.6}$$

is defined. In this equation, α is drawn parallel to z axis. This is a truncation of shape of $\mu_C(z)$ [19].

Example 3.3.2:

Consider the example 3.3.1, assume $x_0 = 40$ in thousands (annual income) and $y_0 = 25$ in ten of thousands (total net worth). The rules are specified as follows:

- If both annual income and total net worth is low, risk tolerance is low,
- If annual income is low and total net worth is medium, risk tolerance is low,
- If annual income is medium and total net worth is low, risk tolerance is moderate (MO),
- If both annual income and total net worth is medium, risk tolerance is low,

$\mu_L(40) = 1/3$, $\mu_M(40) = 2/3$, $\mu_L(25) = 5/6$, $\mu_M(25) = 1/6$ (see Fig. 3.10 and Table 3.1)

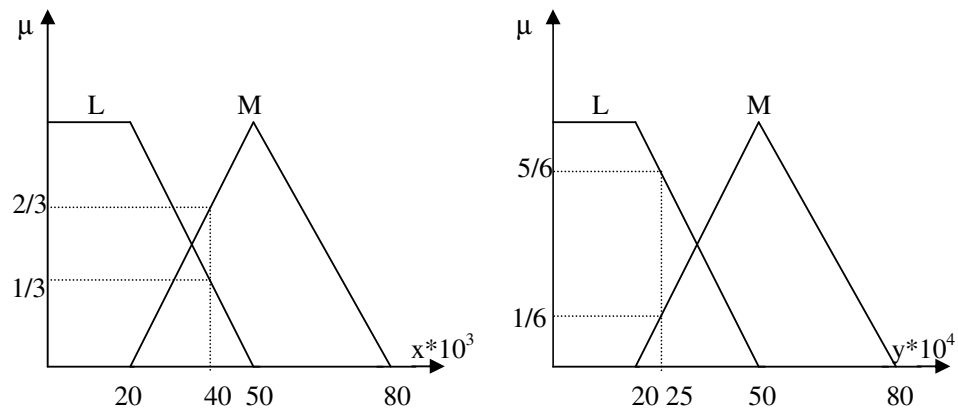


Figure 3.10: Fuzzy Reading Inputs for the Clients Financial Risk Tolerance Model.

Readings $x_0 = 40$ and $y_0 = 25$.

Table 3.1: Representation of the Rules of Clients Financial Risk Tolerance

| | | |
|-----------------|-----------------|-----------------|
| | $\mu_L(25)=5/6$ | $\mu_M(25)=1/6$ |
| $\mu_L(40)=1/3$ | $\mu_L(z)$ | $\mu_L(z)$ |
| $\mu_M(40)=2/3$ | $\mu_{MO}(z)$ | $\mu_L(z)$ |

The strength of these rules are calculated according to (3.3.3)

$$\alpha_{11} = \mu_L(40) \cap \mu_L(25) = \min(1/3, 5/6) = 1/3,$$

$$\alpha_{12} = \mu_L(40) \cap \mu_M(25) = \min(1/3, 1/6) = 1/6,$$

$$\alpha_{21} = \mu_M(40) \cap \mu_L(25) = \min(2/3, 5/6) = 2/3,$$

$$\alpha_{22} = \mu_M(40) \cap \mu_M(25) = \min(2/3, 1/6) = 1/6 \text{ (Fig. 3.11).}$$

Control output (CO) of each rule is shown below according to (3.3.4).

$$\text{CO of rule 1: } \alpha_{11} \cap \mu_L(z) = \min(1/3, \mu_L(z)),$$

$$\text{CO of rule 2: } \alpha_{12} \cap \mu_L(z) = \min(1/6, \mu_L(z)),$$

$$\text{CO of rule 3: } \alpha_{21} \cap \mu_L(z) = \min(2/3, \mu_{MO}(z)),$$

$$\text{CO of rule 4: } \alpha_{22} \cap \mu_{MO}(z) = \min(1/6, \mu_L(z)).$$

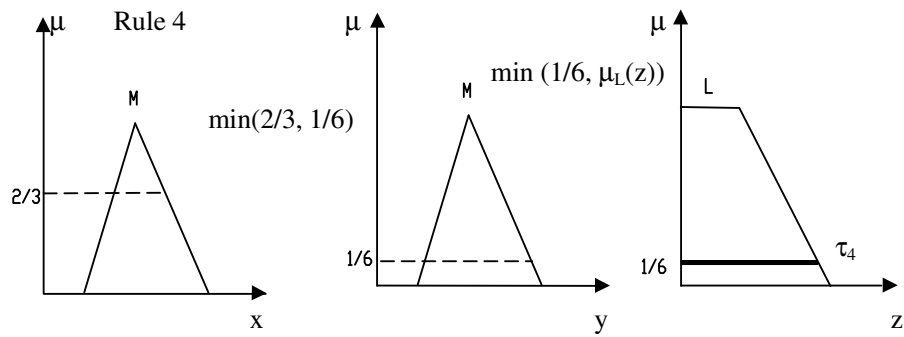
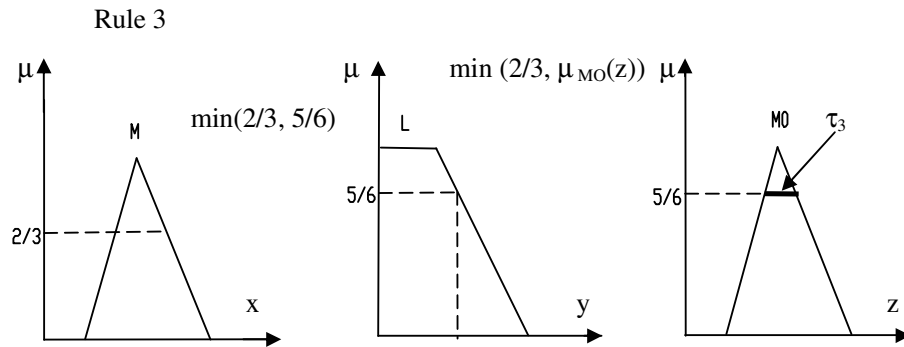
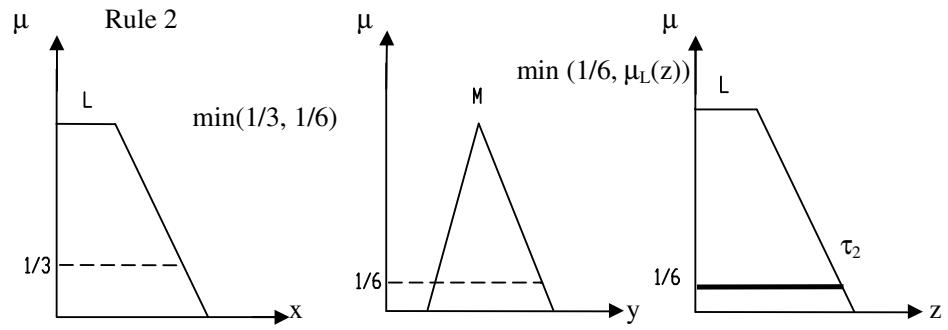
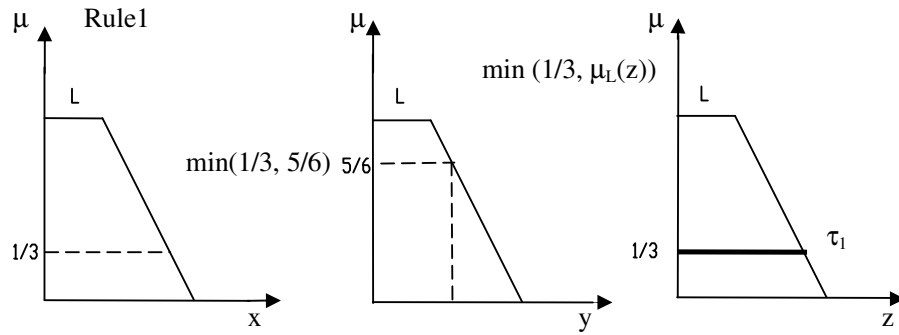


Figure 3.11: Firing of Rules for the Client Financial Risk Tolerance Model

To aggregate the control outputs (CO), equation (3.3.5) is used. As a geometric shape, outputs of rule 2 and rule 4 are the same. These outputs are included in rule 1 which has the high strength. As a result, aggregation of rule1 and rule 3 must be considered.

The aggregated output ($\mu_{agg}(z)=\max\{\min(1/3, \mu_L(z)), \min(2/3, \mu_{MO}(z))\}$) is shown in Fig. 3.12.

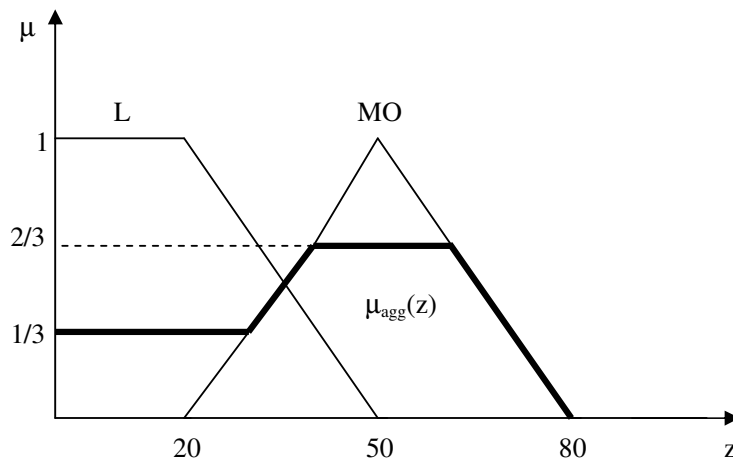


Figure 3.12: Aggregated Output for the Client Financial Risk Tolerance Model

3.3.4 Defuzzification

Defuzzification of the outputs is the operation producing a nonfuzzy control action, a single value z , that adequately represents the membership function $\mu_{agg}(z)$ of an aggregated fuzzy control action.

There are several existing methods [26]. The method used in this study is expressed. The name of it is height defuzzification method.

Height defuzzification method

This method uses all clipped flat segments as a result of firing rules (see Fig. 3.13). The HDM produces Z_h .

$$Z_h = \frac{p \cdot (\zeta_1 + \zeta_2) / 2 + q \cdot (\eta_1 + \eta_2) / 2}{p + q} = w_1 \cdot (\zeta_1 + \zeta_2) / 2 + w_2 \cdot (\eta_1 + \eta_2) / 2 \quad (3.3.7)$$

Z_h is the weighted average of the midpoints of $[\zeta_1, \zeta_2]$ and $[\eta_1, \eta_2]$ with weights $w_1 = p / (p + q)$, $w_2 = q / (p + q)$, where p and q are the heights of the flag segments.

If the existence of more than two segments is in question, formula (3.3.7) can be extended accordingly [19].

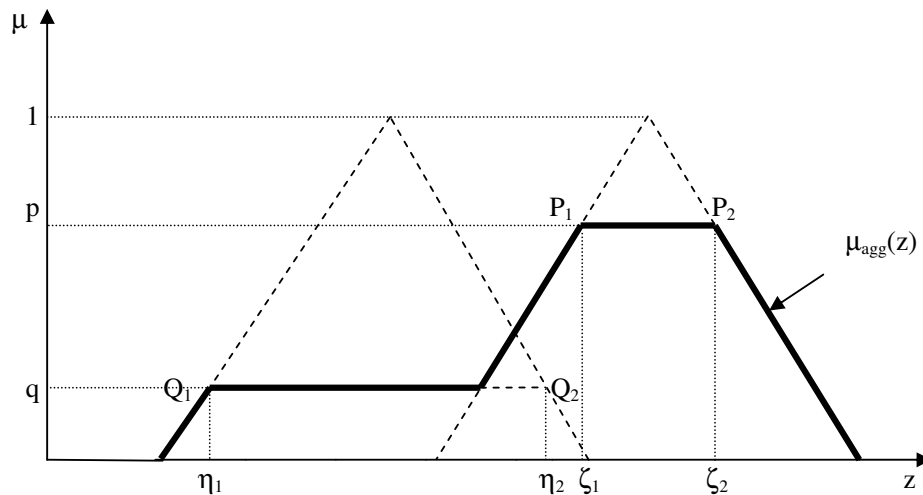


Figure 3.13: Defuzzification by the Height Defuzzification Method (HDM)

Example 3.3.3:

The aggregated output for the client financial risk tolerance model (example 3.3.2) may be defuzzified by this method (see Fig. 3.14).

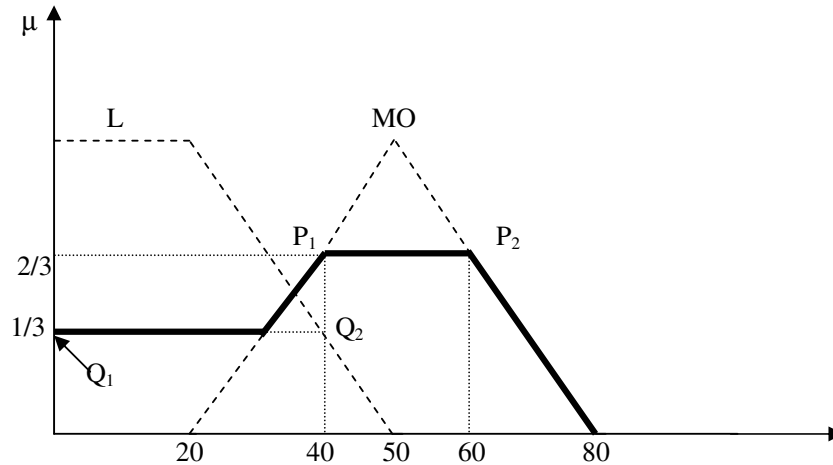


Figure 3.14: Defuzzification: Client Financial Risk Tolerance Model

$Q_1 = 0, Q_2 = 40, P_1 = 40$ and $P_2 = 60$;

$$z_h = \frac{2/3 * (40+60)/2 + 1/3 * (0+45)/2}{2/3 + 1/3} = 40.83$$

Example 3.3.4:

In this example, urgent, serious, and growth potential are inputs and also considered as linguistics variables. The output variable is priority of deviation. Since high precision is not needed, for each variable, it is modelled by three terms by using the trapezoidal or triangular numbers.

- Urgent (U) \triangleq {N, S, V},
- Serious (S) \triangleq {N, S, V},
- Growth potential (GP) \triangleq {L, M, H},
- Priority of deviation (POD) \triangleq {L, M, H}.

Where N, S, V, H, L means “not”, “somewhat”, “very”, “high”, “low”, “medium” respectively. According to if and then rules we have to design $3*3*3 = 27$ rules. In order to simplify the control procedure, the input variables

must be considered as independent of each other. This means that the rules must be like if...then without using and (precondition) part. These rules are shown below:

Rule1: If D is NU then POD is L, }
 Rule2: If D is SU then POD is M, }
 Rule3: If D is VU then POD is H, }

Rule4: If D is NS then POD is L, }
 Rule5: If D is SS then POD is M, }
 Rule6: If D is VS then POD is H, }

Rule7: If D is with LGP then POD is L, }
 Rule8: If D is with MGP then POD is M, }
 Rule9: If D is with HGP then POD is H, }

For instance, the second rule reads “if deviation is somewhat urgent then priority of deviation is medium”.

