Evaluation and Prioritization of Construction Projects on the Basis of Risk Factors Using ANP - DEMATEL - TOPSIS Integrated Approach in Fuzzy Conditions

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ABSTRACT

Construction projects initiate in complicated dynamic environments and due to the close relationships between project parameters and the unknown outer environment, they are faced with several uncertainties and risks. Success in time, cost and quality in large scale construction projects is uncertain in consequence of technological constraints, large number of stakeholders, too much time required, great capital requirements and poor definition of the extent and scope of the project. Projects that are faced with such environments and uncertainties can be well managed through utilization of the concept of risk management in project's life cycle. Although the concept of risk is dependent on the opinion and idea of management, it suggests the risks of not achieving the project objectives as well. Furthermore, project's risk analysis discusses the risks of development of inappropriate reactions.

Since evaluation and prioritization of construction projects has been a difficult task, the network structure is considered to be an appropriate approach to analyze complex systems; therefore, this structure has been used for analyzing and modeling the issue. On the other hand, inadequacy of data in deterministic circumstances was faced, and additionally the experts' opinions are usually mathematically vague and are introduced in the form of linguistic variables instead of numerical expression. Owing to the fact that fuzzy logic is used for expressing the vagueness and uncertainty, formulation of experts' opinion in the form of fuzzy numbers can be an appropriate approach. In other words, the evaluation and prioritization of construction projects on the basis of risk factors in real world is a complicated issue with lots of ambiguous qualitative characteristics. In the present thesis, a combination of fuzzy DEMATEL, fuzzy analytic network process (ANP), and fuzzy TOPSIS was used for the first time for evaluation and prioritization of construction projects on the basis of risk factors. The fuzzy DEMATEL method was used for extraction of the relationships between main risk factors and their sub-criteria. The weight of main risk factors and their sub-criteria was determined by considering the inter-relationships among main risk factors and their related sub-criteria in the fuzzy ANP. Afterwards, these weights were applied into the fuzzy TOPSIS method, and eventually the fuzzy TOPSIS was used for prioritizing the construction projects. The proposed hybrid model is used for prioritization of six construction projects on the basis of risk factors.

Keywords: Risk Factors, Construction Project, Fuzzy DEMATEL, Fuzzy ANP, Fuzzy TOPSIS, Project Prioritization.

ÖZ

Proje parametreleri ve bilinmeyen dış çevreye bağlı olarak karmaşık dinamik çevrelerde başlatılan inşaat projelerinde birçok belirsizlikle ve riskle karşılaşılmaktadır. Teknolojik yetersizlikler, ortak sayısının fazla olması, fazla zaman harcanması, yüksek maliyet ihtiyacı ve proje kapsamının tam olarak tanımlanamaması, yüksek ölçekli inşaat projelerinin zaman, maliyet ve kalite bağlamlarında başarıya ulaşmasını belirsizleştirmektedir. Çevre ve belirsizliklere bağlı olarak sorunlarla karşılaşabilecek projeler, proje süresince risk yönetimi kavramının kullanılmasıyla doğru bir şekilde yönlendirilebilir. Risk kavramı, yönetimin görüş ve düşüncelerine bağlı olsa da, proje amaçlarının tamamlanmamasıyla sonuçlanabilmektedir. Buna ek olarak risk analizi, uygunsuz tepkilerin oluşması riskini tartışmaktadır.

Değerlendirme ve öncelik belirleme projeler için zor bir görev olduğundan dolayı, ağ yapısı, karmaşık sistemleri analiz edebilmek için uygun bir yaklaşım olarak görülmektedir; bu nedenle bu sorunu analiz etmek ve modellemek için seçilmiştir. Diğer yandan, deterministik koşullarda bir very uyumsuzluğu ile karşılaşılmaktadır; buna ek olarak, profesyoneller, fikirlerini sayısal yerine sözel olarak dile getirdiklerinden dolayı matematiksel açıdan bir belirsizlik oluşmaktadır. Belirsizliği dile getirmek için bulanık mantığın kullanıldığı düşünüldüğünde, profesyonellerin fikirlerini bulanık sayılar olarak belirtmeleri uygun bir yaklaşım olarak görülebilir. Bir diğer deyişle, inşaat projelerinde değerlendirme ve öncelik belirlemenin, risk faktörlerini göz önünde bulundurduğunda, birçok belirsiz nitel özellik taşıyan, karmaşık bir süreç olduğu söylenebilir. Bu çalışmada, risk faktörleri bağlamında inşaat projelerinin değerlendirmesi ve öncelik belirlemesi için ilk kez bulanık DEMATEL, bulanık analitik ağ süreci ve bulanık TOPSIS'in bir birleşimi kullanılacaktır. Bulanık DEMATEL, risk faktörleri ve alt kriterleri arasındaki ilişkiyi özütleme için kullanılmaktadır. Temel risk faktörleri ve alt kriterlerin ağırlığı, bulanık ANP'deki risk faktörleri ve alt kriterlerinin ilişkilerarası temelinde belirlenmektedir. Daha sonra, bu ağırlıklar bulanık TOPSIS yöntemine uygulandıktan sonra inşaat projelerinde öncelik belirleme için kullanılmaktadır. Sunulan hibrit model, altı inşaat projesinin risk faktörleri temelinde değerlendirilmesi için kullanılmaktadır.

Anahtar Kelimeler: Risk Faktörleri, İnşaat Projesi, Bulanık DEMATEL, Bulanık ANP, Bulanık TOPSIS.

DEDICATION

پروردگارا:

نه میتوانم موهایشان را که در راه عزت من سفید شده است سیاه کنم و نه برای دستهای پینه بسته اشان که ثمره تلاش برای افتخار من است مرهمی دارم، پس توفیق ده که هر لحظه شکرگزارشان باشم و ثانیه های عمرم را در عصای دست بودنشان بگذرانم.

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To My Supportive Father;

My Symbol of Strength

Who Offered Me Full Support in Life...

And My Affectionate Mother;

My Symbol of Patience

Who Taught Me the Life Alphabets…

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LIST OF ABBREVIATIONS

AHP .... Analytical Hierarchical Process

ANP .... Analytical Network Process

DEMATEL.................................... Decision Making Trial and Evaluation

IS .... Information System

IT .... Information Technology

PMBOK .... Project Management Body of Knowledge

TOPSIS .... Technique for Order-Preference by Similarity Ideal Solution

WBS .... Work Breakdown Structure

WWW .... World Wide Web

Chapter 1

INTRODUCTION

1.1 Introduction

In every project, planning for facing with the risk and its management is one of the most important and subtle steps which should be addressed in the beginning of defining the project and before initiation. In the past, managers did not pay enough attention to this issue, and people were not aware of the importance of risk management until adverse consequences would entangle the managers and other stakeholders. Nowadays, almost no project is free from risk. Tom Lister, a great risk management expert asserts: “All risk-free projects have been carried out before.” (Aghaei, 2011).

Success factors and parameters of a project depend on the accomplishment and completion of the project in due time and within certain budget and the required performance level. The main barrier for these objectives (project completion with desired performance level in due time and with regard to budget constraints) is the changes that occur in the project environment. With increase in dimension of the project, problems will also be increased and thereby the uncertainty in the output of the project will be greater. Large-scale construction projects are subject to uncertainty conditions for the following reasons (khaki, 2003):

- Complex Plan and design

- Variety of interest groups (project's owner, owner's project team, advisors, contractors, sellers, etc.)
- Resources (material, equipment, asset, etc.)
- Accessibility, facility and the possibility of credit obtainment
- Excellent environment
- Economic and political conditions
- Legal bylaws and regulations

Although risk and uncertainty can affect every project, the scale and dimension of the project play a critical role. Other risk factors include project complexity, project progress and construction rate, construction location, and the degree of unfamiliarity with the project (khaki, 2003).

The conventional and traditional method of project management (as shown in Figure 1.1) does not account for the needs and requirements of today's projects (Aghaei, 2011). This conventional and traditional method strips the project management team the following capabilities (Aghaei, 2011):

- Establishment of sufficient relationships between all phases of a project
- Prediction of project success for ensuring the project team
- Actual decision makings with the aid of an available database
- Providing enough information for effective project management
- Establishment of close cooperation among the project team members

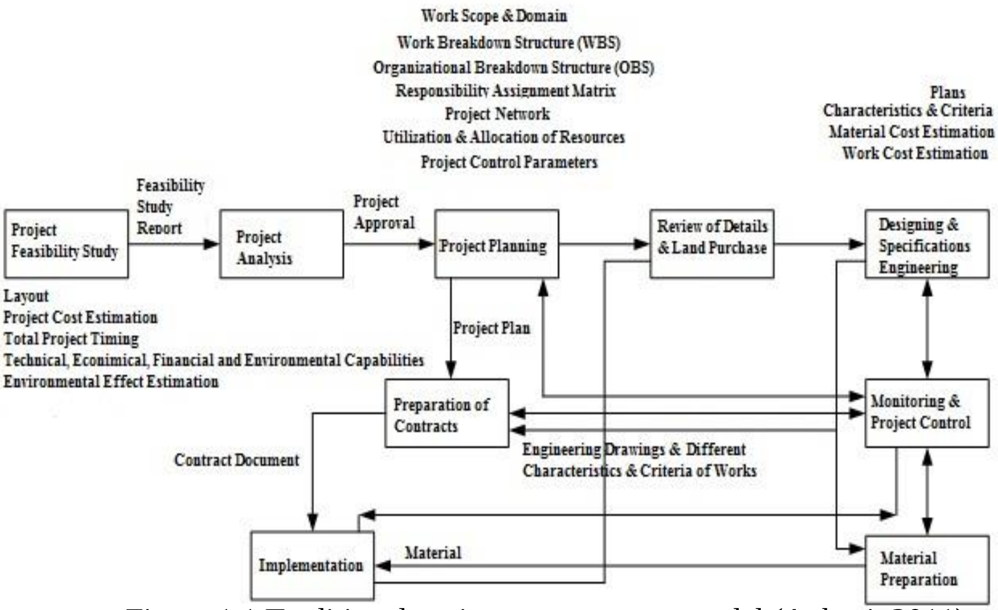

Figure 1.1 Traditional project management model (Aghaei, 2011)

The purpose of this worked is to model a decision support system by means of risk analysis. Also to make real decisions in project planning, designing, engineering and utilization of resources. Completing the project in due time and within the specified budget in accordance with project aims, organizational policies and current business plan.

In the present research, after identification of the criteria and factors that affect risk analysis, a combined model is proposed in fuzzy condition, based on ANP-DEMATEL-TOPSIS method. Subsequently, the proposed model can be used for evaluation and prioritization of construction projects on the basis of the identified risk factors.

This chapter introduces the definition of the subject, necessity and importance of the research, research objectives, implications of the results, research questions, definition of key terms and concepts. Additionally, research framework will be explained at the end of the chapter.

1.2 Introducing the Subject

Construction projects risk management relates to the process of risk management planning, identifying, analyzing, risk response planning, risk controlling and monitoring in construction projects. The aim of project risk management is to add the possibility and effectiveness of positive phenomenon and to reduce the possibility and effectiveness of negative phenomenon in each project. Depending on the project's needs, a risk process can involve endeavours of one or several persons. Each process occurs at least one time in each project, and in case the project involves several phases, it can occur in one or several phases of the project.

The origin of project risks is the uncertainty which exists in all projects. The identified risks are those which are recognized and analyzed, and there is the possibility of planning to respond to these risks; however, for unidentified risks there is no possibility of preventive management, and the project team prepares a probable plan. Organizations have now found that risk is a threat to their project success or an opportunity to effective and influential success.

Project risk is always about the future. Risk is an uncertain event or situation that in case of occurrence can at least affect one objective of the project. Objectives may include scope, schedule, cost, or performance. Every risk can be due to one or several causes, and after occurrence can result in one or several consequences. Each cause may have a requirement, limitation or conditions which create possibility of negative or positive results. For instance, causes may include the need for an environmental license for work initiation or personnel limitations for project planning. In this case, the risk can be such cases as the longer time than planned for issuance of the license by the licensing organization, or limitations of assigning and providing the required personnel in due time. If any of these uncertainty events occur, they will influence the cost, time, or efficiency of the project. Risk conditions may encompass some parts of the organization or project that can be affected by project risk, like weakness in management of the project, unavailability of consistent management systems, various concurrent projects and reliance on outside partners that cannot be controlled. Identification of risk factors in construction projects is a fundamental purpose of the present thesis. Therefore, using this method consist of combination of three model include ANP-DEMATEL-TOPSIS methods in fuzzy condition, which prioritization of construction projects based on the identified risk factors.

1.3 Necessity of the Research

Major changes in business environment such as business globalization and rapid technology changes have led to increased competition and difficulty of management in organizations. In business environments today, managers and staff must have the ability to deal with ambiguous and complex interrelationships and dependencies between technologies, data, tasks, activities, processes, and people. In such complicated environments, the organizations require managers who are able to observe and distinguish these inherent complexities in their vital decision makings. Nowadays, organizations and their systems are standing in a challenging and evolutionary environment, and hence the requisite for survival and endurance in this environment is to keep up with the changes in environment and to have appropriate and due responses to these developments.

Projects in the current market and business conditions are exposed to crisis at any moment. The project environments are highly variable and there are lots of uncertain conditions which become even more problematic for larger projects. Undoubtedly, proper management of these risks is a prerequisite for facilitation of crisis conditions; hence, the need for acquisition of the related sciences and their development is obviously necessary. Proper management necessitates appropriate decision making, which itself requires serious endeavours of managers and stakeholders in each plan and decision. Obviously, all aspects of the works and decisions are not clear in all conditions of decision making; therefore, one thing that must be necessarily considered during decision making should be the possible or definite dangers and risks which can affect the results of decisions, and this is what risk management talks about.

Large-scale construction projects are accompanied by risk elements and hazards. Therefore, considering what was said above, risk management and risk factors analysis are of utmost importance in large-scale construction projects.

1.4 Research Questions

The key questions raised in this research which are to be answered in the following chapters are:

- What are the major risk factors in large-scale construction projects?
- What are the usual methods of evaluation and prioritization of projects?
- How can the evaluation and prioritization be done for construction projects based on risk factors in uncertainty conditions by means of fuzzy ANP-DEMATEL-TOPSIS?