Trapezoidal numbers are used as presentation of inputs and output (see Fig. 3.15, 3.16, 3.17, 3.18).

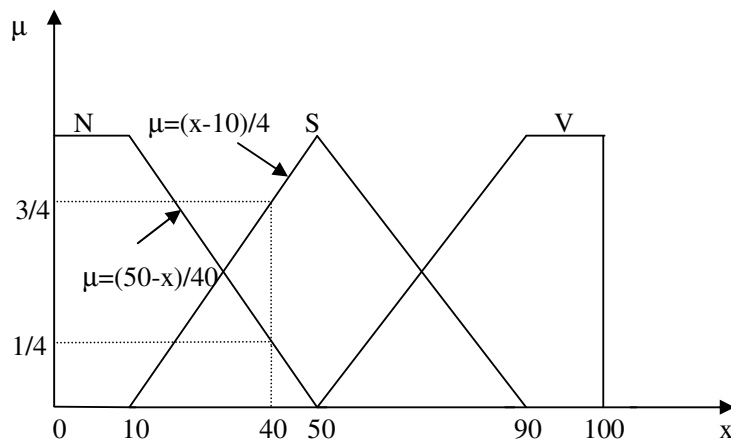


Figure 3.15: Terms of the *Urgent Variable*

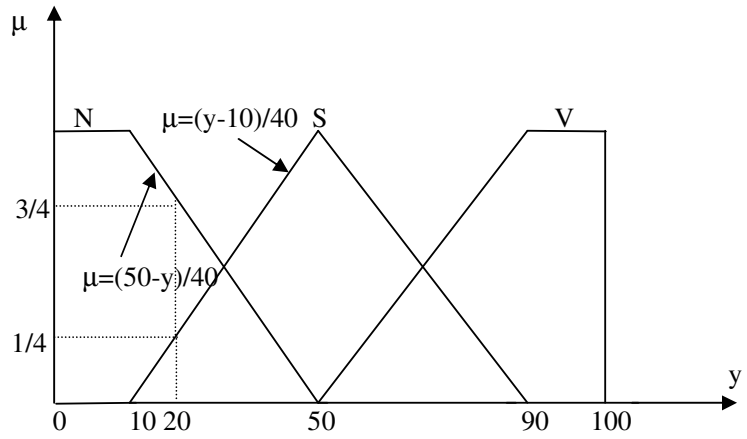


Figure 3.16: Terms of the *Serious* Variable

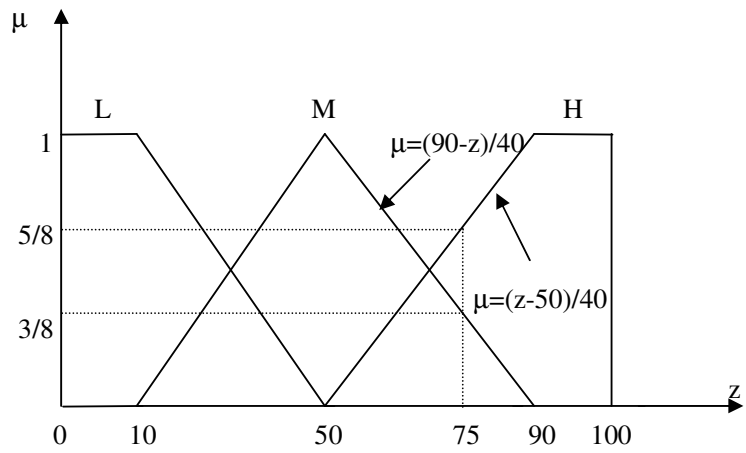


Figure 3.17: Terms of the *Growth Potential* Variable

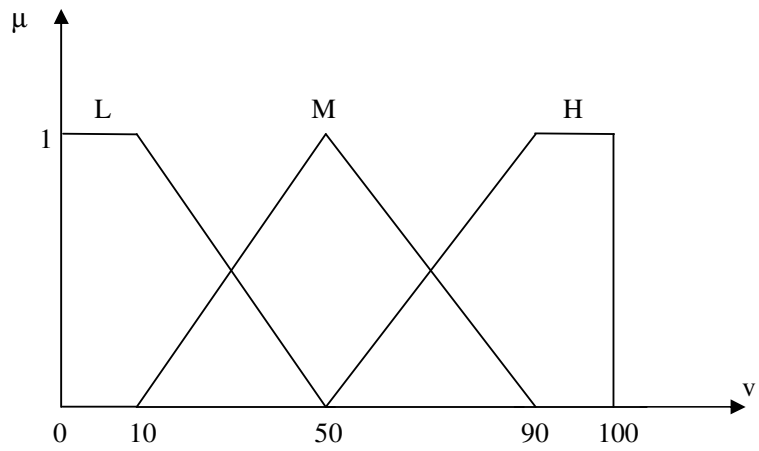
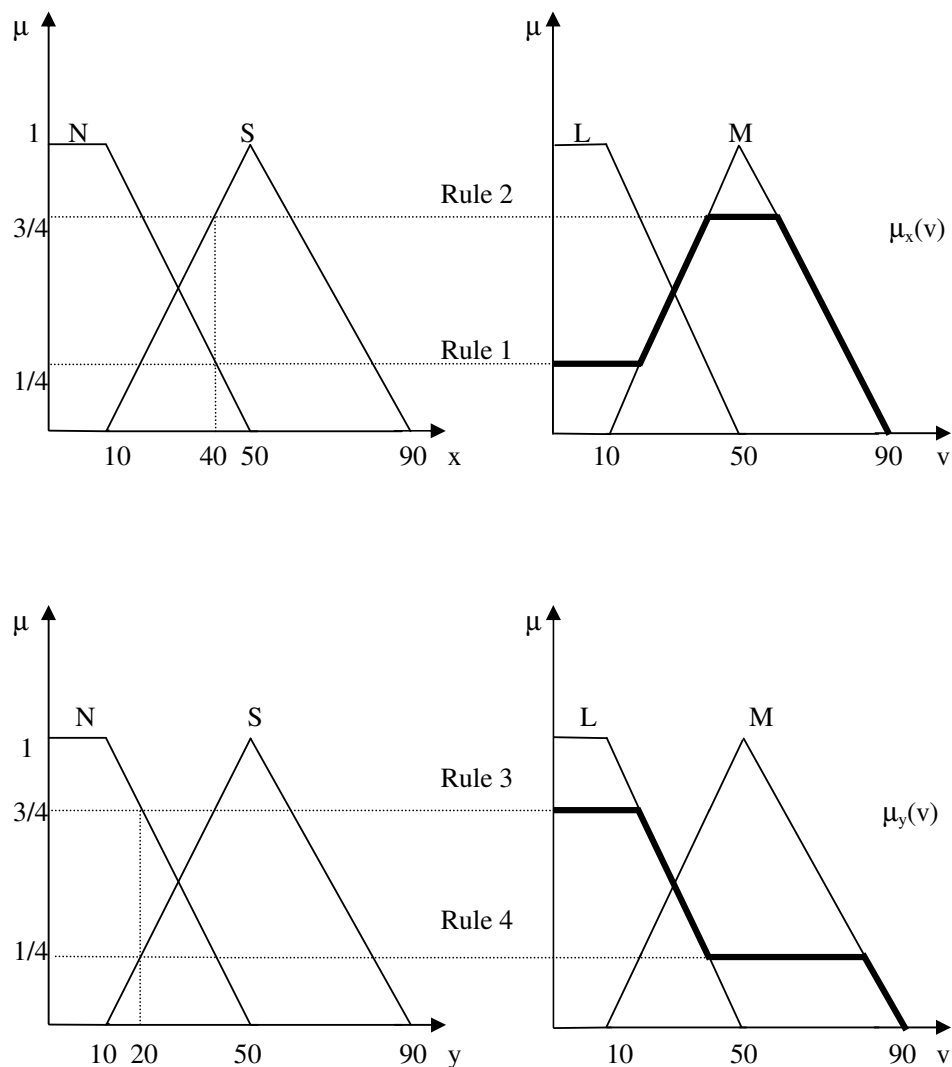


Figure 3.18: Terms of the *Priority of Deviation* Variable

Let's assume x , y , z measures deviation of urgent, deviation of serious and deviation of the growth potential respectively. Let's say what will happen to priority of deviation when $x = 40$, $y = 20$ and $z = 70$. According to FLC, only two rules are fired at specified levels (Fig 3.19). After combining these rules, three independent control outputs $\mu_x(v)$, $\mu_y(v)$, $\mu_z(v)$ are produced. The aggregation of these will give the membership function $\mu_{agg}(v)$ result which is related with priority of deviation (POD).



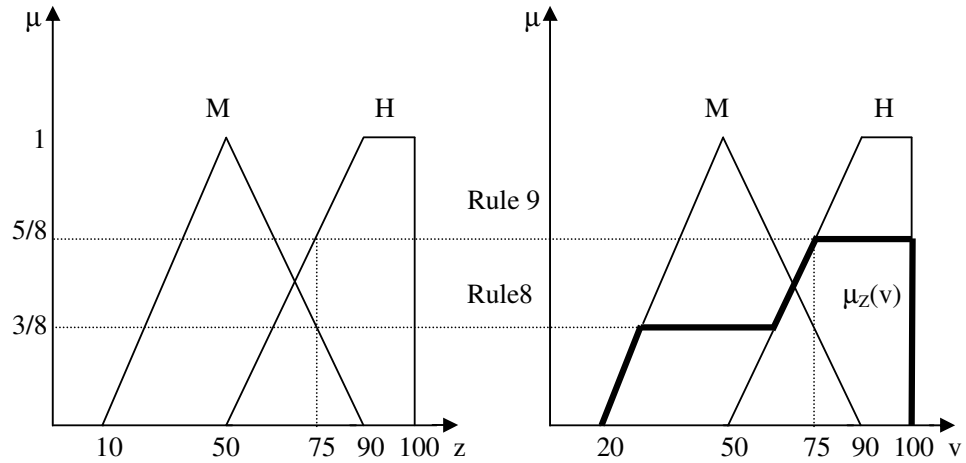


Figure 3.19: Firing of Rules for Three Independent Inputs

By using operation max, the output of $\mu_x(v)$, $\mu_y(v)$, $\mu_z(v)$ is

$$\mu_{agg}(v) = \max\{\mu_x(v), \mu_y(v), \mu_z(v)\} \text{ (see Fig. 3.20)}$$

This graph is obtained by superimposing $\mu_x(v)$, $\mu_y(v)$, $\mu_z(v)$ on top of each other (see section 3.3.3).

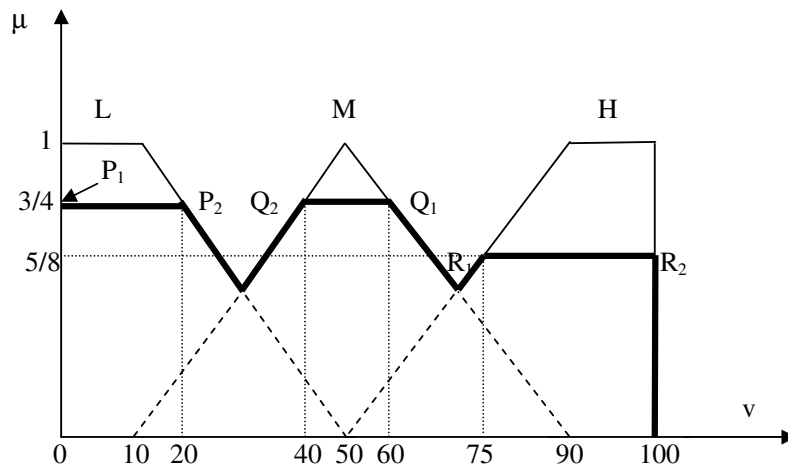


Figure 3.20: Aggregation of the Independent Inputs. Defuzzification

To defuzzify $\mu_{agg}(v)$, HDM is used. The projections of the flat segments (P_1, P_2), (Q_1, Q_2), (R_1, R_2) are (0, 20), (40, 60) and (75, 100). The extended formula (3.3.7) gives

$$v_h = [3/4*(0+20)/2+3/4*(40+60)/2+5/8*(75+100)/2]/ (3/4+3/4+5/8) = 46.91 \\ \approx 47$$

The interpretation is that the priority of deviation is almost medium. The manager will act according to this output [19].

The definitions and rules mentioned are explained as they are used in the proposed fuzzy risk rating approach for international construction projects. Using the basic concepts explained above, a fuzzy risk rating algorithm has been defined and a software that carries out the required calculations such as aggregation, defuzzification etc. has been developed, which is the subject of the forthcoming chapter.

3.4 Applications of Fuzzy Risk Rating in Construction Management

Fuzzy representation is a useful tool in defining and evaluating problems commonly encountered in construction and civil engineering [27]. Civil engineering differs from other engineering disciplines in that each civil engineering project is generally unique in its characteristics. Hence, there is a little chance to test a prototype, as in some other engineering disciplines [28]. Consequently, the uncertainty in applying theoretical solutions to civil engineering projects is more.

It is an interesting paradox that data based on fuzzy variables provides more accurate evidence about real phenomena, than data based upon crisp variables. Since fuzzy variables capture measurement uncertainties as part of experimental data, they are more attuned to reality than crisp variables [28].

The complexity in construction engineering often results in hesitation on the part of the decision maker in selecting specific alternatives. Moreover, FST provides approximate reasoning to better handle partly-defined, or incomplete information as is often the case in construction engineering. It is also a suitable technique to deal with the out of control factors: site, labor, equipment, climate, unforeseen circumstances, time dependence situations, and regulations [29].

Thus, fuzzy logic formulation and computation is applied in a number of engineering tasks ranging from risk assessment, to risk pricing algorithm, to construction time-cost trade-off and to whole life costs of building elements. Examples of fuzzy set theory application in construction industry are specified below.

Hyun-Ho Choi, Hyo-Nam Cho and J.W.Seo (2004) developed a risk assessment methodology for underground construction projects. The main tool of this methodology is risk analysis software. The risk analysis software is built upon an uncertainty model based on fuzzy concept. The fuzzy-based uncertainty model is designed to consider the uncertainty range that represents the degree of uncertainties involved in both (1) probabilistic parameter estimates and (2) subjective judgements. Moreover, they concluded that the proposed risk assessment methodology will provide rational and practical solutions to the insurance companies and contractors with its flexible and easy-to-follow procedure and tools, and robust uncertainty modeling capability [30].

Sou-Sen Leu, An-Ting Chen and Chung-Huei Yang (1999) developed a new optimal construction time-cost trade-off method. The effects of both uncertain activity duration and time-cost trade-off are taken into account in this method. Fuzzy set theory is used to model the uncertainties of activity durations. The method provides an insight into the optimal balance of time and cost under different risk levels defined by decision makers [31].

James R. Paek, Yong W. Lee and Jong H. Ock (1993) developed risk-pricing method for analyzing and pricing construction project risk. The method consists of identifying risk elements and quantifying risk-associated consequences. Assessing risk associated consequences contains elements of uncertainty. They show that the uncertainty inherent in these elements and its impact on results can be characterized by applying fuzzy set theory and incorporated directly into the bidding price decision process. The proposed risk-pricing method will assist contractors in the process of estimation under uncertainty [32].

N.Wang, R.M.W. Horner and M. El-Haram (2004) developed a generic elemental whole life costing model by using the fuzzy logic model. The relationship between the context of use and the cost items is modeled by using linguistic data of experts. This model proved that fuzzy logic approach, which uses experts' knowledge, overcomes lack of data and the uncertainty in forecasting future events. It is anticipated that this model could provide a very wide range of use in estimating whole life costs of public service buildings, such as hospital, school, etc. [33].

J.H.M. Tah and V. Carr (2000) developed a formal model for qualitative risk assessment. Common language for describing risks is presented, which includes terms for quantifying likelihoods and impacts so as to achieve consistent quantification. The relationships between risk factors, risks and their consequences are represented on cause and effect diagrams. These diagrams and the concepts of fuzzy association and fuzzy composition are applied to identify relationships between risk sources and the consequences for project performance measures. A methodology for evaluating the risk exposure, considering the consequences in terms of time, cost, quality and safety performance measures of project based on fuzzy estimates of the risk components is represented [12].

In this thesis, fuzzy rating approach is utilized to quantify cost overrun risk in international projects in the bidding stage. The step-wise procedure is developed for this approach. This procedure consists of modeling cost overrun risk by influence diagramming method, determination of membership functions for fuzzy variables, aggregation and defuzzification process and cost overrun risk output. The proposed fuzzy rating approach for risk assessment enables the manager to decide about whether the projects are to be bid or not according to the cost overrun risk values and strategies of companies.

CHAPTER IV

A FUZZY RISK RATING APPROACH FOR RISK ASSESSMENT OF INTERNATIONAL CONSTRUCTION PROJECTS

4.1 Methodology

In this chapter, the proposed fuzzy rating approach for risk assessment will be explained and an example application of the proposed methodology will be presented to demonstrate the capabilities of the developed fuzzy risk rating tool. The step-wise procedure followed during the development of the fuzzy risk rating tool is depicted in Fig. 4.1.

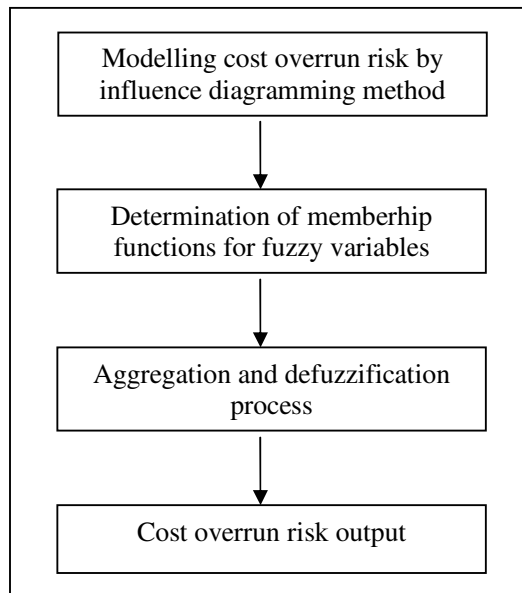


Figure 4.1: Steps of Fuzzy Risk Rating Approach for Risk Assessment

The aim of the proposed methodology is to quantify cost overrun risk in international projects. It is assumed that a number of risk factors stemming from project and country levels lead to cost overrun risk. As well as risk factors, the risk response strategies and given factors such as contract conditions etc. affect the way risks are managed, thus the impact of risks on the total cost of the project. Therefore, a risk breakdown structure is developed to model the cost overrun risk in international projects and following steps are followed to quantify the cost overrun risk in international projects.

1st step: Modelling cost overrun risk by influence diagramming method

International projects have more risks than domestic projects due to the uncertainties stemming from country conditions. A literature survey has been conducted to identify the major sources of risk in international construction projects. Many authors proposed different risk breakdown structures to classify risk in these projects [34, 35]. In this research, influence diagramming method is chosen as the risk identification method as it is capable of showing risks, interrelations between different risk sources, given conditions and consequence variables affected from risk sources. By referring to the literature survey findings, an influence diagrams are drawn to model risks affecting cost of international construction projects (Fig. 4.2, 4.3, 4.4). These diagrams show that the risks affecting cost are composed of two parts. One of them represents country risk influence diagram and the other one represents project risk influence diagram. In these diagrams, circle shape illustrates risk source which is called as state/random (uncertain) variable. Risk source such as “civil unrest” can be defined as any uncertain variable that may affect the cost of the project. Moreover, rectangle shape shows a controllable/given factor such as “experience of the company in the country” and hexagon shape denotes calculated quantity such as “cost risk” (see 2.4.1 part).

The influence diagram is drawn to facilitate risk identification process by the decision-maker. It helps to draw the overall picture about the cost overrun risk.

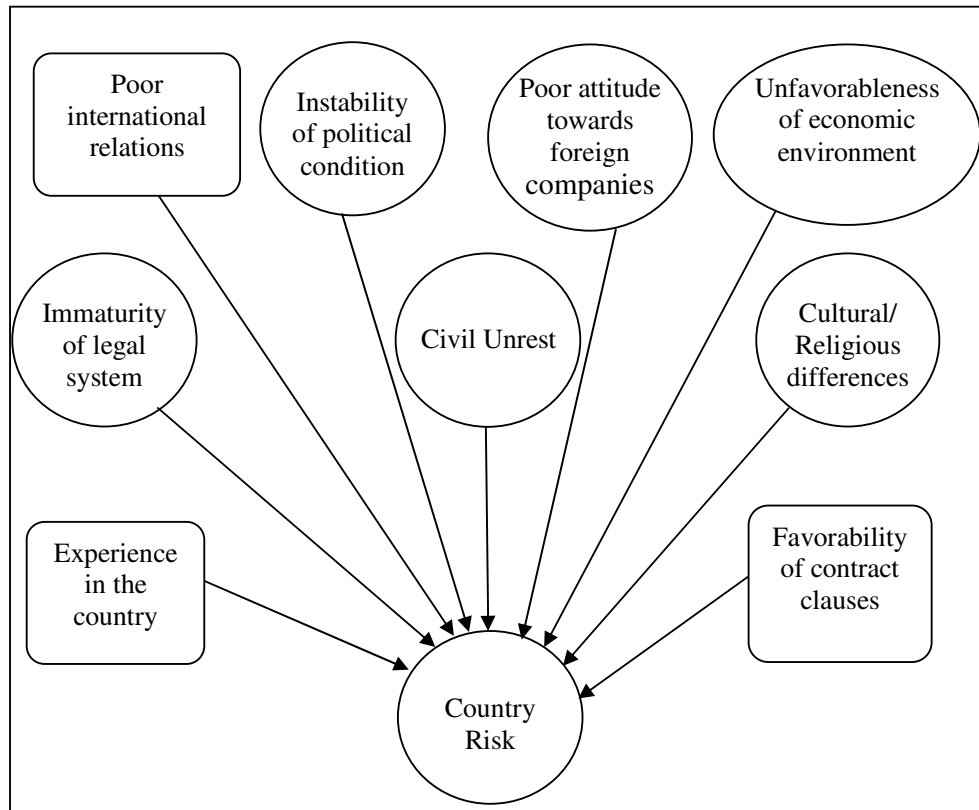


Figure 4.2: Representation of Country Risk Notation

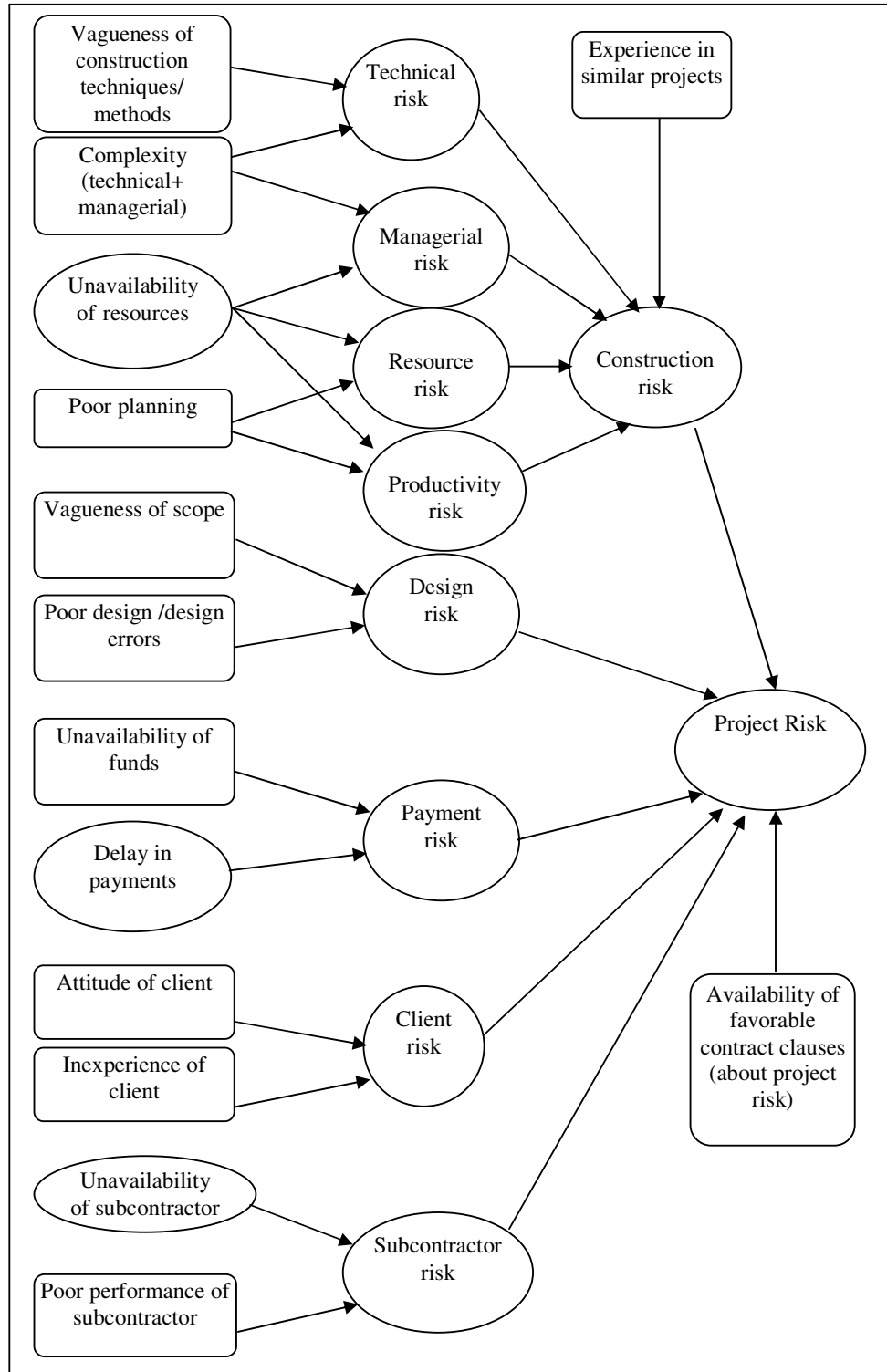


Figure 4.3: Representation of Project Risk Notation

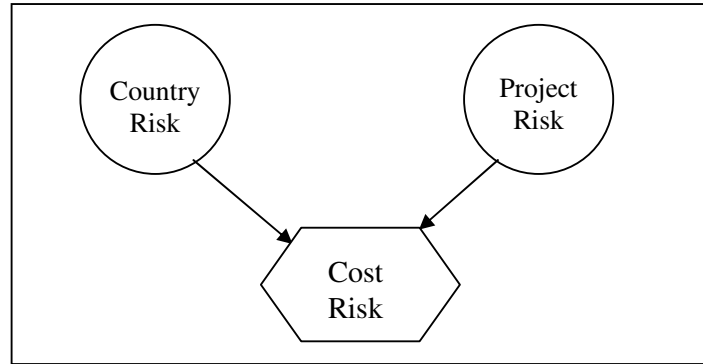


Figure 4.4: Representation of Cost Risk Notation

2nd step: Determination of membership functions for fuzzy variables

These risks and risk factors shown in the proposed influence diagram can not be expressed by absolute/objective numbers. The severity of the risk factors is rather expressed by decision-makers such as “very high risk”, “low risk” etc. Thus, they are defined as linguistic variables (see 3.2.2 part). Because of that, for each linguistic variable, states of those linguistic variables must be determined and demonstrated by fuzzy sets. States of the linguistic variables are defined as low, low-to-medium, medium, medium-to-high, high. All of them are represented by triangular numbers (see Fig. 4.5).

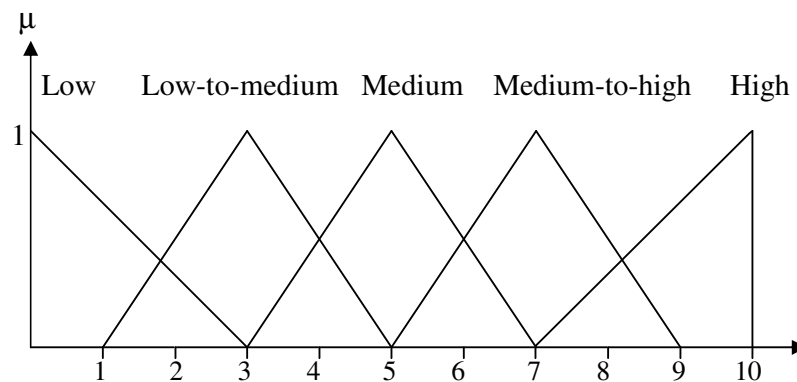


Figure 4.5: Membership Functions for All Linguistic Variables

This graph describes all the values of linguistic variable on the universe. With this graph, fuzzy logic allows an object to belong to different classes at the same time. This notation is helpful when the difference between classes is not well defined. This function is widely used in fuzzy logic applications in the risk management literature, for example in [36].

Thus, at this step, a decision-maker is requested to evaluate the value of factors given in the influence diagram by linguistic terms and further, they are converted to fuzzy triangular numbers by the pre-determined membership function given in Figure 4.5.