1.5 Scope and Objectives of the Research

The objective of the present research is to propose a new approach to evaluation and prioritization of risk factors of large-scale construction projects, using ANP-DEMATEL-TOPSIS combined model in fuzzy conditions. Some specific objectives of this research include:

- Identification of risk factors of large-scale construction projects
- Proposing a hierarchical structure for evaluation and prioritization of construction projects based on risk factors
- Proposing a combined model on the basis of ANP-DEMATEL-TOPSIS methods in fuzzy conditions

1.6 Work Undertaken

Construction projects initiate in complicated dynamic environments and due to the close relationships between project parameters and the unknown outer environment, they are faced with several uncertainties and risks. Since evaluation and prioritization of construction projects has been a difficult task, the following measures (Fuzzy DEMATEL, Fuzzy Analytic Network Process and Fuzzy TOPSIS) were taken in order to solve the problem.

It must be mentioned that identification of risk criteria and sub-criteria is regarded as the most important phase in the process of projects evaluation because without complete identification of risk factors and understanding different dimensions of construction projects evaluation, it is not possible to deal with other phases of projects evaluation.

Comprehensive and extensive study has relatively been carried out in identification of the risk factors that affect construction projects. These criteria along with the scholars who dealt with these criteria in construction projects evaluation are fully discussed in chapter 2. These studies are frequently cited in the risk factors identification part and Table 3.1 which illustrates the identified risks used in the present research.

This proposed model is a combination of the three methods of DEMATEL, ANP and TOPSIS in fuzzy conditions. In other words, the output of each method will become the input of the next method. The main phases of the work done can be mentioned in the following framework:

1.6.1 Application of Fuzzy DEMATEL

In this research, in order to investigate the interrelationships between the factors, experts were asked to perform pair-wise comparisons between the factors regarding the level of influence of factor *i* on factor *j*. Thus, in order to resolve the ambiguity problems for the analyses made by humans, the scale used in deterministic mode was altered, and the fuzzy linguistic scale was used which is expressed in five linguistic terms (very high influence, high influence, low influence, very low influence, no influence) for different degrees of influence. The fuzzy DEMATEL method was used for extraction of the relationships among main risk criteria and their sub-criteria. Output of this phase was then used for formation of the super-matrix in the second phase, i.e. the analytic network process.

1.6.2 Application of Fuzzy Analytic Network Process (ANP)

In this step, after gathering the experts’ answers in the 9-degree fuzzy scale and in the form of linguistic expressions, it is necessary to turn these answers into an analyzable scale because it is impossible to perform mathematical operations on qualitative linguistic variables. Thus, the linguistic variables must be converted to fuzzy scales. Using the pair-wise comparisons and considering the interrelationships among main risk criteria and their related sub-criteria, a super-matrix was created. Afterwards, through performing some calculations, the weight of main risk criteria and their sub-criteria was determined. Output of this phase, i.e. the weights, were regarded as the input for the third phase.

1.6.3 Application of Fuzzy TOPSIS

In this step, the evaluation criteria with the help of experts were identified by the questionnaire. By applying the calculated weights of step 2, the weighted decision-making matrix was calculated. Subsequently, using fuzzy TOPSIS, the act of prioritization of construction projects was performed.

The proposed hybrid model was used in this thesis for prioritization of six construction projects on the basis of risk factors. The chosen case studies are in to the level that provided combine model can be check by them.

1.7 Achievements

The proposed model has been used for evaluation and prioritization of six construction projects in Mahab Ghods Consulting Engineering Company.

The proposed fuzzy combinational method of this research eliminates the incapabilities of uncertainty measurement. In addition to simplicity and understandability, other significant benefits of the proposed model include:

- supporting the network structure (describing complex systems)
- considering the relationships and dependencies between risk main criteria and sub-criteria

- supporting the fuzzy concept (expressing the vagueness and uncertainty)
- ability of rating (aiding better decision-making)

In this project, for the first time a combination of fuzzy DEMATEL, fuzzy ANP, and fuzzy TOPSIS was used for evaluation and prioritization of construction projects, in which the decision makers are able to express their own point of view on the following items, and also to apply their opinions in this regard:

- risk factors weights
- relationships and dependencies between risk criteria
- the score of each construction project in realization of risk sub-criteria

These are in fact the main achievements of this model, though they are not limited to these items.

1.8 Implications of the Research

Results of the present study can be employed by several groups, some of which include:

- Authorities, planners, stakeholders, executors and managers of civil and construction projects
- Contractor companies, consulting companies, technical-engineering offices
- Master and PhD level students of civil engineering, construction management and industrial engineering

1.9 Definition of Technical Terms and Concepts

Risk: The possibility of harm or damage from a particular threat is called risk. It is in fact chance or probability that a person will be harmed or a property will be damaged if exposed to a hazard. Risk is a combination (or function) of probability and consequences due to occurrence of a particular hazardous event (Seyedhosseini, 2007).

Risk Analysis: It is the general process of estimation of the amount of risk and determination of sustainability of the risk (Seyedhosseini, 2007).

Analytic Network Process: It is a widely used multi-criteria decision making method which is able to analyze qualitative and quantitative criteria and their relationships (Saaty, 2005).

TOPSIS Method: It is also a multi-criteria decision making technique. In this method, *m* alternatives are assessed by *n* criteria. The underlying logic of this model defines a positive ideal solution and a negative ideal solution. The optimal alternative is the one with shortest distance from the positive ideal solution and, on the other hand, with longest distance from the negative ideal solution. In other words, in ranking the alternatives with TOPSIS method, the alternative with most similarities with the ideal solution will attain the highest rank (Hwang & Yoon, 1981).

DEMATEL Method: This is another decision making method which is based on pair-wise comparisons, and is used for identification and evaluation of mutual relationships between different criteria and also for creation of network relations map (Battle Geneva Institute, 1972).

Fuzzy Science: The personal knowledge such as the information which is to some extent linguistically describable and explainable, though it is not usually possible to quantify them with traditional mathematics (Lotfizadeh, 1980).

1.10 Research Structure

In chapter two of the present research, the review of literature of risk concepts, risk management, identification of risk factors and previous researches on the current methods and criteria used for construction projects risk management will be discussed. In addition, the review of literature of analytic network process, TOPSIS, and DEMATEL methods will be reviewed.

In chapter three, the research methodology and case study for identification of risk factors and prioritization of projects on the basis of risk factors will be dealt with.

Chapter four will explain the proposed fuzzy ANP-DEMATEL-TOPSIS combined method in details.

Chapter five is case study and discussion of the results that proposed combined methods (FUZZY ANP, FUZZY DEMATEL and FUZZY TOPSIS) will be investigate in the case study.

Chapter six is devoted to the conclusion and further research suggestions.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

In the current chapter, the literature of the key concepts of evaluation and prioritization of construction projects on the basis of risk factors will be reviewed. Moreover at the end of the chapter, the literature review of approaches which have been utilized in the present study, i.e. ANP, TOPSIS, and DEMATEL in fuzzy will be analysed.

2.2 Definition of Risk

Various definitions can be found for the concept of risk in different scientific resources, each of which is based on its own point of view or dimension. A number of risk definitions are proposed as:

- Uncertain event or condition which if occurs will have a positive or negative effect on the project's aim (Konstantinos, 2002).
- Risk involves the potential for negative or unintended outcomes of an event or activity (Rowe, 1977).
- Risk involves the combination of loss and exposure to it (Chicken and Posner, 1998)
- A discrete occurrence that may affect the project for better or worse (PMBOK Guide, 2004).

Despite the variety of definitions given for risk, all of them involve a unique concept. In most of risk definitions, two aspects of loss and uncertainty are clearly addressed.

It must be noticed that the two terms of risk and uncertainty are two different concepts. Generally speaking, uncertainty constitutes risk and represents the doubt that a person has about the occurrence of a possible outcome from among the possible outcomes. If our estimation of the future results is accompanied by certainty and we are sure about their occurrence or nonoccurrence, then there will be no uncertainty. Hence, because the future is known to us, there exists no risk in both cases. As it can be seen, the two concepts of uncertainty and risk seem to be completely intermingled and inseparable. Uncertainty can be considered as a function of probability. Probability of occurrence or non-occurrence of each event fluctuates between zero and one, and is represented by a percentage. When the probability equals to zero, according to what was mentioned above, the uncertainty will be zero too. Gradually and with the increase in probability, uncertainty also increases and eventually reaches its maximum at 0.5. In other words, when the probability of an event is estimated about 50 percent, we will encounter the most uncertain level. With the increase and decrease of the probability from 50 percent, the uncertainty decreases. The 1 or 100 percent probability represents the certainty of occurrence of the event, in which case the uncertainty will equal to zero. Consequently, we can conclude that if the probability of an event is equal to zero or one, the ambiguity of the future will turn to certainty and there will be no uncertainty. Figure 2.1 represents this matter.

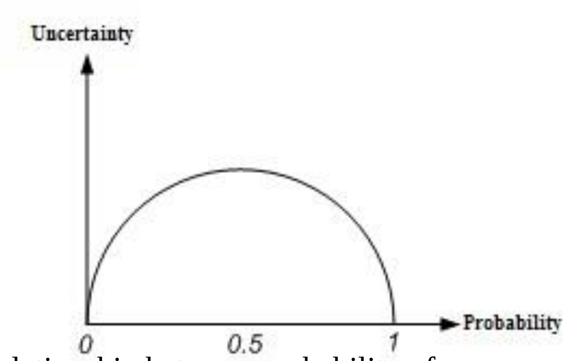

Figure 2.1 The Relationship between probability of occurrence & uncertainty in an event (Project Risk Management, 2008)

Another conclusion drawn from the above discussion is that for a numerical expression of the risk, we cannot use probability; because as mentioned before, when probability equals to 100 percent, the risk is equal to zero. Therefore, probability and risk are not the same concepts.

2.3 Main Elements of Risk

All types of risk include common elements which are (PMBOK Guide, 2004):

- Content
- Activity
- Conditions
- Consequences

Content is the context, environment where the risk is placed to determine activities and conditions which is related to the situation. In other words, content provides a view of all of the measured outcomes. Without determination of the appropriate content, it cannot be certainly asserted that which of the activities, conditions or outcomes must be taken into account for risk analysis and management activities. Therefore, content provides a basis for all subsequent risk management activities.

After content creation, the remaining elements of risk will be appropriately analyzable. The activity element is the action or phenomenon that produces the risk. Activity is regarded as risk active component and it should be mixed with one or several particular conditions in order for a risk to occur. All types of risks occur as a result of an activity. Without existence of an activity, there is not any risk possibility.

Activity is the risk active component; however, the constituent condition is the passive component. These conditions determine the current situation or a set of situations and circumstances which may lead to risk. When condition is combined with a particular initiating activity, it can produce a set of outcomes or outputs. Outcomes, which are the last element of risk, are the potential results or effects of an activity in combination with a particular condition or conditions.

2.4 Risk Classification

A considerable and primary issue in the domain of risk management is the definition and classification of risks. Due to the wide variety of risks and accordingly variety of their management, their management domain will become clear through these classifications. Project risks are defined in a general view associated with the scope, cost and quality of project.

One type of risk classification is the systematic classification. In this method, risks can be associated with some part of the project systematic view. According to this method, risks can be divided into the following subcategories (Swabey, 2005):

- Project risk (internal): This risk is related to the organizational responsibilities within the project, such as the risks related to resource allocation and scheduling software. Project risk is normally classified into the controllable risks category.

- External risk: These kinds of risk usually endanger the completion process of projects from outside the project; so that they are not put in the main input and output scope of the system, such as the natural disasters. These risks are usually uncontrollable.
- Consortium Risk: These risks are somehow between internal and external risks; this means that this kind of risks exist outside the project, but have a close relationship with the components inside the project. This risk is related to such areas as customers, contractors and suppliers. In other words, this risk is associated with the system’s input and output, such as delayed delivery of material by suppliers.

Another criterion for classification of risk is the affected area of risks. Based on these criteria, the risks can be classified into the following categories (US Department of Energy Project Management, 2005):

- Risk associated with operational issues, purpose, quality and technical issues of the project: These risks can affect the evolution and implementation of the project.
- Time Risk: These risks distance the project completion due time from the due time. The impacts of this kind of risk can affect the cost and operational risks of the project.
- Cost Risk: These risks distance the project costs from the approved budget. These risks have a close relation with time risk.

- Advancing Risk: These risks are not important by themselves, but a great risk will appear by their accumulation. For instance, the increase in a contractor’s payment does not have a considerable influence on the budget. However, if there are a large number of contractors, this will turn to a significant risk.
- Catastrophic Risk: Despite the advancing risk, this type of risk has significant impacts by itself, and affects other risks. These risks are of low probability and high impact, such as the critical technologies related to disposal of such waste that requires special equipment.
- Safety and Health Risks: These risks cause detrimental effects of the project on the environment.

Another classification method for risks is the classification on the basis of the type of risk. In order to clarify the issue, different categories of this type of classification are briefly explained:

- Technical Risk: This includes technical risks, such as the risk of old methods of production.
- Human Risks: This includes risks associated with human elements of the project, such as the risk of the experts’ experience.
- Financial Risk: This risk relates to the financial system of the project, such as financial documents.
- Economic and Political Risk: This risk relates to the political and economic environment of the project, such as inflation.
- Risk of Lack of Support: This type of risk is associated with the lack of shareholders’ support for the project.

Various classifications of project risk are not limited to the types described above. For example, the external risk can be itself divided into two predictable and unpredictable categories (Wideman, 1992). In addition, classification of risks can be executed based on the project's lifetime, the product’s lifetime, and location of the project (Revill and Gully, 2003). Moreover, its classification may be done according to the commercial process of the project (Seyedhosseini, 2007).

2.5 Definition of Risk Management

Flanagan and Norman (1993) defined risk management as “a system which aims to identify and quantify all risks to which the business or project is exposed so that a conscious decision can be taken on how to manage the risks”. In the overall standard of project management (PMBOK, 2004), risk management is referred to as the systematic application of management policies, procedures and processes relevant to the analysis, assessment and control of risks.

In other words, risk management is a process of documentation of final decisions taken, identification and implementation of criteria used for modification of the risk to an acceptable level.

Project Management Institute (2004) defined risk management as one of the nine focuses of "Project Management Body of Knowledge" shown in Figure 2.2. In definition proposed by this institute, project risk management is divided into such phases as risk identification, risk analysis, response (a reaction to risk), and risk control. In this definition, project risk management involves "all the processes relevant to identification, analysis, and responding to any kind of uncertainty, which includes the maximization of desirable events and minimization of adverse consequences." (PMBOK, 2004)

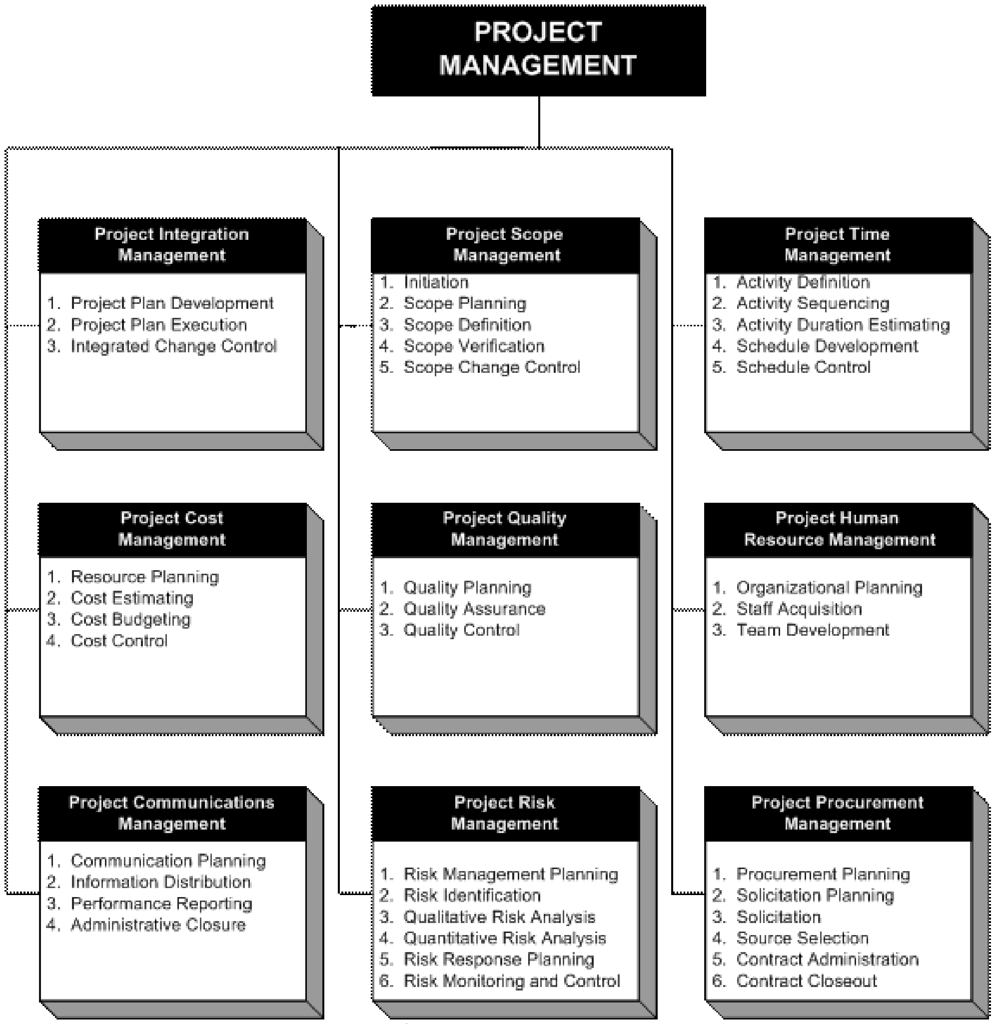

Figure 2.2 Nine areas of project management (PMBOK, 2004)

2.6 Risk Management Process

Risk management process is carried out in order to ensure that all risks have been formally identified, prioritized, monitored and prevented or mitigated (PMBOK, 2004). Project risk management process helps the project's financial sponsors and project teams to make conscious decisions for alternative solutions. Risk management encourages the project team to follow appropriate procedures in order to minimize the negative impact on the scope, cost and plan of the project as well as the crisis management (PMBOK, 2004).

Risk management process is a method by which, the project risks (of scope, project output, resources, etc.) are formally identified, prioritized, and managed during project implementation. This process involves activities that reduce the likelihood and impact of each risk.

In its "Project Management Body of Knowledge" PMBOK (2004), the Project Management Institute introduces six phases for project risk management process:

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

Figure 2.3 display these six phases as well as their relations.

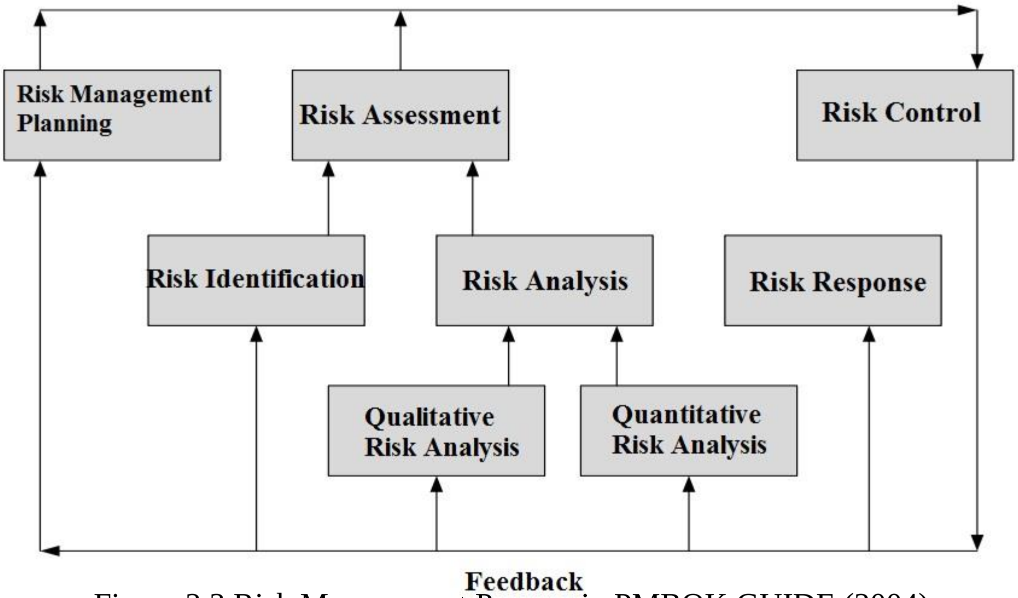

Figure 2.3 Risk Management Process in PMBOK GUIDE (2004)

2.6.1 Risk Management Planning

According to Project Management Institute (2004), risk management planning is the decision making and codifying for risk plan and its method of execution. In a risk management which is called the systematic management, prior to starting the executive works, the aims of project risk management process must be agreed on, and it is necessary therefore to define the roles and responsibilities, revision method, work report, etc.

This is in fact a primary phase of project management process which is called "establishing the context" or project risk management planning; this phase ensures that the project goals are clearly stated and understood. Risk management plan includes the method of organizing and executing the activities relevant to risk management. Thus the methodology, defining of procedures and information resources that may be used during risk management process. The roles and responsibilities, budgeting, scheduling, and frequency of repeated reviewing. Risk management decisions are determined during execution of the project and the method of reporting and pursuits. This phase includes the following activities:

- Structuring the project risk management objectives within the organizational objective framework
- Determining the resources, schedule, location and how to provide them
- Defining the project and activities that fit into risk definition
- Defining risk criteria, risk analysis and risk acceptance
- Defining the risk management scope and domain of activities

2.6.2 Risk Identification

According to definition given by Project Management Institute (2004), risk identification refers to determining which risks might affect the project and documenting and categorizing their characteristics.

In this phase of risk management process, a list of possible events and a list of possible causes and scenarios of occurrence of those events are prepared. Inputs of this phase can be such things as risk management plan, project planning output (work breakdown structure, resources planning, rationale and time schedule, etc.), registered experiences and documents, and project formal reports. Risk identification is an iterative process which is carried out by some part of project management team. Risk management plan, objective planning, schedule and cost estimation plan, resource allocation and list of limitations, different classifications of risks and information from previous projects are all used for risk identification. In order to identify risks and their causes, the following identification methods are utilized. It must be noted that in the process of risk identification, there is no best method, and an appropriate combination of the methods must be utilized.

- Brainstorming: The goal of brainstorming is to obtain a comprehensive list of project risks, under active and creative discussion sessions.
- Delphi Groups: It is a way to reach a consensus of experts on particular subjects. Project risk experts participate in this technique anonymously. This technique helps reduce bias in the data and keeps any person from having undue influence on the outcome of the process.
- Individual Interviewing: Interviewing experienced project managers or experts.
- Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis: This analysis ensures examination of the project from each of the SWOT perspectives separately, in order to increase the breadth of considered risks. This method is used for recognizing the organizational weaknesses, strengths, opportunities, and particular threats of the project.
- Similar Projects: Through reviewing the documentations and archives of previous similar projects as well as other information resources, the project potential and probably influential risks can be identified and documentation of their characteristics can be dealt.
- Diagram Methods: These include such tools as cause-and-effect diagram (which is also called the fishbone or Ishikawa diagram,

and is beneficial for identification of risks' various causes), process or system flowchart (which shows how a system's different components interconnect), and impact diagram (each diagram reflects a problem together with its causes, synchronic order, etc.).

- Hypotheses Analysis: Investigates the validity and reliability of hypotheses of the project. This method identifies the project risks which result from the inaccuracy, contrast, or defect of hypotheses. This process identifies uncertain and probable events which, in case of occurrence, will have a positive or negative impact on the project objectives, causes or symptoms (such as failure in observing the time schedule which might be an imminent warning in the schedule).

Each of the abovementioned general techniques of risk management can appear to be effective in theory for recognizing the opportunities and threats; however, in the process of utilization, most of the project teams' experience is focused on threats. When stakeholders use their conventional method of risk identification, as a matter of habit they do not usually think about any other method- except the methods that involve only threats. Hence, it can be beneficial to use other methods of risk identification such as the "analysis of assumptions and constraints", which can introduce the risk in a clearer way than the current techniques.

2.7 Risk Breakdown Structure (RBS)

The risk breakdown structure has been used as a useful and efficient tool in structuring the risk management processes, and it is now utilized in lots of risk management standards. In the Project Management Body of Knowledge (PMBOK, 2004), risk breakdown structure has a definition similar to work breakdown structure (WBS). The source-oriented classification determines and organizes all risks that a project encounters. By moving down the breakdown structure, there will be more details of sources of risks in a project. Therefore, risk breakdown structure is a hierarchy of potential risks that can have a valuable contribution to determination of future risks of a project. This structure can be used as a framework for determination of risk management processes. A general breakdown structure for project risks can be effective; however, it does not necessarily involve all project risks. Consequently, it is better to prepare an appropriate risk breakdown structure for each project, with respect to the particularities of the project and its relevant industry. An example of a risk breakdown structure is illustrated in the figure 2.4.

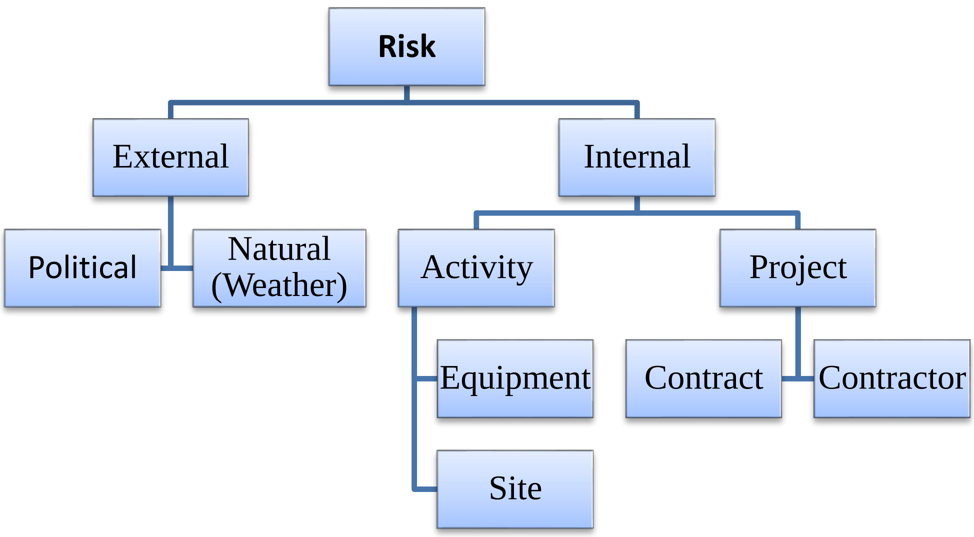

Figure 2.4 Example of a Risk Breakdown Structure (RBS)
(Seyedhosseini, 2007)

Classification of the risks in accordance with a risk breakdown structure, gives us a deep insight on how to analyse project risks, which is not achievable through a simple list. Some of these include:

- Understanding the risks that the project would encounter
- Representing the significant risky resources
- Revealing risk roots through dependence analysis
- Revealing the dependence or correlation fields of risks
- Focusing on developing a plan for responding to significant risks

2.8 History of Risk Management in Construction

According to literature review, the term risk analysis was organized by Hertz (1984). Hertz (1984) proposed computer simulation for extraction of project risk distribution. Risk management is not a new event, and it has been inherently used and managed by individuals' ideas and judgments (Mills, 2001).

People usually tend to use intuition, experience and judgment for making decisions in construction projects. Zack (1996) asserted that in the past, risks that were associated with construction contracts basically had physical or natural existence everywhere. Hidden risks, availability and employee productivity, climatic effects, the ability to access materials or other issues present in project sites which inhibited the progress, are well known and predictable. In general, employers and contractors recognize these risks and have dealt with them.

According to a research by Baker et al. (1999), the formal risk management in construction projects, has been considered as an integrated process only in the past few decades. The reason for this fact could be the rapid technological growth. Thus, since then the risk and risk management in construction projects are inherently regarded as a distinct issue.

In two studies, one by Flanagan et al. (1993) and another by Smith (1999), construction projects were defined as “a set of non-repetitive attempts with unique specifications such as long term period, complex processes, and unfavourable environment, financial/investment issues, and dynamic organizational structure”. Such organizational and technological complexities generate enormous risks. Zou et al. (2006) believed that variety of stakeholders’ interests can intensify changeability and complexity of risks in the construction projects. Focusing on what must be obtained in a construction project (like project’s objectives), the risk management process provides us with an understanding of what endanger the project’s objectives and what must be done for ensuring the success.

The analysis of critical factors of failure and success in construction projects is an effective method for risk factors identification. Rubin and Seeling (1967) proposed the success and failure factors for the first time. They explored the impact of experience of project managers on the failure and success of projects. Avots (1969) continued Rubin and Seeling’s research. He identified the reasons for failure of projects and concluded that the main causes of failure of projects include the inappropriate selection of project managers, the project’s unplanned cessation, and lack of sufficient support from the management. Hughes (1986) carried out a research on factors that affect the performance of projects. He concluded that failure of projects is a result of inappropriate management principles like the unsuitable focus of management system and conducting wrong actions, and the lack of clear stipulation of the project’s aims.

2.9 Identifying the Risk Factors and Evaluation Models of Construction Projects

Table 2.2 display number of studies carried out on identification of the risk factors, with the researcher and the factors separately cited.