3rd step: Aggregation and defuzzification process

Aggregation methodology must be decided and rules must be determined to process all fuzzy variables (see 3.3.3 part). After aggregation is completed, defuzzification has to be done to find a single value so as to represent the membership function $\mu_{agg}(z)$. For the aggregation process, following 3 steps are followed:

4th step: Risk assessment

4.2 Step 4.1: Country Risk Assessment

Step 4.1.1: Country risk assessment by considering only the risk factors:

Initially, poor international relations, instability of political condition, poor attitude towards foreign companies, unfavorableness of economic environment, immaturity of legal system, civil unrest and cultural/religious differences are considered as the risk sources. Instead of using if...and then... rule which

requires $5 \times 5 \times 5 \times 5 \times 5 \times 5 = 78125$ rules, these variables are considered as independent of each other so as to simplify the procedure. Rules are specified as follows:

1- If risk due to “poor international relations” is low, then, the country risk is low,

2- If risk due to “poor international relations” is low-to-medium, the country risk is low-to-medium,

3- If risk due to “poor international relations” is medium, the country risk is medium,

4- If risk due to “poor international relations” is medium-to-high, the country risk is medium-to-high,

5- If risk due to “poor international relations” is high, the country risk is high,

6- If risk due to “instability of political condition” is low, the country risk is low,

7- If risk due to “instability of political condition” is low-to-medium, the country risk is low-to-medium,

8- If risk due to “instability of political condition” is medium, the country risk is medium,

9- If risk due to “instability of political condition” is medium-to-high, the country risk is medium-to-high,

10- If risk due to “instability of political condition” is high, the country risk is high,

11- If risk due to “poor attitude towards foreign companies” is low, the country risk is low,

12 If risk due to “poor attitude towards foreign companies” is low-to-medium, the country risk is low-to-medium,

13- If risk due to “poor attitude towards foreign companies” is medium, the country risk is medium,

14- If risk due to “poor attitude towards foreign companies” is medium-to-high, the country risk is medium-to-high,

15- If risk due to “poor attitude towards foreign companies” is high, the country risk is high,

16- If risk due to “unfavorableness of economic environment” is low, the country risk is low,

17- If risk due to “unfavorableness of economic environment” is low-to-medium, the country risk is low-to-medium,

18- If risk due to “unfavorableness of economic environment” is medium, the country risk is medium,

19- If risk due to “unfavorableness of economic environment” is medium-to-high, the country risk is medium-to-high,

20- If risk due to “unfavorableness of economic environment” is high, the country risk is high,

21- If risk due to “immaturity of legal system” is low, the country risk is low,

22- If risk due to “immaturity of legal system” is low-to-medium, the country risk is low-to-medium,

23- If risk due to “immaturity of legal system” is medium, the country risk is medium,

24- If risk due to “immaturity of legal system” is medium-to-high, the country risk is medium-to-high,

25 If risk due to “immaturity of legal system” is high, the country risk is high,

- 26- If risk due to “civil unrest” is low, the country risk is low,
- 27- If risk due to “civil unrest” is low-to-medium, the country risk is low-to-medium,
- 28- If risk due to “civil unrest” is medium, the country risk is medium,
- 29- If risk due to “civil unrest” is medium-to-high, the country risk is medium-to-high,
- 30- If risk due to “civil unrest” is high, the country risk is high,
-
- 31- If risk due to “cultural/religious differences” is low, the country risk is low,
- 32- If risk due to “cultural/religious differences” is low-to-medium, the country risk is low-to-medium,
- 33- If risk due to “cultural/religious differences” is medium, the country risk is medium,
- 34- If risk due to “cultural/religious differences” is medium-to-high, the country risk is medium-to-high,
- 35- If risk due to “cultural/religious differences” is high, the country risk is high,

The 35 rules depicted above can not be claimed to be exact/objective rules, but they are derived as a result of expert opinion and literature survey findings.

After combining these rules, outputs are obtained. The aggregation (see 3.3.3 part) of these factors give the membership function $\mu_{agg}(z)$ which is related with country risk rating. Then, to defuzzify the $\mu_{agg}(z)$, HDM(see 3.3.4 part) method is used. The decision-maker is able to see the quantifiable country risk rating after defuzzification.

Step 4.1.2: Country risk assessment by considering controllable/given factors (experience in the country):

In this part, output of the previous step is combined with experience of the company in the country and a new country risk rating is obtained. For that, if... and then... rules (see 3.3.2 part) are applied. These rules are elicited from the expert judgement. The decision table is designed according to these rules (see table 4.1). These rules are specified as follows:

- 1- If country risk is low and experience of the company in the country is low, then country risk rating is low,
- 2- If country risk is low and experience of the company in the country is low-to-medium then country risk rating is low,
- 3- If country risk is low and experience of the company in the country is medium then country risk rating is low,
- 4- If country risk is low and experience of the company in the country is medium-to-high then country risk rating is low,
- 5- If country risk is low and experience of the company in the country is high then country risk rating is low,

- 6- If country risk is low-to-medium and experience of the company in the country is low then country risk rating is low-to-medium,
- 7- If country risk is low-to-medium and experience of the company in the country is low-to-medium then country risk rating is low-to-medium,
- 8- If country risk is low-to-medium and experience of the company in the country is medium then country risk rating is low-to-medium,
- 9- If country risk is low-to-medium and experience of the company in the country is medium-to-high then country risk rating is low,
- 10- If country risk is low-to-medium and experience of the company in the country is high then country risk rating is low,

- 11- If country risk is medium and experience of the company in the country is low then country risk rating is medium,
- 12- If country risk is medium and experience of the company in the country is low-to-medium then country risk rating is medium,
- 13- If country risk is medium and experience of the company in the country is medium then country risk rating is medium,
- 14- If country risk is medium and experience of the company in the country is medium-to-high then country risk rating is low-to-medium,
- 15- If country risk is medium and experience of the company in the country is high then country risk rating is low-to-medium,
-
- 16- If country risk is medium-to-high and experience of the company in the country is low then country risk rating is medium-to-high,
- 17- If country risk is medium-to-high and experience of the company in the country is low-to-medium then country risk rating is medium-to-high,
- 18- If country risk is medium-to-high and experience of the company in the country is medium then country risk rating is medium-to-high,
- 19- If country risk is medium-to-high and experience of the company in the country is medium-to-high then country risk rating is medium,
- 20- If country risk is medium-to-high and experience of the company in the country is high then country risk rating is medium,
-
- 21- If country risk is high and experience of the company in the country is low then country risk rating is high,
- 22- If country risk is high and experience of the company in the country is low-to-medium then country risk rating is high,
- 23- If country risk is high and experience of the company in the country is medium then country risk rating is high,
- 24- If country risk is high and experience of the company in the country is medium-to-high then country risk rating is high,

25- If country risk is high and experience of the company in the country is high then country risk rating is medium-to-high (see Table 4.1).

Table 4.1: Decision Table for the *Country Risk Rating* Output

| | | Experience of the company in the country | | | | |
|--------------|------------------------|--|-----------------------|---------------|------------------------|-------------|
| | | Low (L) | Low-to-medium (LM) | Medium (M) | Medium-to-high (MH) | High (H) |
| Country risk | Low (L) | L | L | L | L | L |
| | Low-to-medium (LM) | LM | LM | LM | L | L |
| | Medium (M) | M | M | M | LM | LM |
| | Medium-to-high (MH) | MH | MH | MH | M | M |
| | High (H) | H | H | H | H | MH |

After combining these rules, outputs are obtained. The aggregation (see 3.3.3 part) of these factors give the membership function $\mu_{agg}(z)$ which is related with country risk rating. Then, to defuzzify the $\mu_{agg}(z)$, HDM(see 3.3.4 part) method is used. The decision-maker is able to see the quantifiable country risk rating after defuzzification. But this time, new country risk rating takes into account of the “controllability” of country risks as a result of increased manageability by experience of the company.

Step 4.1.3: Country risk assessment by considering controllable/given factors (contract clauses):

Finally, output of the previous step (Step 4.1.2) is combined with favorability of contract clauses and final country risk rating is obtained. For that, if... and then... rules (see 3.3.2 part) are applied. These rules are obtained from the expert judgement. The decision table is designed according to these rules (see Table 4.2). These rules are specified as follows:

- 1- If country risk is low and favorability of contract clauses is low then country risk rating is low,
- 2- If country risk is low and favorability of contract clauses is low-to-medium then country risk rating is low,
- 3- If country risk is low and favorability of contract clauses is medium then country risk rating is low,
- 4- If country risk is low and favorability of contract clauses is medium-to-high then country risk rating is low,
- 5- If country risk is low and favorability of contract clauses is high then country risk rating is low,

- 6- If country risk is low-to-medium and favorability of contract clauses is low then country risk rating is low-to-medium,
- 7- If country risk is low-to-medium and favorability of contract clauses is low-to-medium then country risk rating is low-to-medium,
- 8- If country risk is low-to-medium and favorability of contract clauses is medium then country risk rating is low-to-medium,
- 9- If country risk is low-to-medium and favorability of contract clauses is medium-to-high then country risk rating is low,
- 10- If country risk is low-to-medium and favorability of contract clauses is high then country risk rating is low,

- 11- If country risk is medium and favorability of contract clauses is low then country risk rating is medium,
- 12- If country risk is medium and favorability of contract clauses is low-to-medium then country risk rating is medium,
- 13- If country risk is medium and favorability of contract clauses is medium then country risk rating is medium,
- 14- If country risk is medium and favorability of contract clauses is medium-to-high then country risk rating is low-to-medium,
- 15- If country risk is medium and favorability of contract clauses is high then country risk rating is low,

- 16- If country risk is medium-to-high and favorability of contract clauses is low then country risk rating is medium-to-high,
- 17- If country risk is medium-to-high and favorability of contract clauses is low-to-medium then country risk rating is medium-to-high,
- 18- If country risk is medium-to-high and favorability of contract clauses is medium then country risk rating is medium-to-high,
- 19- If country risk is medium-to-high and favorability of contract clauses is medium-to-high then country risk rating is medium,
- 20- If country risk is medium-to-high and favorability of contract clauses is high then country risk rating is low-to-medium,

- 21- If country risk is high and favorability of contract clauses is low then country risk rating is high,
- 22- If country risk is high and favorability of contract clauses is low-to-medium then country risk rating is high,
- 23- If country risk is high and favorability of contract clauses is medium then country risk rating is high,
- 24- If country risk is high and favorability of contract clauses is medium-to-high then country risk rating is medium-to-high,

25- If country risk is high and favorability of contract clauses is high then country risk rating is medium (see Table 4.2).

Table 4.2: Decision Table for the *Final Country Risk Rating* Output

| | | Favorability of contract clauses | | | | |
|--------------|------------------------|----------------------------------|-----------------------|---------------|------------------------|-------------|
| | | Low (L) | Low-to-medium (LM) | Medium (M) | Medium-to-high (MH) | High (H) |
| Country risk | Low (L) | L | L | L | L | L |
| | Low-to-medium (LM) | LM | LM | LM | L | L |
| | Medium (M) | M | M | M | LM | L |
| | Medium-to-high (MH) | MH | MH | MH | M | LM |
| | High (H) | H | H | H | MH | M |

After combining these rules, outputs are obtained. The aggregation (see 3.3.3 part) of these factors give the membership function $\mu_{agg}(z)$ which is related with country risk rating. Then, to defuzzify the $\mu_{agg}(z)$, HDM(see 3.3.4 part) is used. The decision-maker is able to see the final country risk rating after defuzzification. Final country risk rating takes into account of all risk factors as well as the “controllability” of country risks as a result of increased manageability by experience of the company and favourable contract conditions (such as escalation due to cost increase as a result of country risk etc.) to mitigate risks.

4.3 Step 4.2: Project Risk Assessment

In the calculation of the project risk, there are 6 steps:

Step 4.2.1: Technical, productivity, resource and managerial risk assessment by considering only the risk factors:

In this part, technical risk, resource risk, productivity risk and managerial risk are calculated. In the calculation of technical risk, vagueness of construction methods/techniques and complexity are considered as independent of each other. For the productivity risk and resource risk calculation, poor planning and unavailability of resources are considered as independent of each other. Complexity and unavailability of resources are considered as independent of each other in the managerial risk calculation. The rules for each risk are specified as follows:

Rules for technical risk:

- 1- If risk due to “vagueness of construction methods/techniques” is low, technical risk is low,
- 2- If risk due to “vagueness of construction methods/techniques” is low-to-medium, technical risk is low-to-medium,
- 3- If risk due to “vagueness of construction methods/techniques” is medium, technical risk is medium,
- 4- If risk due to “vagueness of construction methods/techniques” is medium-to-high, technical risk is medium-to-high,
- 5- If risk due to “vagueness of construction methods/techniques” is high, technical risk is high,

- 6- If risk due to “complexity (technical +managerial)” is low, technical risk is low,

- 7- If risk due to “complexity (technical +managerial)” is low-to-medium, technical risk is low-to-medium,
- 8- If risk due to “complexity (technical +managerial)” is medium, technical risk is medium,
- 9- If risk due to “complexity (technical +managerial)” is medium-to-high, technical risk is medium-to-high,
- 10- If risk due to “complexity (technical +managerial)” is high, technical risk is high,

Rules for productivity risk:

- 1- If risk due to “poor planning” is low, productivity risk is low,
 - 2- If risk due to “poor planning” is low-to-medium, productivity risk is low-to-medium,
 - 3- If risk due to “poor planning” is medium, productivity risk is medium,
 - 4- If risk due to “poor planning” is medium-to-high, productivity risk is medium-to-high,
 - 5- If risk due to “poor planning” is high, productivity risk is high,
-
- 6- If risk due to “unavailability of resources” is low, productivity risk is low,
 - 7- If risk due to “unavailability of resources” is low-to-medium, productivity risk is low-to-medium,
 - 8- If risk due to “unavailability of resources” is medium, productivity risk is medium,
 - 9- If risk due to “unavailability of resources” is medium-to-high, productivity risk is medium-to-high,
 - 10- If risk due to “unavailability of resources” is high, productivity risk is high,

Rules for resource risk:

- 1- If risk due to “poor planning” is low, resource risk is low,

- 2- If risk due to “poor planning” is low-to-medium, resource risk is low-to-medium,
 - 3- If risk due to “poor planning” is medium, resource risk is medium,
 - 4- If risk due to “poor planning” is medium-to-high, resource risk is medium-to-high,
 - 5- If risk due to “poor planning” is high, resource risk is high,
-
- 6- If risk due to “unavailability of resources” is low, resource risk is low,
 - 7- If risk due to “unavailability of resources” is low-to-medium, resource risk is low-to-medium,
 - 8- If risk due to “unavailability of resources” is medium, resource risk is medium,
 - 9- If risk due to “unavailability of resources” is medium-to-high, resource risk is medium-to-high,
 - 10- If risk due to “unavailability of resources” is high, resource risk is high,

Rules for managerial risk:

- 1- If risk due to “complexity (technical +managerial)” is low, managerial risk is low,
 - 2- If risk due to “complexity (technical +managerial)” is low-to-medium, managerial risk is low-to-medium,
 - 3- If risk due to “complexity (technical +managerial)” is medium, managerial risk is medium,
 - 4- If risk due to “complexity (technical +managerial)” is medium-to-high, managerial risk is medium-to-high,
 - 5- If risk due to “complexity (technical +managerial)” is high, managerial risk is high,
-
- 6- If risk due to “unavailability of resources” is low, managerial risk is low,

- 7- If risk due to “unavailability of resources” is low-to-medium, managerial risk is low-to-medium,
- 8- If risk due to “unavailability of resources” is medium, managerial risk is medium,
- 9- If risk due to “unavailability of resources” is medium-to-high, managerial risk is medium-to-high,
- 10- If risk due to “unavailability of resources” is high, managerial risk is high,

These rules for technical risk, productivity risk, resource risk and managerial risk can not be claimed to be exact/objective rules, but they are developed according to expert opinion and literature survey.

After combining these rules for technical, productivity, resource and managerial risks, outputs for each of them are obtained. The aggregation (see 3.3.3 part) of these outputs will give the membership function $\mu_{agg}(z)$ result which is related with technical, productivity, resource and managerial risks respectively. Then, HDM (see 3.3.4 part) approach is used to defuzzify the $\mu_{agg}(z)$ of technical, productivity, resource and managerial risks respectively. Outputs of these risks are evaluated by HDM method. The decision-maker is able to see the quantifiable technical, productivity, resource and managerial risk ratings after process of defuzzification.

Step 4.2.2: Construction risk assessment by considering only technical, productivity, resource and managerial risks:

In this part, construction risk is calculated by combining technical, productivity, resource and managerial risks. In the calculation of construction risk, technical, productivity, resource and managerial risks are considered as independent of each other. The rules for construction risk are specified as follows:

- 1- If technical risk is low, construction risk is low,
- 2- If technical risk is low-to-medium, construction risk is low-to-medium,
- 3- If technical risk is medium, construction risk is medium,
- 4- If technical risk is medium-to-high, construction risk is medium-to-high,
- 5- If technical risk is high, construction risk is high,

- 6- If productivity risk is low, construction risk is low,
- 7- If productivity risk is low-to-medium, construction risk is low-to-medium,
- 8- If productivity risk is medium, construction risk is medium,
- 9- If productivity risk is medium-to-high, construction risk is medium-to-high,
- 10- If productivity risk is high, construction risk is high,

- 11- If resource risk is low, construction risk is low,
- 12- If resource risk is low-to-medium, construction risk is low-to-medium,
- 13- If resource risk is medium, construction risk is medium,
- 14- If resource risk is medium-to-high, construction risk is medium-to-high,
- 15- If resource risk is high, construction risk is high,

- 16- If managerial risk is low, construction risk is low,
- 17- If managerial risk is low-to-medium, construction risk is low-to-medium,
- 18- If managerial risk is medium, construction risk is medium,
- 19- If managerial risk is medium-to-high, construction risk is medium-to-high,
- 20- If managerial risk is high, construction risk is high,

These rules for construction risk can not be claimed to be exact/objective rules, but also they are developed according to expert opinion and literature survey.

After combining these rules, outputs are obtained again. The aggregation (see 3.3.3 part) of these outputs will give the membership function $\mu_{agg}(z)$ result which is related with construction risk rating. Then, to defuzzify the $\mu_{agg}(z)$, HDM approach (see 3.3.4 part) is used. Construction risk rating result is

calculated by the HDM method. At this stage, the decision-maker is able to see the construction risk rating after process of defuzzification.

Step 4.2.3: Construction risk assessment by considering controllable/given factors (experience in similar projects):

In this part output of the previous step is combined with experience in similar projects and final construction risk rating is obtained. For that, if... and then... rules (see 3.3.2 part) are applied. These rules are elicited from the expert judgement. The decision table is designed according to these rules (see Table 4.3). These rules are specified as follows:

- 1- If construction risk is low and experience of the company in similar projects is low then construction risk rating is low,
- 2- If construction risk is low and experience of the company in similar projects is low-to-medium then construction risk rating is low,
- 3- If construction risk is low and experience of the company in similar projects is medium then construction risk rating is low,
- 4- If construction risk is low and experience of the company in similar projects is medium-to-high then construction risk rating is low,
- 5- If construction risk is low and experience of the company in similar projects is high then construction risk rating is low,

- 6- If construction risk is low-to-medium and experience of the company in similar projects is low then construction risk rating is low-to-medium,
- 7- If construction risk is low-to-medium and experience of the company in similar projects is low-to-medium then construction risk rating is low-to-medium,
- 8- If construction risk is low-to-medium and experience of the company in similar projects is medium then construction risk rating is low-to-medium,

9- If construction risk is low-to-medium and experience of the company in similar projects is medium-to-high then construction risk rating is low,

10- If construction risk is low-to-medium and experience of the company in similar projects is high then construction risk rating is low,

11- If construction risk is medium and experience of the company in similar projects is low then construction risk rating is medium,

12- If construction risk is medium and experience of the company in similar projects is low-to-medium then construction risk rating is medium,

13- If construction risk is medium and experience of the company in similar projects is medium then construction risk rating is medium,

14- If construction risk is medium and experience of the company in similar projects is medium-to-high then construction risk rating is low-to-medium,

15- If construction risk is medium and experience of the company in similar projects is high then construction risk rating is low-to-medium,

16- If construction risk is medium-to-high and experience of the company in similar projects is low then construction risk rating is medium-to-high,

17- If construction risk is medium-to-high and experience of the company in similar projects is low-to-medium then construction risk rating is medium-to-high,

18- If construction risk is medium-to-high and experience of the company in similar projects is medium then construction risk rating is medium-to-high,

19- If construction risk is medium-to-high and experience of the company in similar projects is medium-to-high then construction risk rating is medium,

20- If construction risk is medium-to-high and experience of the company in similar projects is high then construction risk rating is medium,

21- If construction risk is high and experience of the company in similar projects is low then construction risk rating is high,

- 22- If construction risk is high and experience of the company in similar projects is low-to-medium then construction risk rating is high,
- 23- If construction risk is high and experience of the company in similar projects is medium then construction risk rating is high,
- 24- If construction risk is high and experience of the company in similar projects is medium-to-high then construction risk rating is high,
- 25- If construction risk is high and experience of the company in similar projects is high then construction risk rating is medium-to-high (see Table 4.3).

Table 4.3: Decision Table for the *Construction Risk Rating* Output

| | | Experience of the company in similar projects | | | | |
|-------------------|------------------------|---|-----------------------|---------------|------------------------|-------------|
| | | Low (L) | Low-to-medium (LM) | Medium (M) | Medium-to-high (MH) | High (H) |
| Construction risk | Low (L) | L | L | L | L | L |
| | Low-to-medium (LM) | LM | LM | LM | L | L |
| | Medium (M) | M | M | M | LM | LM |
| | Medium-to-high (MH) | MH | MH | MH | M | M |
| | High (H) | H | H | H | H | MH |

After combining these rules, outputs are obtained again. The aggregation (see 3.3.3 part) of these outputs will give the membership function $\mu_{agg}(z)$ result which is related with final construction risk rating. Then, to defuzzify the $\mu_{agg}(z)$, HDM approach (see 3.3.4 part) is used. Final construction risk rating result is calculated by the HDM method. The decision-maker is able to see the

quantifiable construction risk rating after defuzzification. But this time, new construction risk rating takes into account of the “controllability” of construction risks as a result of increased manageability by experience of the company in similar projects.

Step 4.2.4: Design, subcontractor, client and payment risk assessment by considering only the risk factors:

In this part, design risk, subcontractor risk, client risk and payment risk is calculated. In the calculation of design risk, vagueness of scope and poor design/design errors are considered as independent of each other. For the subcontractor risk, unavailability of subcontractor and poor performance of subcontractor are considered as independent of each other. Attitude of client and inexperience of client are considered as independent of each other in the client risk calculation. Delay in payments and unavailability of funds are considered as independent of each other. The rules for each risk are specified as follows:

Rules for design risk:

- 1- If risk due to “vagueness of scope” is low, design risk is low,
- 2- If risk due to “vagueness of scope” is low-to-medium, design risk is low-to-medium,
- 3- If risk due to “vagueness of scope” is medium, design risk is medium,
- 4- If risk due to “vagueness of scope” is medium-to-high, design risk is medium-to-high,
- 5- If risk due to “vagueness of scope” is high, design risk is high,

- 6- If risk due to “poor design/design errors” is low, design risk is low,

- 7- If risk due to “poor design/design errors” is low-to-medium, design risk is low-to-medium,
- 8- If risk due to “poor design/design errors” is medium, design risk is medium,
- 9- If risk due to “poor design/design errors” is medium-to-high, design risk is medium-to-high,
- 10- If risk due to “poor design/design errors” is high, design risk is high,

Rules for subcontractor risk:

- 1- If risk due to “unavailability of subcontractor” is low, subcontractor risk is low,
 - 2- If risk due to “unavailability of subcontractor” is low-to-medium, subcontractor risk is low-to-medium,
 - 3- If risk due to “unavailability of subcontractor” is medium, subcontractor risk is medium,
 - 4- If risk due to “unavailability of subcontractor” is medium-to-high, subcontractor risk is medium-to-high,
 - 5- If risk due to “unavailability of subcontractor” is high, subcontractor risk is high,
-
- 6- If risk due to “poor performance of subcontractor” is low, subcontractor risk is low,
 - 7- If risk due to “poor performance of subcontractor” is low-to-medium, subcontractor risk is low-to-medium,
 - 8- If risk due to “poor performance of subcontractor” is medium, subcontractor risk is medium,
 - 9- If risk due to “poor performance of subcontractor” is medium-to-high, subcontractor risk is medium-to-high,
 - 10- If risk due to “poor performance of subcontractor” is high, subcontractor risk is high,

Rules for client risk:

- 1- If risk due to “attitude of client” is low, client risk is low,
 - 2- If risk due to “attitude of client” is low-to-medium, client risk is low-to-medium,
 - 3- If risk due to “attitude of client” is medium, client risk is medium,
 - 4- If risk due to “attitude of client” is medium-to-high, client risk is medium-to-high,
 - 5- If risk due to “attitude of client” is high, client risk is high,
-
- 6- If risk due to “inexperience of client” is low, client risk is low,
 - 7- If risk due to “inexperience of client” is low-to-medium, client risk is low-to-medium,
 - 8- If risk due to “inexperience of client” is medium, client risk is medium,
 - 9- If risk due to “inexperience of client” is medium-to-high, client risk is medium-to-high,
 - 10- If risk due to “inexperience of client” is high, client risk is high,

Rules for payment risk:

- 1- If risk due to “delay in payment” is low, payment risk is low,
 - 2- If risk due to “delay in payment” is low-to-medium, payment risk is low-to-medium,
 - 3- If risk due to “delay in payment” is medium, payment risk is medium,
 - 4- If risk due to “delay in payment” is medium-to-high, payment risk is medium-to-high,
 - 5- If risk due to “delay in payment” is high, payment risk is high,
-
- 6- If risk due to “unavailability of funds” is low, payment risk is low,
 - 7- If risk due to “unavailability of funds” is low-to-medium, payment risk is low-to-medium,
 - 8- If risk due to “unavailability of funds” is medium, payment risk is medium,

9- If risk due to “unavailability of funds” is medium-to-high, payment risk is medium-to-high,

10- If risk due to “unavailability of funds” is high, payment risk is high,

However, these rules for design risk, subcontractor risk, client risk and payment risk can not be claimed to be exact/objective rules, but they are developed according to expert opinion and literature survey.

After combining these rules for design, subcontractor, client and payment risks, outputs for each of them are obtained. The aggregation (see 3.3.3 part) of these outputs will give the membership function $\mu_{agg}(z)$ result which is related with design, subcontractor, client and payment risks respectively. Then, HDM (see 3.3.4 part) is used to defuzzify the $\mu_{agg}(z)$ of design, subcontractor, client and payment risks respectively. Outputs of these risks are evaluated by HDM method. The decision-maker is able to see the quantifiable design, subcontractor, client and payment risk ratings after process of defuzzification.

Step 4.2.5: Project risk assessment by considering only construction, design, subcontractor, client and payment risks:

In this part, outputs of the previous step are combined with output of 4.2.3 step and project risk rating is obtained. Project risk is obtained by aggregation and defuzzification of final construction risk, design risk, client risk, subcontractor risk and payment risks. These risks are considered as independent of each other. These rules are specified as follows:

1- If final construction risk is low, project risk rating is low,

2- If final construction risk is low-to-medium, project risk rating is low-to-medium,

3- If final construction risk is medium, project risk rating is medium,

- 4- If final construction risk is medium-to-high, project risk rating is medium-to-high,
- 5- If final construction risk is high, project risk rating is high,

- 6- If design risk is low, project risk rating is low,
- 7- If design risk is low-to-medium, project risk rating is low-to-medium,
- 8- If design risk is medium, project risk rating is medium,
- 9- If design risk is medium-to-high, project risk rating is medium-to-high,
- 10- If design risk is high, project risk rating is high,

- 11- If client risk is low, project risk rating is low,
- 12- If client risk is low-to-medium, project risk rating is low-to-medium,
- 13- If client risk is medium, project risk rating is medium,
- 14- If client risk is medium-to-high, project risk rating is medium-to-high,
- 15- If client risk is high, project risk rating is high,

- 16- If subcontractor risk is low, project risk rating is low,
- 17- If subcontractor risk is low-to-medium, project risk rating is low-to-medium,
- 18- If subcontractor risk is medium, project risk rating is medium,
- 19- If subcontractor risk is medium-to-high, project risk rating is medium-to-high,
- 20- If subcontractor risk is high, project risk rating is high,

- 21- If payment risk is low, project risk rating is low,
- 22- If payment risk is low-to-medium, project risk rating is low-to-medium,
- 23- If payment risk is medium, project risk rating is medium,
- 24- If payment risk is medium-to-high, project risk rating is medium-to-high,
- 25- If payment risk is high, project risk rating is high,

Beside, these rules for project risk can not be claimed to be exact/objective rules, but they are developed according to expert opinion and literature survey.

After combining these rules, outputs are obtained again. The aggregation (see 3.3.3 part) of these outputs will give the membership function $\mu_{agg}(z)$ result which is related with project risk rating. Then, HDM (see 3.3.4 part) is used to defuzzify the $\mu_{agg}(z)$. Project risk rating result is calculated by the HDM method. The decision-maker is able to see the quantifiable project risk rating after process of defuzzification.