Table 2.1 Risk factors and criteria in projects

Row	Scholar	Factors & Criteria
1	**Martin (1976)**	Definition of Objectives
		Selection of an Organizational Philosophy
		Executives' Support
		Organizing and Delegating the Responsibilities
		Project Team Selection
		Allocation of Sufficient Resources
		Providing the Tools for Control and Informational Mechanisms
		Planning and the Required Analysis
2	**Locke (1984)**	Revealing the Project Obligations
		Determination of Abilities and Authorities of the Project From the Beginning
		Appointing an Efficient Project Manager
		Setting up Communications and Utilization Methods
		Setting the Control Mechanisms (Scheduling, etc.)
		Progress Meetings
3	**Cleland and King (1983)**	Project Summary
		Functional Concepts
		Top Management Support
		Financial Support
		Logistics Requirements
		Skill Support
		Smart Marketing (Who is the Client)
		Project Timing
		Executive Development and Training
		Human Resources and Organization
		Profit
		Information and Communication Methods
		Project Analysis
4	**Sayles and Chandler (1971)**	Competency of Project Managers
		Scheduling
		Control Systems and Responsibilities
		Monitoring and Feedback
		Continuous Involvement in the Project
5	**Backer et al. (1983)**	Clear Objectives
		Main Commitment of the Project Team
		Resident Project Manager

Row	Scholar	Factors & Criteria
5	Backer et al. (1983)	Sufficient Funding
		Sufficient Capability of Project Team
		Primary Detailed Cost Estimate
		Minimal Initiation Problems
		Planning and Control Techniques
		Task
		Lack of Bureaucracy
6	Pinto and Selvin (1989)	Support from Top Management
		Customer Consultation
		Personnel Recruitment
		Technical Tasks
		Customer Reception
		Monitoring and Feedback
		Communications
		Troubleshooting
		Characteristics of the Project Team Leader
		Power and Policies
		Environmental Phenomena
		Immediacy and Urgency
7	Morris and Selvin (1987)	Project Objectives
		Technical Uncertainty
		Policies
		Community Issues
		Courses Scheduling Urgency
		Financial Obligation for Legal Matters
		Implementation Problems
8	Saqib et al. (2008)	Project Management
		Risks Related to Procurement
		Factors Related to the Customer
		Factors Related to the Design Team
		Factors Related to Contractors
		Factors Related to Project Managers
		Factors Related to the Business Environment
9	Belassi and Tukel (1996)	Factors Related to the Project
		Factors Related to Project Managers and Team Members
		Factors Related to the Organization
		Factors Related to the External Environment of Project
10	Zeng et al. (2007)	Human Factors

Row	Scholar	Factors & Criteria
10	**Zeng et al. (2007)**	Work Environment Factors
		Materials Factors
		Equipment Factors
11	**Tah and Carr (2000)**	Internal Risk
		External Risk
12	**Zayed et al. (2008)**	Technology
		Contracts and Legal Issues
		Resources
		Designing
		Quality
		Construction
		Other
13	**Dikmen et al. (2007)**	Industrial Risks
		Management Risks
		Resource Risk
		Productivity Risk
		Design Risk
		Payment (Money) Risk
		Customer Risk
		Stakeholder Risk
14	**Iyer and Jha (2005)**	Project Manager Commitment
		Top Management Support
		Coordinating the Project Manager and Skill Management
		Monitoring and Feedback
		Committed Partners of the Project
		Qualification of the Owners and Desirable Climate Conditions

In a recent work by Taylan et al. (2014), five risk criteria were used for construction project analysis. They analyzed 30 construction projects by using the fuzzy AHP and fuzzy TOPSIS methods. In this study, Time risk, cost risk, safety risk, quality risk and environmental sustainability risk were used as the influential factors in construction projects. The hierarchical structure of the scholars' issue of interest in show in Figure 2.5:

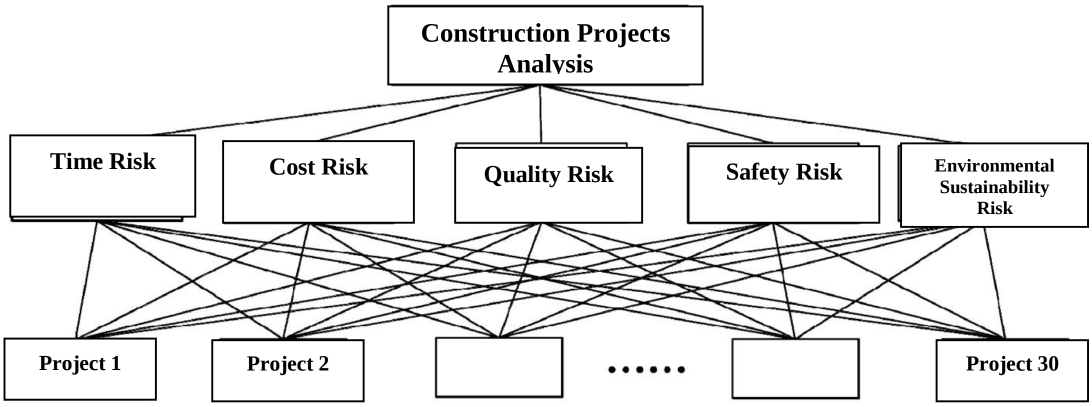

Figure 2.5 Hierarchical Structure of Decision Making in Construction Projects (Taylan et al., 2014)

As can be seen from Figure 2.5, the sub-criteria of each risk factor (e.g. sub-criteria of time risk, cost risk, etc.) are not considered in the process of construction projects analysis. In the present thesis, in addition to the main risk criteria, the related sub-criteria are also extracted from the literature, and are utilized in the process of project analysis.

In another recent study that has dealt with identification of risks associated with construction projects, some sub-criteria were considered for each of the time risk, cost risk, quality risk, safety risk, and environmental sustainability risk (Yazdani-Chamzini, 2014). These sub-criteria are proposed in Table 2.3.

Another major risk element in construction projects is the risk related to human resources, the importance of which is referred to in the research. Human resources risk is involved such things as lack of management competency, lack of experienced professional consultants, key personnel changes during project implementation, and workers' strike (Yazdani-Chamzini, 2014).

In order to summarize the related literature and to focus on Yazdani-Chamzini) (2014) and Taylan et al. (2014) studies, the identified risks of construction projects which will be used in the present research are listed in Table 2.3. It should be noticed that in the present study, a major risk criterion (human resources risk) has been added to the criteria considered by Taylan et al. (2014). Moreover, in contrast to that study which has only considered the main risk criteria, in the present study the sub-criteria of each main risk criterion, are extracted from the literature, and used in the process of construction projects analysis.

Table 2.2 The identified risks according to their main criteria and related sub-criteria

Row	Risk Factors (Main Criteria)	Sub-Criteria
1	**Time Risk**	Weakness in Construction Schedules
		Delay in Supply of Materials
2	**Cost Risk**	High Bid Price
		Increase in Price of the Materials
		Increase in the Work Cost
		Financial Problems
3	**Quality Risk**	Choosing Inappropriate Apparatus and Equipment
		Choosing Unsuitable Materials
		Machinery Failure
		Poor Quality of Work
4	**Safety Risk**	Collapse (Deficiency) of Construction
		Workers' Safety
		Unforeseen Disasters During the Work, such as Fire
5	**Environmental Sustainability Risk**	Physical Injury to the Workers
		Environmental Constraints
		Noise
6	**Human Resources Risk**	Lack of Management Competency
		Lack of Experienced Professional Consultants
		Workers' Strike

According to Sudbury and Suffolk (2003), Severity of a risk can be usually analyzed by two main risk parameters, i.e. Risk Likelihood (RL) and Risk Severity (RS). In any case, it must be noticed that severity of a particular risk is to great extent dependant on several factors such as human factors, workplace factors, materials factors and equipment factors, etc., which are difficult to be quantified in traditional methods

(Zeng et al., 2005). Various systematic models were found for risk management process analysis phase in the literature review. Kangari and Riggs (1989) divided these methods into two general categories:

- Classical Models (Probability Analysis): Like Monte Carlo simulations (AI-Bahar, 1988) and impact diagrams (Al-Bahar, 1988; Ashley,1984)
- Conceptual Models (Fuzzy Set Analysis): Like fuzzy sets (Kangari and Riggs, 1989)

Kangari and Riggs (1989) pointed out that probability models have two major deficiencies and constraints:

- Some of these models require very detailed quantitative information which is usually unavailable in the real world.
- The applicability of such models in risk analysis of actual construction projects is limited. This is mainly due to the fact that many decision making issues of contractors are imprecise and vague. Such features and characteristics are essentially subjective and conceptual, and classical models are not able to use subjectivity.

Zeng et al. (2007) dealt with such methods as Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Monte Carlo Analysis (MCA), Scenario Planning (SP), Sensitivity Analysis (SA), Failure Mode and Effects Analysis (FMEA), and Project Evaluation and Review Technique (PERT). Another method used for risk analysis in the related literature is the Analytic Hierarchy Process (AHP).

Winch (2002) believed that in order for the effective application of these difficult and complex quantitative techniques, accurate data is required. Unfortunately, obtaining such data is either difficult or not available in construction industry. Additionally, it is difficult to make use of this data for representing the uncertainties. Therefore, developing a risk analysis method to identify and assess the risks associated with construction projects, which eliminates the problem of needing accurate data, seems to be necessary.

The nature of construction projects involves some imposing uncertainties and depends on the individual's mentality in risk analysis process. This prevents the application of some risk assessment methods. The fuzzy logic technique is obviously beneficial in management of complex and not well-defined issues that occur in construction projects. For example, Tah and Carr (2000) applied the fuzzy logic for risk assessment in construction projects. Kuchta (2001) also conducted a study of risk analysis in construction projects. He analyzed the risks of construction projects by the use of fuzzy numbers. One other instance is the research by Baloi and Price (2003) in which they made use of the fuzzy set theory for risk management. Zheng and Ng (2005) also used the fuzzy set theory for investigation of the function of cost and time in the context of construction projects management, risk management and generativeness.

2.10 Analytic Network Process (Fuzzy)

The Analytic Hierarchy Process (AHP) is a mathematical method for solving the problems in multi criteria complex decision-makings. This method was developed by Professor Saaty in 1977.also Analytic Hierarchy Process is able to consider both qualitative and quantitative criteria in analysing the decision alternatives (Saaty, 1997).

The Analytic Network Process (ANP) is a generalized form of AHP and on the other hand, it particularly involves AHP. The ANP can be used in decision making issues which are more complex than AHP (Saaty, 2005).

This allows a systematic approach to all kinds of dependence and feedback in a decision making system. The AHP is based on four underlying axioms:

- Reciprocal Axiom: If element (A) is preferred over the element (B), then preference of element (B) to element (A) will be reciprocal.
- Homogeneity Axiom: Element (A) and element (B) must be homogenous and comparable; in other words, the priority of element (A) over element (B) cannot be zero or infinity.
- Synthesis Axiom: Each element in the hierarchy can depend on its higher element, and this dependence can be continued to the highest level in a linear manner.
- Expectation Axiom: Whenever a change occurs in the hierarchical structure, the analysis process should be repeated.

The rank structure is a fundamental basis of AHP, and the prerequisite to having a rank structure is that the possible priorities of a level do not depend on the lower elements and be independent from them; otherwise, the decision making system will be regarded as non-rank and with feedback, and there will be doubt in the application of the classic AHP.

According to the third axiom of AHP, dependences in a hierarchy must be linear (from top to bottom and vice versa). If there is a mutual dependency, i.e. the criteria weigh depends on the alternatives weight and the alternatives weight depends on the criteria weight, it is then out of the scope of hierarchical state, and produces a linear change network or system which involves feedback; in this case, in order to calculate the elements weight, hierarchical rules and formulae cannot be resorted. In this situation, the "Networks Theory" must be utilized in order to calculate the elements weight. Figure 2.6 illustrates the difference between hierarchy (linear) structure, and network (non-linear) structure (Ghodsipour, 2005).

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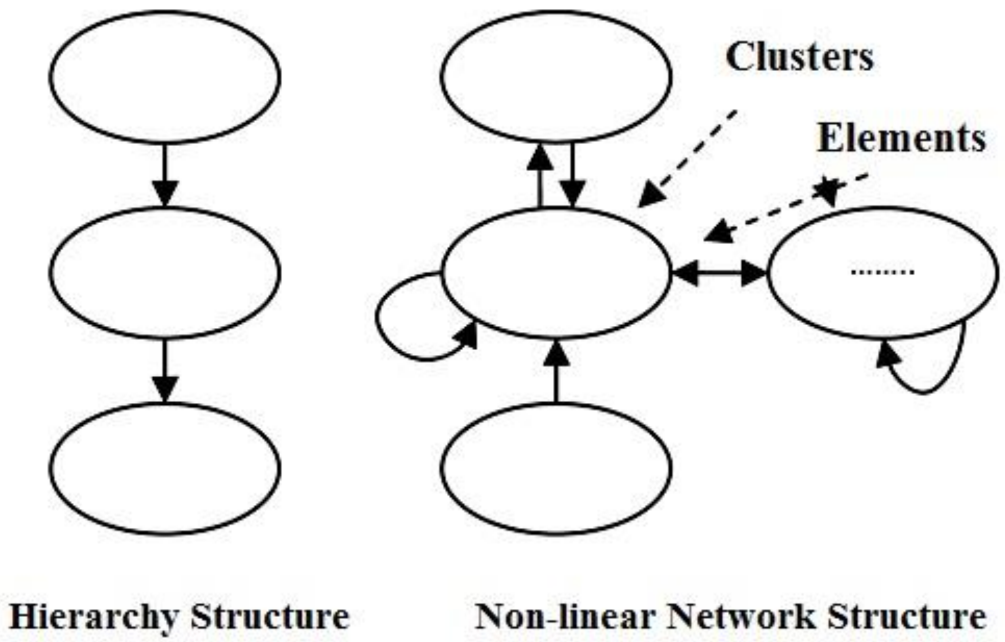

Figure 2.6 The Difference between Hierarchy (Linear) Structure, and Network (Non-linear) Structure (Ghodsipour, 2005)

The ANP involves two parts. The first part consists of a network of criteria and sub-criteria which constitute the interactions inside the system, and the second part is a network of relations between elements and clusters (Asgharpour, 2004).

The decision-making issue which is analyzed by ANP is studied through the network. Decision network is formed by clusters, elements and links. Cluster is a set of interrelated elements inside a network or sub-networks. All interactions and feedbacks inside the clusters are called the "inner dependences", and the interactions and feedbacks between the clusters are called "outer dependences". Inner and outer dependences are the best means for decision-makers who must consider the concepts of influencing and being influenced between the clusters and elements with respect to a particular element. In this case, systematic pairwise comparisons will be performed which include all combinations of the element/cluster relations. Just like AHP, the ANP makes use of the same scales (1 to 9). The decision makers can express their preferences between the numbers of each element pair, as equal importance (non-preference), somewhat more important, much more important, very much more important, and absolutely more important. These descriptive preferences are then turned to numerical values of 1, 3, 5, 7, and 9 and the values of 2, 4, 6, and 8 are considered as the intermediate values for comparisons between two consecutive judgments. The reverse of these values are used for the related transposed judgments (Mehregan, 2004).

After performing all pairwise comparisons, the integrated results will be obtained, and eventually the integrated results are combined with each other to produce the final result which is a set of priorities related to each alternative.

There are only a few risk management studies which use ANP technique for decision-making and analysis. In one of these studies, Ozorhon et al. (2007) dealt with prediction of the performance of international construction projects, through ANP method. Cheng and Li (2005) explained the implementation steps of ANP for prioritization of construction projects, using a practical example. In another research, using the ANP technique and considering the relations of evaluation criteria, Jung and

Seo (2010) dealt with evaluation and prioritization of R&D projects. Dikmen et al. (2007) also used ANP in their research to evaluate the construction projects and select the best one. In another study, this method was utilized for risk analysis in city bridge construction (Shih-Tong, 2007).

Some scholars have developed the ANP method in fuzzy conditions and have used it in the process of alternatives analysis. The use of fuzzy ANP creates a greater flexibility in decision-making process, and it is able to incorporate epistemic uncertainty in the analysis process. Uncertainty results from the lack of familiarity and knowledge about a phenomenon, parameter, a criteria value, etc. Fuzzy ANP is rarely used in construction management. According to the studies, there are only a few researches which have made use of the fuzzy ANP. In one of these studies, Ebrahimnejad et al. (2012) dealt with proposing a method of fuzzy group decision-making for selection of construction projects. The researchers used ANP and VIKOR methods for developing their proposed method. Afterwards, they compared the results with ANP method in absolute state, and offered the advantages of utilization of ANP in fuzzy state.

2.11 DEMATEL Method (Fuzzy)

The word DEMATEL stands for Decision Making Trial and Evaluation. This technique was proposed in 1971 by Fonetla and Gabus. DEMATEL technique, which is a decision-making method based on pairwise comparisons as well as Utilizes experts' judgments for extracting system factors and systematically structuring them. Thus through graph theory principles tries to propose a hierarchy of the present factors of a system. Along with their mutual interaction relations, so as to determine the intensity of the mentioned relations in a numerical score.

DEMATEL technique is used for identification and evaluation of the relationship of the criteria and for creation of the network relations diagram. Since directed graphs can better show the relationships within a system, DEMATEL technique is based on the graphs which can divide the factors into two cause and effect groups, and represent the relationship among them as a structural model.

DEMATEL technique was generally developed for evaluation of the most complex global issues. DEMATEL is also applicable for structuring a sequence of given information; so that it analyzes the intensity of relationships in a scoring method, investigates the feedbacks along with their significance, and accepts the non-transferable relations (Gabus, 1971).

Considering mutual relationships, the advantage of this method over the ANP technique is its clarity and transparency in reflecting the mutual relationships among a large series of components; so that with a better mastery the experts are able to express their views about the impacts (direction and intensity) between the factors. It is worth mentioning that the resulting matrix of DEMATEL technique (internal relations matrix) is in fact a constituent part of the supermatrix. In other words, DEMATEL technique does not act directly, but it is a subsystem of such bigger systems as the ANP.

Investigate on dependent and independent part of DEMATEL technique is one of the main functions and most important reason for wide utilization of this method in problem solving procedures. Through classification of a large series of complex elements in the form of cause and effect groups, DEMATEL technique puts the decision-maker in better circumstances of understanding the relations. This leads to a better knowledge of elements position and role in the process of mutual impacting.

DEMATEL is a comprehensive method for creation and analysis of a causal model among the elements in complex issues (Wei and Yu, 2007). By making use of DEMATEL, it is possible in management and social issues to classify and organize the mutual impacts of a large number of factors affecting a particular issue (Uzunovic et al., 2000).

DEMATEL can be used not only as a tool for classification of factors affecting a particular issue, but also as an appropriate criterion for measurement of the extent of the internal relations among factors. For instance, through fuzzy scales and DEMATEL, Tseng (2009) proposed an appropriate analysis method for investigation of customer satisfaction of service qualities of hotels. The internal relations among the influential factors in this issue were divided into cause and effect relationships through group decision-makings. Lin and Wu (2008) also made use of DEMATEL to investigate the factors affecting the selection of R&D projects. In other cases, DEMATEL was used in order to investigate the influential factors in electronic learning. According to Tzeng and Chiang (2007), although lots of researches have been carried out on the analysis of factors affecting the E-learning, still an appropriate quantitative method has not been utilized which is able to reveal first the internal impact and relations between these factors and second the existence of uncertainty condition. In the present research, the relationships which result from the dependency between elements are analyzed via DEMATEL. Results of the mentioned research have been used for determination of priority of the elements that impact the risk in construction projects.

DEMATEL technique, which was proposed by American scientists for the first time, was a method for complex issues. This technique was based on graph theory, and was able to solve problems through a simple method. However, the defect of DEMATEL technique, i.e. decision-making in uncertainty condition, led to development of fuzzy DEMATEL technique. The fuzzy DEMATEL facilitates decision-making in the condition of uncertainty of the environment, via fuzzy linguistic variables. This technique can be applied in the contexts of production, organizational management, information system and social sciences (Quan et al., 2011). Additionally, this technique can solve all the problems an organization would face, by making use of group decision-making in fuzzy condition (Jassbi et al., 2010).

Several applications of DEMATEL method have been identified in the related literature. For example, Moradi et al. (2013) have used this method for identification of factors influencing the investor's decision-making for purchase of stock.

Jamali and Hashemi (2011) used fuzzy DEMATEL for investigation of the relationships among the factors affecting risk in IT projects of Mellat Bank of Boushehr Province, Iran. Other cases of utilization of this method are the identification of cause and effect relationships among strategy, culture, structure, organizational efficiency, and knowledge management variables in a study by Aghaei et al. (2011) and analysis of perfect production in a study by Jafar Nezhad et al. (2011). In addition, Shieh and Huang (2010) used DEMATEL method for identification of success factors in hospitals service quality.

2.12 TOPSIS Method (Fuzzy)

TOPSIS technique was first introduced by Hwang and Yoon (1981) for ranking the alternatives. In this method, the best alternative is the one with shortest distance from the positive ideal solution and longest distance from the negative ideal solution. This method was proposed in several steps:

Step 1: Calculation of the normalized matrix. Components of this matrix can be extracted from Eq. 2.1:

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_{j=1}^{J} x_{ij}^2} \qquad \text{Eq. 2.1}$$

In this equation, *J* and *n* are respectively the number of alternatives (number of classification algorithms) and the number of criteria (performance indices). For the $A_{ij,}$ alternative, the performance index of i th criterion is shown by $x_{ij.}$

Step 2: Development of the w_i weight set for each criterion and calculation of the weighted normalized decision matrix. Components of this matrix are calculated from the formula Eq. 2.2, in which w_i is weight of the i th criterion, and $\sum_{i=1}^{n} w_i = 1$:

$$v_{ij} = w_i x_{ij}, i = 1,..., J; i = 1,..., n \qquad \text{Eq. 2.2}$$

Step 3: Calculation of the positive ideal solution S^+ which can be done by Eq. 2.3:

$$S^+ = \{v_1^+,....,v_n^+\} = \{(\max_j v_{ij} \mid i \in I'), (\min_j v_{ij} \mid i \in I'')\} \qquad \text{Eq. 2.3}$$

in which, I' is the benefit criterion and I'' is the cost criterion.

Step 4: Calculation of the negative ideal solution S^- which can be done via Eq. 2.4:

$$S^- = \{v_1^-,....,v_n^-\} = \{(\min_j v_{ij} \mid i \in I'), (\max_j v_{ij} \mid i \in I'')\} \qquad \text{Eq. 2.4}$$

Step 5: Calculation of the separation measures, i.e. the distance, using the n dimensional Euclidean distance. The distance of each alternative from the positive ideal solution, is given by Eq. 2.5:

$$D_j^+ = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^+\right)^2},\ j = 1,\dots,J \qquad \text{Eq. 2.5}$$

The distance of each alternative from the negative ideal solution, is given by Eq. 2.6:

$$D_j^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^-\right)^2},\ j = 1,\dots,J \qquad \text{Eq. 2.6}$$

Step 6: Calculation of the relative closeness index (similarity), by Eq. 2.7:

$$R_j^+ = \frac{D_j^-}{D_j^+ + D_j^-},\ j = 1,\dots,J \qquad \text{Eq. 2.7}$$

Step 7: Ranking of the alternatives by the use of R_j^+. The greater the R_j^+ is, the better rank the alternative will attain.

In the related literature, AHP and TOPSIS methods have been frequently used for different decision-making issues. There are two main differences between AHP and

TOPSIS. In AHP, pairwise comparisons must be done for the alternatives and attributes, but in TOPSIS there is no pairwise comparison. In AHP, the hierarchy of the alternatives and attributes is used, but it is not used in TOPSIS. Today's modern developed TOPSIS methods do not consider the hierarchy in multiple-criteria issues. Fewer pairwise comparisons in hierarchical fuzzy TOPSIS, gives it a preference over the AHP.

The hierarchical fuzzy TOPSIS is thoroughly discussed in the next part. Several scholars have developed the TOPSIS method in fuzzy condition and have used it for alternatives analysis process. TOPSIS is able to incorporate the identified uncertainties in the analysis process.

Fuzzy TOPSIS is frequently applied in construction management. For instance, in a recent study, Taylon et al. (2014) used fuzzy TOPSIS for analysis of civil projects on the basis of risk factors. Results of that research were compared by the fuzzy AHP method. Results revealed that both methods had consistent results. In another research in construction management scope, the fuzzy TOPSIS was utilized for analysis and selection of contractors for construction projects (Zavadskas et al., 2010). TOPSIS method was also used in a study for development of a decision-making support system, in which the researchers used the developed system for analysis of construction projects managers.

Using fuzzy TOPSIS approach, Golbaharzadeh et al. (2013) dealt with analysis of the contractors in another research. Application of this method has been proved for analysis of the contractors in oil projects in Iran. Additionally, this method was used in another study for evaluation of contractors' qualifications in construction projects

(Nieto-Morote and Ruz-Vila. 2012). A risk analysis model was proposed by KarimiAzari et al. (2011) for analysis of the risk in construction projects, where the researchers had used TOPSIS method.

From among the other applications of fuzzy TOPSIS method in management scope, the papers by Khazaeni et al. (2013) and Ravanshadnia et al. (2013) can be referred, which used this method for risk analysis of civil and construction projects.

Chapter 3

METHODOLOGY

3.1 Introduction

The research method, organized process of analysis for determination of an indefinite scientific situation (Bazargan, et al., 1997). In other words, scientific method is a particular and systematic method that is always looking for the truth. Researching can be defined as a systematic and organized activity for examination of a particular problem which needs a solution. Every research consists of a series of phases that are conducted with the aim of finding an answer to problems of the organization. In order to attain any objective and aim, recognizing the correct path and knowing how to achieve the objectives are among the most significant phases. Utilization of an appropriate research method is one of the most important characteristics of a scientific study which aims at finding the reality, and selection of an appropriate research method depends on the objectives, nature and subject of the research as well as the implementation facilities (Khaki, 2003). The importance of this part is due to the fact that through this, the researchers can repeat a particular research and compare the results. Hence, it is necessary for the researchers to pay enough attention to this phase, and discuss their research methodology clearly and comprehensively; so that future researchers will be able to reexamine or test the research again via the same research method if they desire so. This chapter deals respectively with research type, examination of the case study, research tools and the statistical population.

3.2 Research Type

Generally speaking, research methods in behavioural sciences can be classified according to two criteria: a) research objective, b) data collection method. Regarding the objective, the present study is an applied research because the aim of applied researches is to develop the practical knowledge in a particular field. In other words, practical researches are guided toward scientific application of knowledge, and results of such studies can aid the adoption of better decisions in the research population (Sarmad et al., 2004). Since the evaluation of construction projects is addressed, and also an appropriate model for the mentioned subject is aime to be proposed, this study is considered to be an applied research; because as soon as the research is over, its findings can be applied to the research population. Regarding the data collection, the present research is a descriptive- case study research because descriptive researches include a set of methods which aim at describing the studied condition or phenomenon.In what follows, each of these items will be dealt with.

3.2.1 Applied Research

Applied researches apply the theories, rules, principles and techniques codified in basic researches for the sake of solving executive and actual problems. These studies usually focus on the most dignified actions, and they usually pay less attention to the causes. The aim of applied researches is to develop practical knowledge in a particular field. Putting it differently, applied researches are guided toward scientific application of knowledge (Bazargan, et al., 1997). The following properties can be mentioned for applied researches:

- Testing the effectiveness of scientific theories in a particular field
- Determining the empirical relationships in a particular domain
- Adding to practical knowledge in a particular field

- Promoting the research and methodology in a particular field
- Providing a body of verified practical knowledge in particular field (Sarmad et al., 2004)

3.2.2 Descriptive Research

The purpose of this type of research is detailed description of components of a situation or a set of circumstances. Descriptive research describes and interprets what really exists, and notices the current conditions and relationships, conventional beliefs, current processes, visible works and procedures in progress (Khaki, 2003). Regarding the method of data collection, research can be divided into the following categories:

- Descriptive research (non-experimental)
- Experimental research

Descriptive research includes a set of methods which aim at describing the study conditions or phenomena. Conduction of descriptive research can be merely for better understanding of the current conditions or for aiding the decision-making process. Descriptive research can be classified into the following subcategories:

- Survey research
- Correlation research
- Action research
- Case study
- Ex– post Facto research (Bazargan, et al., 1997)

Descriptive research, which presents data in a meaningful way, can be beneficial in the following cases:

- Identifying the characteristics of a group in a studied situation

- Contributing to system-oriented thinking about a situation
- Providing viewpoints for the necessity of further examination and research
- Aiding the special decision-makings (Sakaran, 2002)

Considering what was explained pervious, the present research is of descriptive/case study type. The case study here is related to a civil construction company that are active in construction projects in IRAN.