Step 4.2.6: Project risk assessment by considering controllable/given factors (availability of favorable contract clauses about project risk):

In this part, output of the previous step is combined with availability of favorable contract clauses (about project risk) and final project risk rating is obtained. For that, if... and then... rules (see 3.3.2 part) are applied. These rules are obtained from the expert judgement. The decision table is designed according to these rules (see Table 4.4). These rules are specified as follows:

- 1- If project risk is low and availability of favorable contract clauses (about project risk) is low then country risk rating is low,
- 2- If project risk is low and availability of favorable contract clauses (about project risk) is low-to-medium then country risk rating is low,
- 3- If project risk is low and availability of favorable contract clauses (about project risk) is medium then country risk rating is low,
- 4- If project risk is low and availability of favorable contract clauses (about project risk) is medium-to-high then country risk rating is low,
- 5- If project risk is low and availability of favorable contract clauses (about project risk) is high then country risk rating is low,

- 6- If project risk is low-to-medium and availability of favorable contract clauses (about project risk) is low then country risk rating is low-to-medium,
- 7- If project risk is low-to-medium and availability of favorable contract clauses (about project risk) is low-to-medium then country risk rating is low-to-medium,
- 8- If project risk is low-to-medium and availability of favorable contract clauses (about project risk) is medium then country risk rating is low-to-medium,
- 9- If project risk is low-to-medium and availability of favorable contract clauses (about project risk) is medium-to-high then country risk rating is low,
- 10- If project risk is low-to-medium and availability of favorable contract clauses (about project risk) is high then country risk rating is low,

- 11- If project risk is medium and availability of favorable contract clauses (about project risk) is low then country risk rating is medium,
- 12- If project risk is medium and availability of favorable contract clauses (about project risk) is low-to-medium then country risk rating is medium,
- 13- If project risk is medium and availability of favorable contract clauses (about project risk) is medium then country risk rating is medium,
- 14- If project risk is medium and availability of favorable contract clauses (about project risk) is medium-to-high then country risk rating is low-to-medium,
- 15- If project risk is medium and availability of favorable contract clauses (about project risk) is high then country risk rating is low,

- 16- If project risk is medium-to-high and availability of favorable contract clauses (about project risk) is low then country risk rating is medium-to-high,
- 17- If project risk is medium-to-high and availability of favorable contract clauses (about project risk) is low-to-medium then country risk rating is medium-to-high,

- 18- If project risk is medium-to-high and availability of favorable contract clauses (about project risk) is medium then country risk rating is medium-to-high,
- 19- If project risk is medium-to-high and availability of favorable contract clauses (about project risk) is medium-to-high then country risk rating is medium,
- 20- If project risk is medium-to-high and availability of favorable contract clauses (about project risk) is high then country risk rating is low-to-medium,
- 21- If project risk is high and availability of favorable contract clauses (about project risk) is low then country risk rating is high,
- 22- If project risk is high and availability of favorable contract clauses (about project risk) is low-to-medium then country risk rating is high,
- 23- If project risk is high and availability of favorable contract clauses (about project risk) is medium then country risk rating is high,
- 24- If project risk is high and availability of favorable contract clauses (about project risk) is medium-to-high then country risk rating is medium-to-high,
- 25- If project risk is high and availability of favorable contract clauses (about project risk) is high then country risk rating is medium (see Table 4.4)

Table 4.4: Decision Table for the *Final Project Risk Rating* Output

Availability of favorable contract clauses (about project risk)

| | | Low (L) | Low-to-medium (LM) | Medium (M) | Medium-to-high (MH) | High (H) |
|--------------|------------------------|------------|-----------------------|---------------|------------------------|-------------|
| Project risk | Low (L) | L | L | L | L | L |
| | Low-to-medium (LM) | LM | LM | LM | L | L |
| | Medium (M) | M | M | M | LM | L |
| | Medium-to-high (MH) | MH | MH | MH | M | LM |
| | High (H) | H | H | H | MH | M |

After combining these rules, outputs are obtained again. The aggregation (see 3.3.3 part) of these outputs will give the membership function $\mu_{agg}(z)$ result which is related with final project risk rating. Then, HDM (see 3.3.4 part) is used to defuzzify the $\mu_{agg}(z)$. Final project risk rating result is calculated by the HDM method. The decision maker is able to see the final project risk rating after defuzzification. Final project risk rating takes into account of all risk factors, risks as well as the “controllability” of project risks as result of favorable contract clauses about project risks (such as escalation due to cost increase as a result of project risk etc.) to alleviate risks.

4.4 Step 4.3: Cost Overrun Risk Assessment

Cost overrun risk rating is obtained by aggregation and defuzzification of final country risk rating and final project risk rating. These risk ratings are considered as independent of each other. Following rules are derived,

- 1- If final country risk rating is low, cost risk rating is low,
- 2- If final country risk rating is low-to-medium, cost risk rating is low-to-medium,
- 3- If final country risk rating is medium, cost risk rating is medium,
- 4- If final country risk rating is medium-to-high, cost risk rating is medium-to-high,
- 5- If final country risk rating is high, cost risk rating is high,

- 6- If final project risk rating is low, cost risk rating is low,
- 7- If final project risk rating is low-to-medium, cost risk rating is low-to-medium,
- 8- If final project risk rating is medium, cost risk rating is medium,
- 9- If final project risk rating is medium-to-high, cost risk rating is medium-to-high,
- 10- If final project risk rating is high, cost risk rating is high,

These rules for cost risk rating can not be claimed to be exact/objective rules, but they are developed according to expert opinion and literature survey.

After combining these rules, outputs are obtained. The aggregation (see 3.3.3 part) of these outputs gives the membership function $\mu_{agg}(z)$ which is related with cost risk rating. Then, HDM (see 3.3.4 part) is used to defuzzify the $\mu_{agg}(z)$. Finally, a quantifiable cost risk rating is found which may help the decision-maker to decide on the overall risk level of the project and further determine a reliable contingency in the light of this rating.

The aggregation and defuzzification calculations explained above can not be conducted without a computer support. Thus, a computer program is written by the author to simplify the process. The program is written in C++ programming language using Borland C++ 6.0.

4.5 Case Study

In order to test the reliability of the proposed fuzzy risk rating methodology, it is applied to a real case study. An interview has been conducted by the consultant of a foreign construction company conducting a hydropower plant project in Turkey. The consultant can be considered as an expert of international construction and has got significant information about country and project risks in this project. Construction company is an Austrian company which has extensive international construction activity all over the world. Before this project, they have conducted another project in Turkey and they are familiar with the risks in the Turkish construction industry as well as risks in dam construction projects.

The project is carried out on Çoruh River. The project covers the dam construction and hydroelectric power plant construction of the dam including necessary services and the supply and the erection of the relevant electromechanical equipments, hydraulic equipment and the cranes and the commissioning of the plant. The full financing of the work is secured by a Loan Agreement arranged by the consortium and is concluded between the Prime Ministry Undersecretariat of Treasury and a Consortium of Banks. The owner of the project is DSI (State Hydraulic Works). The project is carried out by the consortium group. Consortium members for civil works are two Turkish companies and an Austrian company. Group members for electromechanical works are three different Austrian companies. Responsibilities of the Austrian company for civil works are diversion tunnel underground works, spillway, power house, energy structures, grouting works, cutoff wall, galleries, shafts and road tunnel construction. The civil works are completed on the basis that 5 year 9 months (2100 calendar days) of total construction period, and in accordance with the work schedule. Moreover, payment method of this project is lump-sum. The contract prices of the civil works are as follows:

Two Turkish Companies: 78.115.300 USD

Austrian Company: 805.453.000 ATS ¹

In order to carry out the fuzzy risk rating project and run the computer program, expert is requested to provide the necessary information about risks in this project. The inputs received from the expert are given in Table 4.5.

¹ 1USD = 12,684 ATS

Table 4.5: Risk Information Input by the Expert

| | | |
|---|---|-------------|
| <i>Country risk</i> | | |
| Poor international relations | = | 2 |
| Instability of political condition | = | 8 |
| Poor attitude towards foreign companies | = | 5 |
| Unfavorableness of economic environment | = | 2 |
| Immaturity of legal system | = | 9 |
| Civil unrest | = | 6 |
| Cultural/religious differences | = | 4 |
| Experience in the country | = | 3 |
| <u>Favorability of contract clauses</u> | = | <u>1</u> |
| Country risk rating | = | 5.58 |
| | | |
| <i>Project risk</i> | | |
| Vagueness of construction methods/techniques | = | 7 |
| Complexity (technical+managerial) | = | 5 |
| Poor Planning | = | 6 |
| Unavailability of resources | = | 6 |
| Experience in similar projects | = | 9 |
| Vagueness of scope | = | 5 |
| Poor design/design errors | = | 4 |
| Unavailability of subcontractor | = | 7 |
| Poor performance of subcontractor | = | 5 |
| Attitude of client | = | 4 |
| Inexperience of client | = | 2 |
| Delay in payments | = | 9 |
| Unavailability of funds | = | 1 |
| Availability of favorable contract clauses (about project risk) | = | 1 |
| <u>Project risk rating</u> | = | <u>4.61</u> |
| | | |
| <i>Cost risk</i> | | |
| Country risk rating | = | 5.58 |
| <u>Project risk rating</u> | = | <u>4.61</u> |
| Cost risk rating | = | 5.16 |

4.6 Discussion

In the calculation of country risk rating, the risk due to “instability of political condition” and risk due to “immaturity of legal system” are high and also experience of the company in the country and favorability of contract clauses are low. Nevertheless, country risk is obtained as medium, since risk due to “poor international relations”, “unfavorableness of economic environment” is low and risk due to “cultural/religious differences” is low to medium. These factors alleviate the country risk rating.

When the calculation of project risk is taken into account, controllable factor such as availability of favorable contract clauses is low and the risk due to “delay in payments” is high. Also, the risk due to “vagueness of construction methods/techniques” and “unavailability of subcontractor” are medium to high. But, project risk is elicited as approximately medium, because the risk due to “unavailability of funds” and “inexperience of client” is low and also the controllable factor such as experience in similar project is high, and these factors decrease the project risk rating.

Thus, cost risk for this company for the project in Turkey is obtained as medium risk.

Expert said that his expected cost risk rating is between 5 and 6. Thus, the risk rating procedure can be claimed to produce an acceptable result. Codes of this program are given in Appendix A.

Screen shots of the software are presented below to demonstrate the inputs and outputs of the case study (see Fig. 4.6, Fig. 4.7 and Fig. 4.8).

| | |
|--|--------------------------------|
| Poor international relations: | <input type="text" value="2"/> |
| Immaturity of legal system: | <input type="text" value="8"/> |
| Instability of political condition: | <input type="text" value="5"/> |
| Unfavorableness of economic environment: | <input type="text" value="2"/> |
| Poor attitude towards foreign companies: | <input type="text" value="9"/> |
| Cultural/religious differences: | <input type="text" value="6"/> |
| Civil unrest: | <input type="text" value="4"/> |

| | |
|--|---|
| <input type="button" value="Defuzzify"/> | |
| Country risk: | <input type="text" value="5,55555555555556"/> |
| Experience in the country: | <input type="text" value="3"/> |

| | |
|--|---|
| <input type="button" value="Defuzzify"/> | |
| Country risk: | <input type="text" value="5,55555555555556"/> |
| Favorability of contract clauses: | <input type="text" value="1"/> |

| | |
|--|---|
| <input type="button" value="Defuzzify"/> | |
| Country risk: | <input type="text" value="5,58823529411765"/> |

Figure 4.6: Country Risk Rating

| | | | |
|---|-----------|--|--|
| Vagueness of construction techniques/methods: <input type="text" value="7"/> Complexity (technical + managerial): <input type="text" value="5"/> Unavailability of resources: <input type="text" value="6"/> Poor planning: <input type="text" value="6"/> | Defuzzify | Technical risk: <input type="text" value="6"/> Managerial risk: <input type="text" value="5.66666"/> Resource risk: <input type="text" value="6"/> Productivity risk: <input type="text" value="6"/> Construction risk: <input type="text" value="5.85714"/> | |
| Experience in similar projects: <input type="text" value="9"/> | Defuzzify | Final construction risk: <input type="text" value="3.85714"/> | Defuzzify |
| Vagueness of scope: <input type="text" value="5"/> Poor design/Design errors: <input type="text" value="4"/> | Defuzzify | Design risk: <input type="text" value="4.33333"/> | Project risk: <input type="text" value="4.68421"/> |
| Unavailability of funds: <input type="text" value="1"/> Delay in payments: <input type="text" value="9"/> | Defuzzify | Payment risk: <input type="text" value="5"/> | Availability of favorable contract clauses(about project risk): <input type="text" value="1"/> |
| Attitude of client: <input type="text" value="4"/> Inexperience of client: <input type="text" value="2"/> | Defuzzify | Client risk: <input type="text" value="3.25"/> | Defuzzify |
| Unavailability of subcontractor: <input type="text" value="7"/> Poor performance of subcontractor: <input type="text" value="5"/> | Defuzzify | Subcontractor risk: <input type="text" value="6"/> | Final project risk: <input type="text" value="4.61702"/> |
| | | | Next |

Figure 4.7: Project Risk Rating

| |
|---|
| Final country risk: <input type="text" value="5.58823529"/> |
| Final project risk: <input type="text" value="4.61702127"/> |
| Defuzzify |
| Cost risk: <input type="text" value="5.15860735"/> |

Figure 4.8: Cost Risk Rating

CHAPTER V

CONCLUSION

5.1 Conclusion

Risk management is an important project management activity for the success of construction projects. Risk management activities, namely, risk identification, analysis and response, should be carried out systematically so that an optimum risk-reward structure can be maintained in a construction project and necessary risk response strategies may be developed before risk happen. Different risk identification and analysis tools are used at different stages of a construction project by different parties. One of the risk analysis tools that may be used to quantify risk impacts is fuzzy risk rating technique. In this thesis, a fuzzy risk rating approach has been used to quantify cost overrun risk in international construction projects. For this purpose, a risk model has been constructed by using influence diagramming method and software has been developed to carry out fuzzy number calculations as a decision support tool for decision makers during the bidding stage of international projects.

The reason why fuzzy set theory has been selected as the reliable analysis technique is that, it may handle the subjectivity which resides during risk assessment of international construction projects. Fuzzy set theory is used as a basis for developing more useful models in operations research and management science such as investment advisory models, pest management,

inventory control models [37]. Moreover, it can be applied to systems that are naturally vague such as those in the behavioral and social sciences. While other approaches require accurate equations to model real-world behaviors, fuzzy set theory can accommodate the ambiguities of human languages and logics. It provides both an intuitive method for describing systems in human terms and automates the conversion of those system specifications into effective models. Fuzzy set theory is able to quickly express the control structure of a system using priori knowledge, and is less dependent on the availability of a precise mathematical model. Moreover, it can handle multiple inputs easily and quantify more realistically the classical problem analysis. On the other hand, priori knowledge is required. Therefore, if a case is missed, the fuzzy logic controller will not work properly. Fuzzy-logic rules and their interactions depend on the expertise. In other words, scientifically established mathematical models are not used to determine the rules and interactions. Thus, a fuzzy rating tool has been developed for international risk assessment rather than an accurate mathematical model and expert judgments and priori knowledge have been used instead of probabilistic reasoning.

There are major benefits of the proposed methodology and software. First, the risk model constructed by using influence diagramming method can help construction professionals in the identification of risks in international projects. Second, by using the software, a decision-maker may enter the required input related with project, country and company information and without making complex calculations, output, which is the risk rating, is obtained. According to the risk rating, decision-maker may select the right projects and determine an appropriate risk premium.

However, there are some shortcomings of the research. There exist some assumptions made during model and software development which increase subjectivity of the proposed tools. Although, risk sources in the risk model and

fuzzy rules are based on expert judgement and literature survey findings, it is clear that a completely different model may be proposed by other researchers based on different expert opinions. For instance, there are some fuzzy rules specified in this approach. These rules differ from people to people. For example, how the magnitude of risk changes with the given conditions such as contract conditions, experience etc. has been defined by fuzzy rules which may vary according to different expert judgement. In addition to assumptions related with these fuzzy rules, there are assumptions related with membership functions. Different membership functions may be used by different experts. For example, a “high” linguistic variable may start from 8 instead of 7, or these linguistic variables may be represented by trapezoidal numbers instead of triangular numbers. Moreover, defuzzification method can change. For example, other methods such as center of area method can be used for the defuzzification process or all defuzzification methods can be applied and the mean value of the outputs of those models may be accepted as the output. Briefly, this study is not applicable for all cases and it does not reflect all expert judgements. Thus, the proposed methodology and corresponding software should not be treated as universally accepted tools applicable for all cost overrun risk rating problems, rather, they should be considered as examples of how fuzzy risk rating may be used during risk analysis in construction projects.

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APPENDICES

A. CODES OF THE PROGRAM

```
//-----  
-----  
#pragma hdrstop  
#include "Unit2.h"  
#include "Unit3.h"  
#include "Unit5.h"  
  
//-----  
-----  
  
#pragma package(smart_init)  
  
#include <stdlib.h>  
#include <iostream>  
#include "Graphs.h"  
#include <Windows.h>  
#include <vector>  
  
using namespace std;  
  
#define MIN(x, y) (x < y ? x : y)  
//clear screen  
int clrscr();
```

```

//max of double values
double max4(double y1, double y2, double y3, double y4);

//max of double values
double max5(double y1, double y2, double y3, double y4, double y5);

//max of double values
double max8(double y1, double y2, double y3, double y4, double y5, double
y6, double y7, double y8);
//max of double values
double max7(double y1, double y2, double y3, double y4, double y5, double
y6, double y7);

//max of double value
double maxVector(std::vector<double> yValues);

//matrix compare
double* minFunction(double* yc, double* yfactor);

double
countryRisk(double xpi,double xpc,double xpatc,double xuoe, double
xils,double xsc,double xcrd)
{double limit = 10;
//the graph
Graph* g = new Graph(3, 1, 5, 3, 7, 5, 9, 7, limit);
//double xpi, xpc, xpatc, xuoe, xils, xsc, xcrd;
double *ypi, *ypc, *ypatc, *yuoe, *yils, *ysc, *ycrd;
//get the 5 y values from each
ypi = g->getYValues(xpi);
ypc = g->getYValues(xpc);
ypatc = g->getYValues(xpatc);

```

```

yuoe = g->getYValues(xuoe);
yils = g->getYValues(xils);
ysc = g->getYValues(xsc);
ycrd = g->getYValues(xcrd);

//get their maximum's to get the 5 y values for country risk
double maxOfY[5];
maxOfY[0] = max7(ypi[0], ypc[0], ypatc[0], yuoe[0],yils[0], ysc[0],ycrd[0]);
maxOfY[1] = max7(ypi[1], ypc[1], ypatc[1], yuoe[1],yils[1], ysc[1],ycrd[1]);
maxOfY[2] = max7(ypi[2], ypc[2], ypatc[2], yuoe[2],yils[2], ysc[2],ycrd[2]);
maxOfY[3] = max7(ypi[3], ypc[3], ypatc[3], yuoe[3],yils[3], ysc[3],ycrd[3]);
maxOfY[4] = max7(ypi[4], ypc[4], ypatc[4], yuoe[4],yils[4], ysc[4],ycrd[4]);

//get 10 x values which correspond to the 5 y values
double* xab;
xab = g->getXValues(maxOfY);

//the risks entered by the user
//double xd, xsub, xcl, xrs, xpay, xpr, xcon, xtech;

//now calculate Xcr1 from these xab's and 5 y values
//Country Risk

double Xcr1 = (maxOfY[0] * (xab[0] + xab[1]) / 2.0 + maxOfY[1] * (xab[2] +
xab[3]) / 2.0 + maxOfY[2] * (xab[4] + xab[5]) / 2.0 +
maxOfY[3] * (xab[6] + xab[7]) / 2.0 + maxOfY[4] * (xab[8] +
xab[9]) / 2.0) / (maxOfY[0] + maxOfY[1] + maxOfY[2] +
maxOfY[3] + maxOfY[4]);

//cout<<endl;
//cout<<"Xcr1="<<Xcr1<<endl;
return Xcr1;}

```

```

double
countryRisk2(double Xcr1,double xExprienceInC)
{double limit = 10;
Graph* g = new Graph(3, 1, 5, 3, 7, 5, 9, 7, limit);
//get 5 values for XCr1
double* Ycr1 = g->getYValues(Xcr1);

//get 5 values for xExprienceInC
double* yExprienceInC = g->getYValues(xExprienceInC);
int matrix1[5][5]={{ 1,1,1,1,1},{2,2,2,1,1},{3,3,3,2,2},{4,4,4,3,3},{5,5,5,5,4}};
std::vector<double> yMatrix[6];

int i;
for(i=0;i<5;++i)
cout<<"Country Risk Y"<<i+1<<" = "<<Ycr1[i]<<"\n";
for(i=0;i<5;++i)
cout<<"Exprience in Country Y"<<i+1<<" = "<<yExprienceInC[i]<<"\n";

for(i=0;i<5;i++)
{cout<<"\n";
for(int j=0;j<5;j++)
{if(Ycr1[i]<=yExprienceInC[j])
{yMatrix[matrix1[i][j]].push_back(Ycr1[i]);cout<<Ycr1[i]<<" ";}
else
{yMatrix[matrix1[i][j]].push_back(yExprienceInC[j]);
cout<<yExprienceInC[j]<<" ";}}

cout<<endl;
cout<<"Maximum Y's are"<<"\n";
double yMaxs[5];
for(i=1;i<=5;++i)

```

```

{yMaxs[i-1]=maxVector(yMatrix[i]);
cout<<"Y"<<i<<"max = "<<yMaxs[i-1]<<"\n";}
cout<<endl;

double *Xcrab2;
Xcrab2= g->getXValues(yMaxs);

double Xcr2 = (yMaxs[0] * (Xcrab2[0] + Xcrab2[1]) / 2.0 + yMaxs[1] *
              (Xcrab2[2] + Xcrab2[3]) / 2.0 + yMaxs[2] * (Xcrab2[4] +
              Xcrab2[5]) / 2.0 + yMaxs[3] * (Xcrab2[6] + Xcrab2[7]) / 2.0 +
              yMaxs[4] * (Xcrab2[8] + Xcrab2[9]) / 2.0) / (yMaxs[0] +
              yMaxs[1] + yMaxs[2] + yMaxs[3] + yMaxs[4]);

return Xcr2;
//cout<<endl<<"Xcr2="<<Xcr2<<endl;}

double
countryRisk3(double Xcr2,double xfcc)
{int
matrix1[5][5]={{ 1,1,1,1,1},{2,2,2,1,1},{3,3,3,2,2},{4,4,4,3,3},{5,5,5,5,4}};
double yMaxs[5];
int i;
double limit = 10;
Graph* g = new Graph(3, 1, 5, 3, 7, 5, 9, 7, limit);

double* Ycr2 = g->getYValues(Xcr2);
//get 5 values for xfcc
double* Yxfcc = g->getYValues(xfcc);

/--MATRIX 2
//int
matrix2[5][5]={{ 1,1,1,1,1},{2,2,2,1,1},{3,3,3,2,1},{4,4,4,3,2},{5,5,5,4,3}};

```

```

std::vector<double> yMatrix2[6];

for(i=0;i<5;++i)
cout<<"Country Risk2 Y"<<i+1<<" = "<<Ycr2[i]<<"\n";
for(i=0;i<5;++i)
cout<<"Favourability of CC. Y"<<i+1<<" = "<<Yxfcc[i]<<"\n";

for(i=0;i<5;i++)
{cout<<"\n";
for(int j=0;j<5;j++)
{if(Ycr2[i]<=Yxfcc[j])
{yMatrix2[matrix1[i][j]].push_back(Ycr2[i]);cout<<Ycr2[i]<<" ";}
else
{yMatrix2[matrix1[i][j]].push_back(Yxfcc[j]);cout<<Yxfcc[j]<<" "}}}

cout<<endl;
cout<<"Maximum Y's are"<<"\n";

//double yMaxs[5];
for(i=1;i<=5;++i)
{yMaxs[i-1]=maxVector(yMatrix2[i]);
cout<<"Y"<<i<<"max ="<<yMaxs[i-1]<<"\n";}
cout<<endl;

double *Xfinalcr;
Xfinalcr= g->getXValues(yMaxs);
double Xfinal = (yMaxs[0] * (Xfinalcr[0] + Xfinalcr[1]) / 2.0 + yMaxs[1] *
(Xfinalcr[2] + Xfinalcr[3]) / 2.0 + yMaxs[2] * (Xfinalcr[4] +
Xfinalcr[5]) / 2.0 + yMaxs[3] * (Xfinalcr[6] + Xfinalcr[7]) /
2.0 + yMaxs[4] * (Xfinalcr[8] + Xfinalcr[9]) / 2.0) /
(yMaxs[0] + yMaxs[1] + yMaxs[2] + yMaxs[3] + yMaxs[4]);

```

```

return Xfinal;}

void function1(){
Graph* g = new Graph(3, 1, 5, 3, 7, 5, 9, 7, 10);
Form3->xvctm = Form3->Edit1->Text.ToDouble();;
Form3->xcmp = Form3->Edit2->Text.ToDouble();;

//double xpi, xpc, xpatc, xuoe, xils, xsc, xcrd;
double *yvctm, *ycmp;
//get the 5 y values from each
yvctm = g->getYValues(Form3->xvctm);
ycmp = g->getYValues(Form3->xcmp);

//get their maximum's to get the 5 y values for country risk
double maxOfY[5];
maxOfY[0] = MAX(yvctm[0], ycmp[0]);
maxOfY[1] = MAX(yvctm[1], ycmp[1]);
maxOfY[2] = MAX(yvctm[2], ycmp[2]);
maxOfY[3] = MAX(yvctm[3], ycmp[3]);
maxOfY[4] = MAX(yvctm[4], ycmp[4]);

//get 10 x values which correspond to the 5 y values
double* xab;
xab = g->getXValues(maxOfY);

//the risks entered by the user
//double xd, xsub, xcl, xrs, xpay, xpr, xcon, xtech;
//now calculate Xcr1 from these xab's and 5 y values
//Country Risk

```



```

double Xtr = (maxOfY[0] * (xab[0] + xab[1]) / 2.0 + maxOfY[1] * (xab[2] +
             xab[3]) / 2.0 + maxOfY[2] * (xab[4] + xab[5]) / 2.0 +
             maxOfY[3] * (xab[6] + xab[7]) / 2.0 + maxOfY[4] * (xab[8] +
             xab[9]) / 2.0) / (maxOfY[0] + maxOfY[1] + maxOfY[2] +
             maxOfY[3] + maxOfY[4]);

```

```

Form3->Edit5->Text = FloatToStr(Xtr);
Form3->xpp = Form3->Edit4->Text.ToDouble();
Form3->xus = Form3->Edit3->Text.ToDouble();

```

```

//double xpi, xpc, xpatc, xuoe, xils, xsc, xcrd;
double *ypp, *yus;
//get the 5 y values from each
ypp = g->getYValues(Form3->xpp);
yus = g->getYValues(Form3->xus);

//get their maximum's to get the 5 y values for country risk
//double maxOfY[5];
maxOfY[0] = MAX(ypp[0], yus[0]);
maxOfY[1] = MAX(ypp[1], yus[1]);
maxOfY[2] = MAX(ypp[2], yus[2]);
maxOfY[3] = MAX(ypp[3], yus[3]);
maxOfY[4] = MAX(ypp[4], yus[4]);

//get 10 x values which correspond to the 5 y values
//double* xab;
xab = g->getXValues(maxOfY);

//the risks entered by the user
//double xd, xsub, xcl, xrs, xpay, xpr, xcon, xtech;
//now calculate Xcr1 from these xab's and 5 y values

```

```

//Country Risk

double Xpror = (maxOfY[0] * (xab[0] + xab[1]) / 2.0 + maxOfY[1] * (xab[2] +
    xab[3]) / 2.0 + maxOfY[2] * (xab[4] + xab[5]) / 2.0 +
    maxOfY[3] * (xab[6] + xab[7]) / 2.0 + maxOfY[4] * (xab[8] +
    xab[9]) / 2.0) / (maxOfY[0] + maxOfY[1] + maxOfY[2] +
    maxOfY[3] + maxOfY[4]);

Form3->Edit8->Text = FloatToStr(Xpror);
double Xresr = Xpror;
Form3->Edit7->Text = FloatToStr(Xresr);
//manag. risk
//get their maximum's to get the 5 y values for country risk
//double maxOfY[5];
maxOfY[0] = MAX(ycmp[0], yus[0]);
maxOfY[1] = MAX(ycmp[1], yus[1]);
maxOfY[2] = MAX(ycmp[2], yus[2]);
maxOfY[3] = MAX(ycmp[3], yus[3]);
maxOfY[4] = MAX(ycmp[4], yus[4]);

//get 10 x values which correspond to the 5 y values
//double* xab;
xab = g->getXValues(maxOfY);

//the risks entered by the user
//double xd, xsub, xcl, xrs, xpay, xpr, xcon, xtech;
//now calculate Xcr1 from these xab's and 5 y values
//Country Risk

```

```

double Xmanr = (maxOfY[0] * (xab[0] + xab[1]) / 2.0 + maxOfY[1] * (xab[2]
+ xab[3]) / 2.0 + maxOfY[2] * (xab[4] + xab[5]) / 2.0 +
maxOfY[3] * (xab[6] + xab[7]) / 2.0 + maxOfY[4] * (xab[8] +
xab[9]) / 2.0) / (maxOfY[0] + maxOfY[1] + maxOfY[2] +
maxOfY[3] + maxOfY[4]);

```

```

Form3->Edit6->Text = FloatToStr(Xmanr);

```

```

//double xpi, xpc, xpatc, xuoe, xils, xsc, xcrd;
double *ytr, *yrr, *ypr, *ymr;
//get the 5 y values from each
ytr = g->getYValues(Xtr);
yrr = g->getYValues(Xresr);
ymr = g->getYValues(Xmanr);
ypr = g->getYValues(Xpror);

//get their maximum's to get the 5 y values for country risk
//double maxOfY[5];
maxOfY[0] = max4(ytr[0], yrr[0], ymr[0], ypr[0]);
maxOfY[1] = max4(ytr[1], yrr[1], ymr[1], ypr[1]);
maxOfY[2] = max4(ytr[2], yrr[2], ymr[2], ypr[2]);
maxOfY[3] = max4(ytr[3], yrr[3], ymr[3], ypr[3]);
maxOfY[4] = max4(ytr[4], yrr[4], ymr[4], ypr[4]);

//get 10 x values which correspond to the 5 y values
//double* xab;
xab = g->getXValues(maxOfY);
//the risks entered by the user
//double xd, xsub, xcl, xrs, xpay, xpr, xcon, xtech;

//now calculate Xcr1 from these xab's and 5 y values