3.3 Research Approach

As it was explained in the previous chapter, construction projects evaluation model has been provided by different approaches. These are usually qualitative and quantitative approaches. Any of the approaches have their own special tools and techniques. In the present research, the qualitative approach is utilized for evaluation of construction projects on the basis of risk factors; however, in this research in consequence of the following reasons the qualitative approach is merely used:

- Prioritization and quantitative analysis of risk criteria requires the accessibility to accurate information about these criteria in construction projects; and owing to the fact that the researcher did not access such information, it was not possible to perform a quantitative analysis.
- Assessments and judgments about the influential risk factors in projects is well possible by the means of qualitative analysis, and considering what was discussed in the literature review in chapter two, it was revealed that the qualitative methods are currently more frequently used for evaluation and prioritization of construction projects.

- Most of the risk factors that are involved in the evaluation of construction projects are not normally quantitative (for example the quality risk, safety risk, etc. have a qualitative nature rather than a quantitative one). It is worth mentioning that the quantitative analysis is most frequently used for those criteria that have a numerical nature (e.g. final cost, delivery time, etc.).

Hence, according to the above-mentioned reasons and the executive and practical constraint in this thesis, merely the qualitative analysis method has been adopted.

3.4 Research Tools

In order to provide a model for evaluation of construction projects on the basis of risk factors, it is necessary to determine the hierarchical structure according to experts' opinions. Consequently, in the present research the determination of risk factors which include main risk criteria and sub-criteria, and also the creation of a network structure were both carried out on the basis of the related literature and experts' opinions. Accordingly, in order to collect the experts' opinions, questionnaire was used as the research tool. In fact, three questionnaires related to FUZZY ANP and FUZZY DEMATEL and FUZZY TOPSIS questions were used in this research. The designing foundation of these questionnaires was based on pair-wise comparisons. The amount of importance of various risk criteria and sub-criteria in construction projects evaluation process was determined by the ANP questionnaire, and the relationships among the factors (risk criteria and sub-criteria) were determined through the DEMATEL questionnaire. These three designed questionnaires are presented in full details in Appendix A.

3.5 Identification of Risk Criteria and Sub-Criteria of Construction Projects and Their Network Structure

Before designing the research tool, it is necessary to identify its primary pre-requisite, i.e. risk criteria and sub-criteria which impact the evaluation process of construction projects, and to create their network structure. According to what was discussed in chapter 1 and considering the objectives of the present study, the identification of risk criteria and sub-criteria is regarded as the most important phase in the process of projects evaluation; because without complete identification of risk factors and understanding different dimensions of construction projects evaluation, it is not possible to deal with other phases of projects evaluation.

Taking into account that in the literature review, relatively comprehensive and extensive studies have been carried out in identification of the risk factors that affect construction projects (these criteria along with the scholars who dealt with these criteria in construction projects evaluation were fully discussed in chapter 2). These studies are cited frequently in the risk factors identification part.

In addition to results of similar researches, checklists are also regarded as another useful and acceptable tool for defining and identifying the risk factors by most researchers; therefor, checklist was used here for domestication and completion of risk factors that affect the evaluation of construction projects. The risk factors of evaluation of construction projects to be relevant to the environmental condition of Iran as well as to the studied civil construction condition. This check list including the main criteria and also sub criteria which have enough adaptability by environmental situations of Iran. Checklist is a tool that enables construction managers to think about unknown criteria and to include them in their available lists. Therefore, interviews about the checklist were performed with 20 experts in Mahab Ghodss Construction Corporation, and eventually some risk factors were determined which had the greatest conformity to the construction status in Iran. It must be noted that the three factors of delay in payment of costs in accordance with the contract, disturbance to residents near the construction site, and key personnel changes are from among the items that are added from checklist results to risk factors list.

In fact, identification of the criteria in this research was conducted through a combination of library studies and field surveys. Table 3.1 illustrates the factors selected by experts for evaluation of construction projects.

Table 3.1 The identified risks used in the present research

Row	Risk Factors (Main Criteria)	Sub-Criteria
1	**Time Risk (T)**	Weakness in Construction Schedules **(T1)**
		Delay in Supply of Materials **(T2)**
2	**Cost Risk (C)**	High Bid Price **(C1)**
		Increase in Price of the Materials **(C2)**
		Increase in the Work Cost **(C3)**
		Delay in Payment of Costs in Accordance with the Contract **(C4)**
		Financial Problems **(C5)**
3	**Quality Risk (Q)**	Choosing Inappropriate Apparatus and Equipment **(Q1)**
		Choosing Unsuitable Materials **(Q2)**
		Machinery Failure **(Q3)**
		Poor Quality of Work **(Q4)**
4	**Safety Risk (A)**	Collapse (Deficiency) of Construction **(A1)**
		Workers' Safety **(A2)**
		Unforeseen Disasters During the Work, such as Fire **(A3)**
5	**Environmental Sustainability Risk (S)**	Disturbance to Residents Near the Construction Site **(S1)**
		Physical Injury to the Workers **(S2)**
		Environmental Constraints **(S3)**
		Noise **(S4)**
6	**Human Resources Risk (HR)**	Lack of Management Competency **(HR1)**
		Lack of Experienced Professional Consultants **(HR2)**
		Key Personnel Changes **(HR3)**
		Workers' Strike **(HR4)**

3.6 Validation of the Research Tool

The aim of validation is to ensure the clarity, accuracy, and meaningfulness of questionnaire's expressions for the respondents. In this phase, a group of scholars of construction and civil engineering domain were tentatively asked to fill the questionnaire in the presence of the researcher and express their ideas to the researcher, after carefully reading explanations of the questionnaire, and being informed about the nature of risk factors. Consequently, before distribution of the questionnaire and collection of experts' opinions, validity of the questionnaire was confirmed by a group of scholars of construction projects, including the following people:

- Two professors of construction and project management
- Three project managers of construction projects from two contractors active in construction projects
- Two doctorate level students of construction and project management, and one master level student with the same major who were all experienced in construction projects.

Since the designed questionnaires are based on pair-wise comparisons, it is necessary to calculate the consistency ratio (CR) of the data of pair-wise comparison matrices before using the questionnaire's data and information. The consistency ratio of the answers should be less than the acceptable consistency ratio. After collecting the pilot questionnaires, it was revealed that the consistency ratio of answers of some experts, who were not familiar with pair-wise comparisons, was considerably more than the acceptable consistency ratio. Consequently, by bringing an example, the respondents were asked at the end of the first page of the questionnaire to pay attention to the logical consistency of their answers.

3.7 Statistical Population

The purpose of this phase of research is evaluation and prioritization of construction projects on the basis of risk factors of construction projects. Hence, it is necessary for the population who will fill the questionnaire to have enough experience in the field of construction and civil construction projects, as well as the risk management scope. Construction projects evaluation is a multidimensional issue, understanding of which requires full command of such domains as risk management, project management, construction, project operations, management, financial management, etc.; therefore, the target expert population must be selected in a way that the members have sufficient command of the mentioned domains. Accordingly, in the present research, the construction projects managers of Mahab Ghodss Consulting Engineering Company were selected as the target expert population of the study. This company has carried out large construction projects; for instance, Mahab Ghodss Co. has studied and designed more than 200 large dams, has supervised the construction of more than 45 dams and has designed and controlled many building operations. The present study deals with prioritization of six in-progress civil projects of Mahab Ghodss Co.

It is worth mentioning that in the present study, the method of selection of the aimed population is similar to a research conducted by Tueysuez and Kahraman (2006), in which 11 information technology project managers were used for IT project risk analysis.

Chapter 4

THE PROPOSED METHOD

4.1 Introduction

In this chapter, first the proposed model for evaluation and prioritization of construction projects on the basis of risk factors will be explained. This proposed model is a combination of the three methods of DEMATEL, ANP and TOPSIS in fuzzy conditions. In other words, the output of each method will become the input of the next method. After describing the proposed model, it will be implemented in a case study.

4.2 The Proposed Model

As discussed before, the proposed model is made up of the integration of three multi-criteria decision-making methods. In general, the main phases of the proposed model can be mentioned in the following three phase (A), (B) and (C):

- A is Application of Fuzzy DEMATEL, the fuzzy DEMATEL method was used for extraction of the relationships among main risk criteria and their sub-criteria. Output of this phase was used for formation of the super-matrix in the second phase, the analytic network process.
- B is Application of Fuzzy Analytic Network Process (ANP), using the pair-wise comparisons and considering the interrelationships among main risk criteria and their related sub-criteria, a super-matrix was created. Afterwards, through performing some calculations, the weight of main risk criteria and their

sub-criteria was determined. The weights as the outputs of this phase were regarded as the input for the third phase.

- C is Application of Fuzzy TOPSIS, by applying the calculated weights of phase B, the weighted decision-making matrix was calculated. Subsequently, using fuzzy TOPSIS, the act of prioritization of construction projects was performed.

In what follows, these three phases are described in full details and illustrated in Figure 4.1.

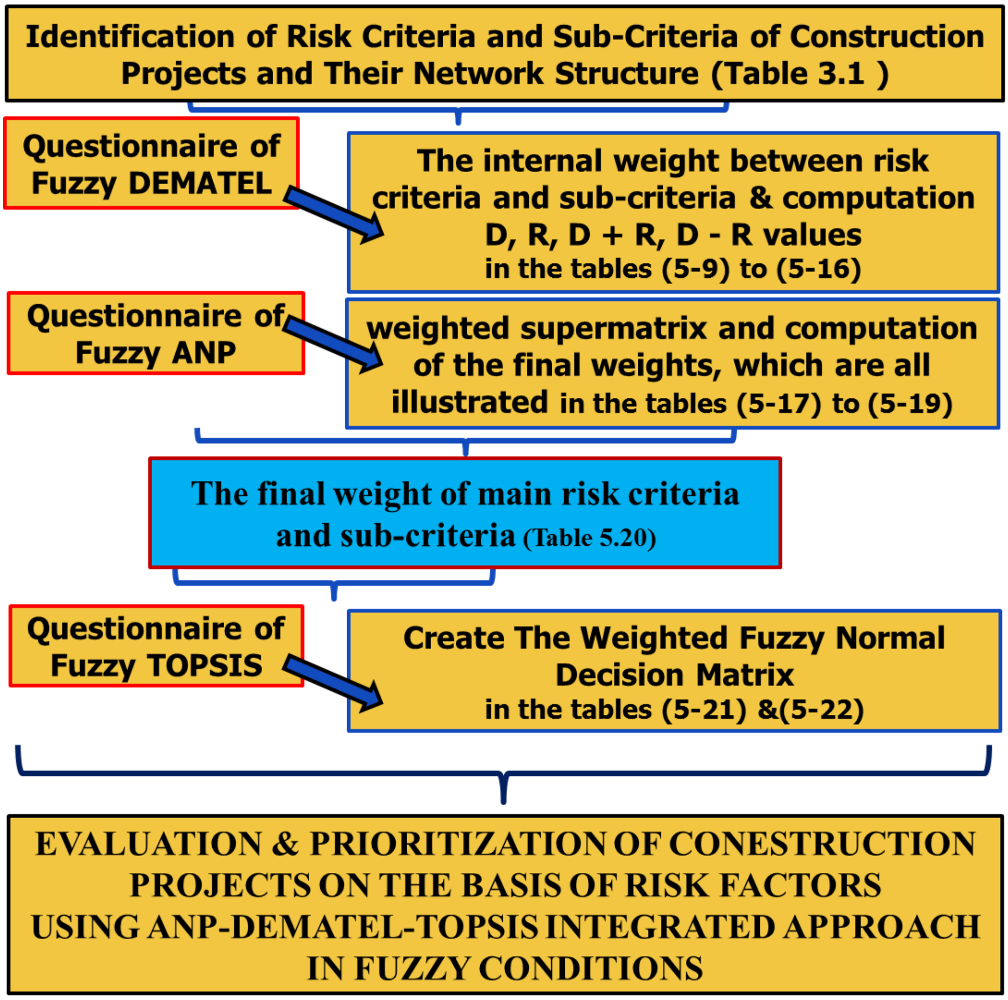

Figure 4.1 The PROPOSED METHOD

4.2.1 Fuzzy DEMATEL (A)

Practically, one is often confronted with data that are derived from human judgments and seem to be full of ambiguity and uncertainty. This makes the decision-making process more complicated. Hence, application of traditional methods which use definitive values seem to be inappropriate. Therefore, in the present study the fuzzy form of DEMATEL method was utilized. This makes the results more accurate, and the decision-making process will be performed easily.

The method and steps of execution of fuzzy DEMATEL is also completely based on its deterministic mode steps except that in this fuzzy form, with utilizing the fuzzy values, the related defuzzification calculations and operations have to be done (Lin & Wu, 2008). For conduction of fuzzy DEMATEL method, the following steps were implemented:

4.2.1.1 Setting Up the Direct-Relation Fuzzy Matrix

In this research, in order to investigate the interrelationships between the factors, experts were asked to perform pair-wise comparisons between the factors regarding the level of influence of factor *i* on factor *j*. Thus, in order to resolve the ambiguity problems for the analyses made by humans, the scale used in deterministic mode were altered, and the fuzzy linguistic scale was used which is expressed in five linguistic terms (very high influence, high influence, low influence, very low influence, no influence) for different degrees of influence. The corresponding positive fuzzy numbers of the linguistic terms used in this research were derived from a research by Yu and Lee (2007). These numbers are illustrated in Table 4.1.