```

```

//Country Risk
double Xcrr1 = (maxOfY[0] * (xab[0] + xab[1]) / 2.0 + maxOfY[1] * (xab[2] +
                xab[3]) / 2.0 + maxOfY[2] * (xab[4] + xab[5]) / 2.0 +
                maxOfY[3] * (xab[6] + xab[7]) / 2.0 + maxOfY[4] * (xab[8] +
                xab[9]) / 2.0) / (maxOfY[0] + maxOfY[1] + maxOfY[2] +
                maxOfY[3] + maxOfY[4]);

Form3->Edit26->Text = FloatToStr(Xcrr1);}
void function2(){ Graph* g = new Graph(3, 1, 5, 3, 7, 5, 9, 7, 10);
double Xcrr1 = Form3->Edit26->Text.ToDouble();
//y values for xccr1
double *Ycrr1 = g->getYValues(Xcrr1);
//double xexp;
xexp = Form3->Edit21->Text.ToDouble();
//double xpi, xpc, xpatc, xuoe, xils, xsc, xcrd;
double *yexp;
//get the 5 y values from each
yexp = g->getYValues(xexp);
int matrix3[5][5]={{ 1,1,1,1,1 },{ 2,2,2,1,1 },{ 3,3,3,2,2 },{ 4,4,4,3,3 },{ 5,5,5,4,4 }};
std::vector<double> yMatrix3[6];
for(int i=0;i<5;i++)
{for(int j=0;j<5;j++)
{if(Ycrr1[i]<=yexp[j])
{yMatrix3[matrix3[i][j]].push_back(Ycrr1[i]);}
else
{yMatrix3[matrix3[i][j]].push_back(yexp[j]);}}}

double yMaxs[5];
for(int i=1;i<=5;++i)
{yMaxs[i-1]=maxVector(yMatrix3[i]);}

```

```

double* xab;
xab = g->getXValues(yMaxs);

//the risks entered by the user
//double xd, xsub, xcl, xrs, xpay, xpr, xcon, xtech;

//now calculate Xcr1 from these xab's and 5 y values
//Country Risk
double Xfcr = (yMaxs[0] * (xab[0] + xab[1]) / 2.0 + yMaxs[1] * (xab[2] +
                xab[3]) / 2.0 + yMaxs[2] * (xab[4] + xab[5]) / 2.0 + yMaxs[3] *
                (xab[6] + xab[7]) / 2.0 + yMaxs[4] * (xab[8] + xab[9]) / 2.0) /
                (yMaxs[0] + yMaxs[1] + yMaxs[2] + yMaxs[3] + yMaxs[4]);

Form3->Edit22->Text = FloatToStr(Xfcr);}

void function3(){
Graph* g = new Graph(3, 1, 5, 3, 7, 5, 9, 7, 10);
double xvsc;
xvsc = Form3->Edit9->Text.ToDouble();

double xppd;
xppd = Form3->Edit10->Text.ToDouble();

//double xpi, xpc, xpatc, xuoe, xils, xsc, xcrd;
double *yvsc, *yppd;
//get the 5 y values from each
yvsc = g->getYValues(xvsc);
yppd = g->getYValues(xppd);

//get their maximum's to get the 5 y values for country risk
double maxOfY[5];

```

```

maxOfY[0] = MAX(yvsc[0], yppd[0]);
maxOfY[1] = MAX(yvsc[1], yppd[1]);
maxOfY[2] = MAX(yvsc[2], yppd[2]);
maxOfY[3] = MAX(yvsc[3], yppd[3]);
maxOfY[4] = MAX(yvsc[4], yppd[4]);

//get 10 x values which correspond to the 5 y values
double* xab;
xab = g->getXValues(maxOfY);

//the risks entered by the user
//double xd, xsub, xcl, xrs, xpay, xpr, xcon, xtech;

//now calculate Xcr1 from these xab's and 5 y values
//Country Risk
double Xdesr = (maxOfY[0] * (xab[0] + xab[1]) / 2.0 + maxOfY[1] * (xab[2] +
    xab[3]) / 2.0 + maxOfY[2] * (xab[4] + xab[5]) / 2.0 +
    maxOfY[3] * (xab[6] + xab[7]) / 2.0 + maxOfY[4] * (xab[8] +
    xab[9]) / 2.0) / (maxOfY[0] + maxOfY[1] + maxOfY[2] +
    maxOfY[3] +maxOfY[4]);

Form3->Edit11->Text = FloatToStr(Xdesr);}

void function4(){
Graph* g = new Graph(3, 1, 5, 3, 7, 5, 9, 7, 10);
double xunf;
xunf = Form3->Edit12->Text.ToDouble();
double xdelp;
xdelp = Form3->Edit13->Text.ToDouble();

//double xpi, xpc, xpatc, xuoe, xils, xsc, xcrd;

```

```

double *yunf, *ydelp;
//get the 5 y values from each
yunf = g->getYValues(xunf);
ydelp = g->getYValues(xdelp);

//get their maximum's to get the 5 y values for country risk
double maxOfY[5];
maxOfY[0] = MAX(yunf[0], ydelp[0]);
maxOfY[1] = MAX(yunf[1], ydelp[1]);
maxOfY[2] = MAX(yunf[2], ydelp[2]);
maxOfY[3] = MAX(yunf[3], ydelp[3]);
maxOfY[4] = MAX(yunf[4], ydelp[4]);

//get 10 x values which correspond to the 5 y values
double* xab;
xab = g->getXValues(maxOfY);

//the risks entered by the user
//double xd, xsub, xcl, xrs, xpay, xpr, xcon, xtech;

//now calculate Xcr1 from these xab's and 5 y values
//Country Risk
double Xpayr = (maxOfY[0] * (xab[0] + xab[1]) / 2.0 + maxOfY[1] * (xab[2]
+ xab[3]) / 2.0 + maxOfY[2] * (xab[4] + xab[5]) / 2.0 +
maxOfY[3] * (xab[6] + xab[7]) / 2.0 + maxOfY[4] * (xab[8] +
xab[9]) / 2.0) / (maxOfY[0] + maxOfY[1] + maxOfY[2] +
maxOfY[3] + maxOfY[4]);

Form3->Edit14->Text = FloatToStr(Xpayr);}

void function5(){

```

```

Graph* g = new Graph(3, 1, 5, 3, 7, 5, 9, 7, 10);
double xattc;
xattc = Form3->Edit15->Text.ToDouble();

double xinexpc;
xinexpc = Form3->Edit16->Text.ToDouble();

//double xpi, xpc, xpatc, xuoe, xils, xsc, xcrd;
double *yattc, *yinexpc;
//get the 5 y values from each
yattc = g->getYValues(xattc);
yinexpc = g->getYValues(xinexpc);

//get their maximum's to get the 5 y values for country risk
double maxOfY[5];
maxOfY[0] = MAX(yattc[0], yinexpc[0]);
maxOfY[1] = MAX(yattc[1], yinexpc[1]);
maxOfY[2] = MAX(yattc[2], yinexpc[2]);
maxOfY[3] = MAX(yattc[3], yinexpc[3]);
maxOfY[4] = MAX(yattc[4], yinexpc[4]);

//get 10 x values which correspond to the 5 y values
double* xab;
xab = g->getXValues(maxOfY);

//the risks entered by the user
//double xd, xsub, xcl, xrs, xpay, xpr, xcon, xtech;
//now calculate Xcr1 from these xab's and 5 y values
//Country Risk

```



```

double Xclr = (maxOfY[0] * (xab[0] + xab[1]) / 2.0 + maxOfY[1] * (xab[2] +
                xab[3]) / 2.0 + maxOfY[2] * (xab[4] + xab[5]) / 2.0 +
                maxOfY[3] * (xab[6] + xab[7]) / 2.0 + maxOfY[4] * (xab[8] +
                xab[9]) / 2.0) / (maxOfY[0] + maxOfY[1] + maxOfY[2] +
                maxOfY[3] + maxOfY[4]);

```

```

Form3->Edit17->Text = FloatToStr(Xclr);}

```

```

void function6(){

```

```

Graph* g = new Graph(3, 1, 5, 3, 7, 5, 9, 7, 10);

```

```

double xunsc;

```

```

xunsc = Form3->Edit18->Text.ToDouble();

```

```

double xppsc;

```

```

xppsc = Form3->Edit19->Text.ToDouble();

```

```

//double xpi, xpc, xpatc, xuoe, xils, xsc, xcrd;

```

```

double *yunsc, *yppsc;

```

```

//get the 5 y values from each

```

```

yunsc = g->getYValues(xunsc);

```

```

yppsc = g->getYValues(xppsc);

```

```

//get their maximum's to get the 5 y values for country risk

```

```

double maxOfY[5];

```

```

maxOfY[0] = MAX(yunsc[0], yppsc[0]);

```

```

maxOfY[1] = MAX(yunsc[1], yppsc[1]);

```

```

maxOfY[2] = MAX(yunsc[2], yppsc[2]);

```

```

maxOfY[3] = MAX(yunsc[3], yppsc[3]);

```

```

maxOfY[4] = MAX(yunsc[4], yppsc[4]);

```

```

//get 10 x values which correspond to the 5 y values
double* xab;
xab = g->getXValues(maxOfY);

//the risks entered by the user
//double xd, xsub, xcl, xrs, xpay, xpr, xcon, xtech;

//now calculate Xscr1 from these xab's and 5 y values
//Country Risk
double Xscr = (maxOfY[0] * (xab[0] + xab[1]) / 2.0 + maxOfY[1] * (xab[2] +
xab[3]) / 2.0 + maxOfY[2] * (xab[4] + xab[5]) / 2.0 +
maxOfY[3] * (xab[6] + xab[7]) / 2.0 + maxOfY[4] * (xab[8] +
xab[9]) / 2.0) / (maxOfY[0] + maxOfY[1] + maxOfY[2] +
maxOfY[3] + maxOfY[4]);

Form3->Edit20->Text = FloatToStr(Xscr);}

void function7(){
Graph* g = new Graph(3, 1, 5, 3, 7, 5, 9, 7, 10);

//double xpi, xpc, xpatc, xuoe, xils, xsc, xcrd;
double Xfcr = Form3->Edit22->Text.ToDouble();
double Xdesr = Form3->Edit11->Text.ToDouble();
double Xpayr = Form3->Edit14->Text.ToDouble();
double Xclr = Form3->Edit17->Text.ToDouble();
double Xscr = Form3->Edit20->Text.ToDouble();

```

```

double *yfcrr, *ydesr, *ypayr, *yclr, *yscr;
//get the 5 y values from each
yfcrr = g->getYValues(Xfcrr);
ydesr = g->getYValues(Xdesr);
ypayr = g->getYValues(Xpayr);
yclr = g->getYValues(Xclr);
yscr = g->getYValues(Xscr);

double maxOfY[5];
maxOfY[0] = max5(yfcrr[0], ydesr[0], ypayr[0], yclr[0], yscr[0]);
maxOfY[1] = max5(yfcrr[1], ydesr[1], ypayr[1], yclr[1], yscr[1]);
maxOfY[2] = max5(yfcrr[2], ydesr[2], ypayr[2], yclr[2], yscr[2]);
maxOfY[3] = max5(yfcrr[3], ydesr[3], ypayr[3], yclr[3], yscr[3]);
maxOfY[4] = max5(yfcrr[4], ydesr[4], ypayr[4], yclr[4], yscr[4]);

double* xab;
xab = g->getXValues(maxOfY);

//the risks entered by the user
//double xd, xsub, xcl, xrs, xpay, xpr, xcon, xtech;

//now calculate Xcr1 from these xab's and 5 y values
//Country Risk
double Xpr1 = (maxOfY[0] * (xab[0] + xab[1]) / 2.0 + maxOfY[1] * (xab[2] +
xab[3]) / 2.0 + maxOfY[2] * (xab[4] + xab[5]) / 2.0 +
maxOfY[3] * (xab[6] + xab[7]) / 2.0 + maxOfY[4] * (xab[8] +
xab[9]) / 2.0) / (maxOfY[0] + maxOfY[1] + maxOfY[2] +
maxOfY[3] + maxOfY[4]);

```

```

Form3->Edit23->Text = FloatToStr(Xpr1);}

void function8(){
Graph* g = new Graph(3, 1, 5, 3, 7, 5, 9, 7, 10);
double xavcc;
xavcc = Form3->Edit24->Text.ToDouble();

double Xpr1 = Form3->Edit23->Text.ToDouble();

//double xpi, xpc, xpatc, xuoe, xils, xsc, xcrd;
double *yavcc, *ypr1;
//get the 5 y values from each
yavcc = g->getYValues(xavcc);
ypr1 = g->getYValues(Xpr1);
/--MATRIX 2
int matrix4[5][5]={ { 1,1,1,1,1 }, { 2,2,2,1,1 }, { 3,3,3,2,1 }, { 4,4,4,3,2 }, { 5,5,5,4,3 } };
std::vector<double> yMatrix4[6];

for(int i=0;i<5;i++)
{ for(int j=0;j<5;j++)
{ if(ypr1[i]<=yavcc[j])
{ yMatrix4[matrix4[i][j]].push_back(ypr1[i]);}
else
{ yMatrix4[matrix4[i][j]].push_back(yavcc[j]);} }}

double yMaxs[5];
for(int i=1;i<=5;++i)
{ yMaxs[i-1]=maxVector(yMatrix4[i]);}

```

```

double *Xfinalpr;
Xfinalpr= g->getXValues(yMaxs);

double Xfinalpr = (yMaxs[0] * (Xfinalpr[0] + Xfinalpr[1]) / 2.0 + yMaxs[1] *
(Xfinalpr[2] + Xfinalpr[3]) / 2.0 + yMaxs[2] *
(Xfinalpr[4] +Xfinalpr[5]) / 2.0 + yMaxs[3] * (Xfinalpr[6]
+ Xfinalpr[7]) /2.0 + yMaxs[4] * (Xfinalpr[8] +
Xfinalpr[9]) / 2.0) / (yMaxs[0] + yMaxs[1] + yMaxs[2] +
yMaxs[3] + yMaxs[4]);

Form3->Edit25->Text = FloatToStr(Xfinalpr);
Form3->xfpr = Xfinalpr;}
void function9(){
Graph* g = new Graph(3, 1, 5, 3, 7, 5, 9, 7, 10);
double Xfinal;
Xfinal = Form5->Edit12->Text.ToDouble();
double Xfinalpr;
Xfinalpr = Form5->Edit25->Text.ToDouble();
//double xpi, xpc, xpatc, xuoe, xils, xsc, xcrd;
double *yfcrrr, *yprrr;
//get the 5 y values from each
yfcrrr = g->getYValues(Xfinal);
yprrr = g->getYValues(Xfinalpr);

//get their maximum's to get the 5 y values for country risk
double maxOfY[5];
maxOfY[0] = MAX(yfcrrr[0], yprrr[0]);
maxOfY[1] = MAX(yfcrrr[1], yprrr[1]);
maxOfY[2] = MAX(yfcrrr[2], yprrr[2]);
maxOfY[3] = MAX(yfcrrr[3], yprrr[3]);
maxOfY[4] = MAX(yfcrrr[4], yprrr[4]);

```

```

//get 10 x values which correspond to the 5 y values
double* xab;
xab = g->getXValues(maxOfY);

//the risks entered by the user
//double xd, xsub, xcl, xrs, xpay, xpr, xcon, xtech;

//now calculate Xcr1 from these xab's and 5 y values
//Country Risk
double Xcostr = (maxOfY[0] * (xab[0] + xab[1]) / 2.0 + maxOfY[1] * (xab[2]
+ xab[3]) / 2.0 + maxOfY[2] * (xab[4] + xab[5]) / 2.0 +
maxOfY[3] * (xab[6] + xab[7]) / 2.0 + maxOfY[4] * (xab[8]
+ xab[9]) / 2.0) / (maxOfY[0] + maxOfY[1] + maxOfY[2] +
maxOfY[3] + maxOfY[4]);

Form5->Edit1->Text = FloatToStr(Xcostr);}

```