Table 4.1 Linguistic variables and their corresponding fuzzy numbers

Linguistic Scale Expressions	Fuzzy Triangle Numbers
Very High Influence (VH)	(0.75,1.0,1.0)
High Influence (H)	(0.5,0.75,1)
Low Influence (L)	(0.25,0.5,0.75)
Very Low Influence (VL)	(0,0.25,0.5)
No Influence (NO)	(0,0,0.25)

4.2.1.2 Defuzzification of Direct-Relation Fuzzy Matrix

In order to obtain the interrelationships between the factors, the initial direct relations must be defuzzified and be transformed to the deterministic mode. Consequently, CFCS method was used for defuzzification of the decision-making results. The purpose of this first step is to construct the matrix$\tilde{Z}$, which is called the initial direct-relation matrix. These calculations do not have much impact on accuracy of the results in terms of transformation of the opinions to crisp numbers. Suppose that ${z_{ij}}^{k} = (l_{ij}^{k}, m_{ij}^{k}, r_{ij}^{k})$ is the triangular fuzzy entry of fuzzy matrix$\tilde{Z}$, which denotes the fuzzy evaluation resulting from the k^{th} evaluation of the expert, about the level of influence of criteria *i* on criteria *j*. Likewise, a similar matrix is obtained for other decision makers. In order to defuzzify the experts' opinion by CFCS method, the following five stages (a, b, c, d and e) and (Eq. 4.1) to (Eq. 4.8) should be followed (Opricovic and Tzeng, 2003):

4.2.1.2.1 Establishment of the normalized direct-relation matrix (a)

In this stage, in order to normalize the direct-relation matrix, the CFCS method was used, which was first introduced by Opricovic and Tzeng (2003). In order to establish the normalized matrix of the direct-relation matrix, the equations 4.1 to 4.3 were used, in which ($\Delta_{\text{min}}^{\text{max}} = \max \mathrm{r}_{\mathrm{ij}}^{\mathrm{k}} - \min \mathrm{l}_{\mathrm{ij}}^{\mathrm{k}}$):

$$\mathbf{xl_{ij}^{k} = (l_{ij}^{k} - minl_{ij}^{k})/\Delta_{min}^{max}},$$ Eq. 4.1

$$\mathrm{xm_{ij}^{k} = (m_{ij}^{k} - minl_{ij}^{k})/\Delta_{min}^{max}},$$ Eq. 4.2

$$\mathrm{xr_{ij}^{k} = (r_{ij}^{k} - minl_{ij}^{k})/\Delta_{min}^{max}},$$ Eq. 4.3

4.2.1.2.2 Calculation of the normal left (ls) and right (rs) values (b)

$$\mathbf{x}\boldsymbol{ls}_{\mathbf{ij}}^{\mathbf{k}} = \mathbf{xm_{ij}^{k}/(1 + xm_{ij}^{k} - xl_{ij}^{k})}$$ (Eq. 4.4

$$\mathrm{x}rs_{\mathrm{ij}}^{\mathrm{k}} = \mathrm{xr_{ij}^{k}/(1 + xr_{ij}^{k} - xm_{ij}^{k})}$$ Eq. 4.5

4.2.1.2.3 Calculation of the final definite normal value (c)

$$\mathbf{x_{ij}^{k} = \left[xls_{ij}^{k}\left(1 - xls_{ij}^{k}\right) + xrs_{ij}^{k}xrs_{ij}^{k}\right]/[1 - xls_{ij}^{k} + xrs_{ij}^{k}]}$$ Eq. 4.6

4.2.1.2.4 Calculation of the final definite values (d)

$$\mathbf{z_{ij}^{k} = min\ l_{ij}^{k} + x_{ij}^{k}\Delta_{min}^{max}}$$ Eq. 4.7

4.2.1.2.5 Combining the corresponding final definite values with p xperts' opinion (e)

$$\mathbf{z_{ij} = \frac{1}{p}\left({z_{ij}}^{1} + {z_{ij}}^{2} + \cdots + {z_{ij}}^{P}\right)}$$ Eq. 4.8

The Z_{ij}Z represents the level of influence of criteria *i* on criteria *j*.

4.2.1.3 Normalizing the Direct-Relation Defuzzificated Matrix

Direct-relation matrix Z can be transformed to a normalized direct-relation matrix through application of equations 4.9 and 4.10 (Ying, et al., 2004).

$$\mathbf{X} = \mathbf{s.Z} \qquad \text{Eq. 4.9}$$

$$s = \min\{1/max_{1\le i\le n} \sum_{j=1}^{n} z_{ij}, 1/max_{1\le j\le n} \sum_{i=1}^{n} z_{ij}\} \ , \ \ i,j = 1,2,\dots,n \qquad \text{Eq. 4.10}$$

4.2.1.4 Establishment of the Total-Relation Matrix

When matrix X , i.e. the normalized direct-relation matrix, was computed, the total-relation matrix T was computed by the equation 4.11 in which I is the identity matrix (Tzeng, et al., 2007).

$$\mathbf{T} = \mathbf{X}(\mathbf{I} - \mathbf{X})^{-\mathbf{1}} \qquad \text{Eq. 4.11}$$

It must be mentioned that the normalized matrix T can be also used for an estimation of the internal weight between the intended criteria in ANP model. In the present research, the normalized matrix T was used for finding the internal relationships between the main risk factors and the internal weight of their relations. Thus, in this study the outputs of this section were used for the input of the second phase of the proposed model.

4.2.1.5 Creation of the Causal Diagram

Elements of the rows and columns of matrix T are altogether named respectively and as D&R vectors, which can be calculated by Eq. 4.12 to Eq. 4.14. Afterwards, the horizontal axis of the diagram or the so called “importance axis” was computed, which represents the degree of importance of the related criteria and is computed through the sum of D and R $(D + R)$ vectors. Similarly, the vertical axis of the diagram or the so called “dependence axis” was computed by $(D - R)$ relation. Through this vector, the criteria could be divided into two groups of cause and effect. Generally, when $(D - R)$ is a positive value, the related criterion belongs to the cause group, and otherwise it belongs to the effect group. Accordingly, the causal diagram can be obtained by drawing some points with $(D + R, D - R)$ coordinates and it provides valuable information for future decision-makings.

$$\mathbf{T} = [\mathbf{t_{ij}}]_{\mathbf{n\times n}}, \quad \mathbf{i}, \mathbf{j} = \mathbf{1}, \mathbf{2}, \ldots, \mathbf{n} \qquad \text{Eq. 4.12}$$

$$D = [\sum_{j=1}^{n} t_{ij}]_{n\times 1} = [t_{i.}]_{n\times 1} \qquad \text{Eq. 4.13}$$

$$R = [\sum_{i=1}^{n} t_{ij}]_{1\times n} = [t_{.j}]_{n\times 1} \qquad \text{Eq. 4.14}$$

4.2.2 Analytic Network Process (B)

The analytic network process does not only consider a hierarchical structure of the issue; rather it models the issue via a system with feedback approach. A system with feedback can be shown with a network in which the nodes represent the levels or the components (Asgharpour, 2004). The structural difference between a hierarchical structure and a network structure was previously shown in Figure 2.6.

Elements in a node (or level) may affect all or some parts of the elements in other nodes. There may be source (original) nodes, intermediate nodes, and lower nodes in a network. The relationships within a network are shown with an arrow, and the arrow direction determines the dependency direction. Systems with feedback refer to the manner of attention to outer and inner dependencies with feedback. The interdependence between two nodes is called outer dependency, which is illustrated by a bidirectional arrow, and the inner dependency of the elements of a node is shown by a round arrow.

The analytic network process in deterministic mode involves four major steps (Qodsipour, 2005) which are:

4.2.2.1 Creating a Model and Structuralizing the Issu

The issue must be clearly stated and decomposed to a logical system like a network. This structure can be obtained by making use of the decision-makers' opinion and through such methods as brain-storming or other appropriate methods.

4.2.2.2 Pair-Wise Comparisons and Priority Vectors

Just similar to the analytic hierarchy process method, in the analytic network process the decision-making elements in each part are compared in pair-wise manner with regard to their level of importance in the criteria control, and the parts themselves are compared in pair-wise manner with regard to their influence on the objective. In a framework of pair-wise comparisons, the decision-makers are asked the question that what impacts can two elements or parts have on their upper hand criteria.

In addition, if there exists an interrelationship between the decision-making elements of a part, the level of influence of other factors on it must be shown using pair-wise comparisons and computing the eigenvector for each element. The relative importance is obtained through a relative scale. For instance, scale of 1 to 9 can be used, while the score 1 represents the equal importance of two elements in comparison with each other and the score 9 represents the higher importance of an element (matrix row) compared with the other (matrix column) (Mehregan, 2004).

In a pair-wise comparison matrix, the value of the opposite side is inverse; that means $a_{ij} = \frac{1}{a_{ij}}$ where a_{ij} represents the relative importance of the i^{th} element in comparison with the j^{th} element. Similar to analytic hierarchy process, in analytic network process the pair-wise comparisons are performed in the framework of a matrix, and the local priority vector with an estimation of the relative importance of the elements (or parts) is obtained, which is the result of $\lambda_{\max} W = AW$; where A is the pair-wise comparison matrix, W is the eigenvector, the largest special amount of matrix A. It is worth mentioning that in 1980, Saaty (2005) proposed several algorithms for estimation of W.

4.2.2.3 Formation of the Supermatrix

The concept of supermatrix is similar to Markov chain process. The supermatrix is able to limit the coefficients in order to calculate all priorities resulting from the aggregated impact of each element on the other interacting elements. When regardless of the goal, a network merely involves two clusters of criteria and alternatives, the matrix approach proposed by Saaty and Takizawa (1986) can be used for dealing with dependencies of the elements in a system. They asserted that in order to obtain the general priorities in system with mutual interactions, the local priority vectors must be inserted into specific columns of a matrix which is here referred to as supermatrix. A supermatrix is in fact a sectional matrix, with each section representing the relationship between two groups (parts or clusters) of a system. Suppose that a decision system has

C_k decision components, and $K = 1,2,...,n$, and each K component has M_k which are shown by $e_{k1}, e_{k2},....,e_{km}$. The local priority vectors obtained from the second phase which are grouped on the basis of the direction of influence from another part or within one part are placed in their appropriate positions in the supermatrix according to the circle arrow as shown in Figure 4.1:

$$W = \begin{pmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{21} & W_{22} & \cdots & W_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ W_{n1} & W_{n2} & \cdots & W_{nn} \end{pmatrix} \quad , \quad W_n = \begin{pmatrix} 0 & 0 & 0 \\ W_{21} & 0 & 0 \\ 0 & W_{32} & I \end{pmatrix}$$

Figure 4.2 The supermatrix of a linear network, AHP (saaty, 2005)

Where W_{21} the vector of the influence of the target on criteria is, W_{32} is the matrix of the influence of the criteria on each alternative, and I represents the identity matrix, and zeroes denote the lack of impressibility of independent elements (Saaty, 2005).

In this example, if there exists an inner dependency (relationship) between criteria, the hierarchy is replaced by network in which case the supermatrix W_n will be as shown in Figure 4.2, where W_{22} represents this inner dependency (Saaty, 2005):

$$W_n = \begin{pmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & I \end{pmatrix}$$

Figure 4.3 The supermatrix of a Non-linear network, ANP (saaty, 2005)

It must be noted that in cases that there are mutual interactions of the elements in one part and below two parts, the zeroes can be replaced too. Since there is usually dependency among the clusters in a network, the 1 columns of the matrix will be more than one. What should be taken into account here is that the normalized matrix T can be used for an estimation of the internal weight between risk main factors and sub-factors of a supermatrix.

4.2.2.4 Selection of the Final Weight and Determination of the Best Alternative

In case the established supermatrix of the previous phase covers the whole network, the priority weights can be found in the alternatives column of a normalized supermatrix. On the other hand, if a supermatrix merely includes interrelated parts, there is the need for more calculations in order to find general priorities of the alternatives. The final preferences for each alternative can be obtained by $\underset{k \to \infty}{Lim} (W_n)^{2k+1}$ (Saaty, 2005); where W_n is the study supermatrix and *k* is an arbitrarily large number, and exponentiation of the supermatrix enables the convergence and consequently the stability of the weights. In this situation, the final weight of the sub-criteria is revealed and also eventually the alternative with greater priority can be chosen as the ideal option. What should be taken into account is that these complicated calculation steps can be easily performed by the Super-Decisions software, and accordingly the difficulty of this method is practically eliminated.

It should be noted that in the present research, the analytic network process was just used for determination of the final weight of criteria in which the internal and external relationships of the risk factors are applied. These weights were utilized as the input for fuzzy TOPSIS method.

4.2.2.5 Fuzzy Analytic Network Process (ANP)

The steps which have been described in the previous topics relate to ANP calculations in non-fuzzy mode. However, so many decisions in the real world involve unclear and equivocal human utterances. In order to integrate the experiences, opinions and ideas of a decision maker, it is better to turn the linguistic expressions into fuzzy numbers. In order for valuation and prioritization of the preferences, the ANP method uses a pair-wise comparison matrix which has definite numbers as its inputs, and when its input data face with ambiguity, this matrix cannot be utilized for desirable results. Leung and Cao (2000) believed that a reason which can be mentioned for low accuracy of this type of opinion polling from individuals is that the individual is asked to assign an exact amount to the phenomena based on their own understanding while a person's understanding of a phenomena cannot be expressed in the form of a crisp; rather, an interval of numbers can better reflect the person's understanding of the importance of a phenomena in comparison with another phenomena. Thus, the fuzzy ANP is able to simulate the decision-making process in human's mind better than the traditional ANP. Accordingly, in the phase of experts' opinion collection, some tangible and common expressions are used in the fuzzy ANP questionnaire instead of the crisp attributes prevalent in the traditional ANP. The scale used in this research is a 9-degree fuzzy scale introduced by Tesfamariam and Sadiq on the basis of Saaty (2006) scale. The use of the 9-degree fuzzy scale gives greater freedom of action to experts in the process of pair-wise comparisons. After gathering the experts' answers in the 9-degree fuzzy scale and in the form of linguistic expressions, it is necessary to turn these answers into an analyzable scale because it is impossible to perform mathematical operations on qualitative linguistic variables. Thus, the linguistic variables must be converted to fuzzy scales as shown in table 4.2.

Table 4.2 Transformation of linguistic variables to triangular fuzzy numbers (Viovi, 2007)

Linguistic Variable	Fuzzy Triangular Number
Equal Importance	(1 ،1 ،1)
Somewhat More Important	(2، 3، 4)
Much More Important	(4، 5، 6)
Very Much More Important	(6، 7، 8)
Absolutely More Important	(8، 9، 9)
Intermediate Level of Importance Between Two Levels	($X + 1$، X،$X - 1$)
Corresponding Triangular Numbers	(1/($X - 1$)، 1/ X، 1/($X + 1$))
	(1/9، 1/9، 1/8)

4.2.2.6 Defuzzification of Experts' Judgments

Although the use of fuzzy ANP increases the capability of decision-making method in reflecting the expert's idea of the level of importance of phenomena, investigation of the consistency of experts' fuzzy responses is much more difficult than investigation of the consistency of crisp matrix; because in this method it is necessary to investigate the consistency in an interval of numbers (Leung and Cao, 2000). Since the consistency of experts' judgments in the present research needed to be ensured, first the fuzzy judgments were converted to crisp scales and then assessment of the accuracy and consistency of responses were dealt by making use of the definition of consistency in traditional analytic hierarchy process which is a generally accepted method.

Transformation of the pair-wise comparisons matrix from fuzzy to crisp scale is technically referred to as defuzzification of the fuzzy pair-wise comparisons matrix. Different methods have been proposed for defuzzification of the fuzzy pair-wise comparisons matrix. As mentioned before, Opricovic and Tzeng's method and equations 4.1 to 4.8 of group fuzzy DEMATEL method were used in the present study for defuzzification of the experts' fuzzy answers.

4.2.2.7 Computing the Consistency Ratio (CR)

After transformation of the fuzzy pair-wise comparisons matrix to crisp pair-wise comparisons matrix, it is time to investigate the consistency of experts' responses. In this state, the equations 4.15 and 4.16 were used in order to compute the consistency ratio.

Suppose that matrix $CFCS(\tilde{A})$ is the defuzzificated matrix of a fuzzy pair-wise comparisons matrix named A, which is obtained through equations 4.1 to 4.8. Also $\lambda_{\max}$ is the largest amount of the decision-making matrix $CFCS(\tilde{A})$. Then the consistency index is calculated by the equation 4.15:

$$CI = (\lambda_{\max} - n)/(n-1) \qquad \text{Eq. 4.15}$$

This index illustrates the consistency rate of the crisp decision-making matrix. As can be seen, this index depends on *n* (number of rows or columns of pair-wise comparisons matrix $\tilde{A}$). In order to make this index independent from *n*, this index was divided on another index called the random index (*RI*). This index is obtained from the average consistency index of decision-making matrices which are produced randomly. Table 4.3 presents *RI* values for different values. This new index is named *CR* and its equation 4.16 is as follows (Saaty, 1980):

$$CR = {CI}/{RI} \qquad \text{Eq. 4.16}$$

If the $CR \leq 0.1$ relation exists for a pair-wise comparisons matrix, then the consistency ratio is acceptable, otherwise some modifications must be performed in the pair-wise comparisons matrix in order to reduce its inconsistency.

Table 4.3 Random index values (Opricovic and Tzeng, 2003)

N	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

4.2.2.8 Integrating the Experts' Opinions

After evaluating the consistency of each expert's opinion, the integration of experts' opinions must be conducted. As it was explained before, due to the great capability of fuzzy numbers in simulation of the decision-making process in human's mind, the linguistic variables which were convertible to triangular fuzzy numbers were used for converting the qualitative answers of experts to some quantitative values. Therefore, one of the common methods must be used for integration of the experts' opinions. The equation 4.17 was utilized in the present research in order to obtain a combination of their opinions as well as the final tables of pair-wise comparisons:

$$\tilde{Z}_{ij} = \left(\sqrt[k]{l_1 \times l_2 \times \ldots \times l_k}, \sqrt[k]{m_1 \times m_2 \times \ldots \times m_k}, \sqrt[k]{r_1 \times r_2 \times \ldots \times r_k}\right) \qquad \text{Eq. 4.17}$$

Hence, not only the opinions obtained from the pair-wise comparisons matrix in ANP but also the experts' opinions in fuzzy DEMATEL method were integrated through this method.

4.2.3 Fuzzy TOPSIS (C)

The TOPSIS method was originally developed by Hwang and Yoon (1981) for prioritization of the alternatives. In this method, the best alternative is the one with the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution. It is tried in this section to introduce the fuzzy TOPSIS technique proposed by Chen (2000). This method can be outlined as the following steps:

4.2.3.1 Step 1:

The evaluation criteria and the subject experts are identified.

4.2.3.2 Step 2:

The linguistic variables proposed in the Table 4.4 were used for evaluation of the alternatives with respect to the evaluation criteria. In other words, Table 4.4 can be utilized for determination of the alternatives' score in relation with sub-criteria.

Table 4.4 Linguistic scales for determination of the alternatives' score in relation with sub-criteria

Linguistic Variables	**Related Fuzzy Triangular Number**
Very Weak	0,0,0.2
Weak	0,0.2,0.4
Average	0.3,0.5,0.7
Good	0.6,0.8,1
Very Good	0.8,1,1

4.2.3.3 Step 3:

Experts' opinions on evaluation of the alternatives in relation with the criteria were integrated through the geometrical mean and equation 4.17.

4.2.3.4 Step 4:

The fuzzy decision-making matrix and the normalized fuzzy decision-making matrix were computed and established by equation 4.18.

$$\left.\begin{aligned}
&R = \left[\tilde{r}_{ij}\right]_{m\times n} \\
&\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^{\max}}, \frac{b_{ij}}{c_j^{\max}}, \frac{c_{ij}}{c_j^{\max}}\right),\ j \in B \\
&\tilde{r}_{ij} = \left(\frac{a_j^{\min}}{c_{ij}}, \frac{a_j^{\min}}{b_{ij}}, \frac{a_j^{\min}}{a_{ij}}\right),\ j \in C \\
&c_j^{\max} = \max_i c_{ij}\ \ if\ j \in B \\
&a_j^{\min} = \min_i a_{ij}\ \ if\ j \in C
\end{aligned}\right\} \qquad \text{Eq. 4.18}$$

Where *m* is the number of alternatives, *n* is the number of criteria, *B* is the set of benefit criteria, and *C* is the set of cost criteria.

4.2.3.5 Step 5:

Computing the weighted normalized fuzzy decision-making matrix through equation 4.19.

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{m\times n}$$
$$\tilde{v}_{ij} = \tilde{r}_{ij} \times w_j \qquad \text{Eq. 4.19}$$

Where w_j is the weight of the j^{th} criterion. In this research, the weight of w_j is the output of the second phase of the proposed model, i.e. the fuzzy ANP implementation phase.

4.2.3.6 Step 6:

Determining the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) using equation 4.20.

$$FPIS:\ A^{*} = (\tilde{v}_1^{*}, \tilde{v}_2^{*}, ..., \tilde{v}_n^{*})$$
$$FNIS:\ A^{-} = (\tilde{v}_1^{-}, \tilde{v}_2^{-}, ..., \tilde{v}_n^{-}) \qquad \text{Eq. 4.20}$$

4.2.3.7 Step 7:

Calculating the sum of distances of each of the alternatives from the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) through the equation 4.21:

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_{ij}^*), i = 1,2,....,m$$
$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_{ij}^-), i = 1,2,....,m \qquad \text{Eq. 4.21}$$

If $\tilde{v}_{ij} = (v_{ij}^p, v_{ij}^m, v_{ij}^o)$ and $\tilde{v}_{ij}^* = (v_{ij}^{p*}, v_{ij}^{m*}, v_{ij}^{o*})$, then the distance between these two fuzzy numbers is calculated by equation 4.22:

$$d(\tilde{v}_{ij}, \tilde{v}_{ij}^*) = \sqrt{\frac{1}{3}\left(v_{ij}^{p*} - v_{ij}^p\right)^2 + \left(v_{ij}^{m*} - v_{ij}^m\right)^2 + \left(v_{ij}^{o*} - v_{ij}^o\right)^2} \qquad \text{Eq. 4.22}$$

4.2.3.8 Step 8:

Prioritizing the alternatives on the basis of the closeness coefficient. In this step, after calculation of distances, the closeness index can be obtained by equation 4.23:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, i = 1,2,....,m \qquad \text{Eq. 4.23}$$

Chapter 5

CASE STUDY AND DISCUSSION OF THE RESULTS

5.1 Introduction

In this chapter, the proposed model for prioritization of six civil construction projects including: Balarood Reservoir Dam Project (P1), Karun IV Reservoir Dam Project (P2), Doyraj Reservoir Dam Project (P3), Siazakh Reservoir Dam Project (P4), Shahre Bijar Resevoir Dam Project (P5), and Gadir Reservoir Dam Project (P6) on the basis of the risk factors identified in section 3.5 will be implemented. For this purpose, the results obtained by the proposed model will be presented and analyzed phase by phase. Accordingly, in what follows, the results of fuzzy DEMATEL, fuzzy ANP, and fuzzy TOPSIS are provided. It should be noted that Excel and Super Decisions programming software were used for executing fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS. Computations of defuzzification of a fuzzy matrix, fuzzy DEMATEL and fuzzy ANP were codified in MATLAB programming software. Further, calculations of fuzzy TOPSIS have been directly performed in Excel software.

5.2 Results of Fuzzy DEMATEL

As mentioned before, in fuzzy DEMATEL method, the relationships between the main indices of the issue (main criteria) and then between the sub-indices (sub-criteria) are investigated. In this method, the impact of main risk criteria on construction projects should be established by making use of the experts' opinions. For instance, Table 5.1 illustrates the relationship between the main risk criteria according to an expert's opinion.

Table 5.1 An expert’s opinion about the risk factors’ influence

	Time Risk	Cost Risk	Quality Risk	Safety Risk	Environmental Sustainability Risk	Human Resources Risk
Time Risk	No Influence	Very High Influence	High Influence	Low Influence	Very Low Influence	Very Low Influence
Cost Risk	Very High Influence	No Influence	Very High	High Influence	No Influence	High Influence
Quality Risk	Low Influence	Very Low Influence	No Influence	High Influence	High Influence	Low Influence
Safety Risk	Very Low Influence	No Influence	High Influence	No Influence	No Influence	Low Influence
Environmental Sustainability Risk	Low Influence	High Influence	High Influence	High Influence	No Influence	Very Low Influence
Human Resources Risk	High Influence	High Influence	Low Influence	Low Influence	Low Influence	No Influence

According to Table 4.1, the following numerical values can be replaced for the linguistic variable of the rate of influence of the factors on each other, and therefore we will have Table 5.2:

Table 5.2 Numerical values corresponding to an expert’s opinion based on fuzzy scales

	Time Risk	Cost Risk	Quality Risk	Safety Risk	Environmental Sustainability Risk	Human Resources Risk
Time Risk	(0,0,0.25)	(0.75,1,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)
Cost Risk	(0.75,1, 1)	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(0.5,0.75,1)
Quality Risk	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)
Safety Risk	(0,0.25,0.5)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)
Environmental Sustainability Risk	0.25,0.5,0.75)	0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(0,0.25,0.5)
Human Resources Risk	(0.5,0.75,1)	0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0,0.25)

The obtained 18×6 matrix is defuzzificated through the equations of the second step of fuzzy DEMATEL method. In the Tables 5.3 to 5.6, the step by step results of these equations can be seen, i.e. the normalized values, normal left (***ls***) and normal right (***rs***) values, final definite normal value and final definite values.

Table 5.3 The normalized values

	Time Risk	**Cost Risk**	**Quality Risk**	**Safety Risk**	**Environmental Sustainability Risk**	**Human Resources Risk**
Time Risk	(0,0,0.25)	(0.75,1,1)	(0.5,0.75,1)	0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)
Cost Risk	(0.75,1, 1)	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(0.5,0.75,1)
Quality Risk	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)
Safety Risk	(0,0.25,0.5)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)
Environmental Sustainability Risk	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(0,0.25,0.5)
Human Resources Risk	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0,0.25)

Table 5.4 The normal left (ls) and normal right (rs) values

	Time Risk	**Cost Risk**	**Quality Risk**	**Safety Risk**	**Environmental Sustainability Risk**	**Human Resources Risk**
Time Risk	(0, 0.2)	(0. 8,1)	(0. 6,0.8)	(0. 4,0.6)	(0. 2,0.4)	(0. 2,0.4)
Cost Risk	(0. 8,1)	(0, 0.2)	(0. 6,0.8)	(0. 6,0.8)	(0, 0.2)	(0. 6,0.8)
Quality Risk	(0. 4.1)	(0. 2,0.4)	(0, 0.2)	(0. 6,0.8)	(0. 6,0.8)	(0. 4,0.6)
Safety Risk	(0. 2,0.4)	(0, 0.2)	(0. 6,0.8)	(0, 0.2)	(0, 0.2)	(0. 4,0.6)
Environmental Sustainability Risk	(0. 4,0.6)	(0. 6,0.8)	(0. 6,0.8)	(0. 6,0.8)	(0, 0.2)	(0. 2,0.4)
Human Resources Risk	(0. 6,0.8)	(0. 6,0.8)	(0. 4,0.6)	(0. 4,0.6)	(0. 4,0.6)	(0, 0.2)

Table 5.5 The final definite normal value

	Time Risk	Cost Risk	Quality Risk	Safety Risk	Environmental Sustainability Risk	Human Resources Risk
Time Risk	0.0333	0.9667	0.7333	0.5000	0.2667	0.2667
Cost Risk	0.9667	0.0333	0.7333	0.7333	0.0333	0.7333
Quality Risk	0.5000	0.2667	0.0333	0.7333	0.7333	0.5000
Safety Risk	0.2667	0.0333	0.7333	0.0333	0.0333	0.5000
Environmental Sustainability Risk	0.5000	0.7333	0.7333	0.7333	0.0333	0.2667
Human Resources Risk	0.7333	0.7333	0.5000	0.5000	0.5000	0.0333

Table 5.6 The final definite values

	Time Risk	Cost Risk	Quality Risk	Safety Risk	Environmental Sustainability Risk	Human Resources Risk
Time Risk	0.0333	0.9667	0.7333	0.5000	0.2667	0.2667
Cost Risk	0.9667	0.0333	0.7333	0.7333	0.0333	0.7333
Quality Risk	0.5000	0.2667	0.0333	0.7333	0.7333	0.5000
Safety Risk	0.2667	0.0333	0.7333	0.0333	0.0333	0.5000
Environmental Sustainability Risk	0.5000	0.7333	0.7333	0.7333	0.0333	0.2667
Human Resources Risk	0.7333	0.7333	0.5000	0.5000	0.5000	0.0333

5.2.1 Determination of the Internal Weight of Main Risk Criteria

Accordingly, the final definite values for ten other experts can be obtained in a similar way. The average defuzzificated results for these ten persons, i.e. the direct-relation matrix or the matrix Z are illustrated in Table 5.7.

Table 5.7 The direct-relation matrix

	Time Risk	Cost Risk	Quality Risk	Safety Risk	Environmental Sustainability Risk	Human Resources Risk
Time Risk	0.0333	0.6159	0.5828	0.4436	0.1316	0.3228
Cost Risk	0.3912	0.0333	0.1063	0.2154	0.3661	0.5398
Quality Risk	0.3024	0.3024	0.0333	0.6793	0.4790	0.3429
Safety Risk	0.1995	0.3661	0.0619	0.0333	0.3952	0.1063
Environmental Sustainability Risk	0.5548	0.1421	0.5398	0.5398	0.0333	0.2667
Human Resources Risk	0.5398	0.2154	0.1063	0.6793	0.1995	0.0333

By making use of the values presented in Table 5.7, and through application of equations 4.9 and 4.11, the normalized direct-relation and the total-relation matrix are obtained. These values are illustrated in Tables 5.8 and 5.9.

Table 5.8 The normalized direct-relation matrix

	Time Risk	Cost Risk	Quality Risk	Safety Risk	Environmental Sustainability Risk	Human Resources Risk
Time Risk	0.0118	0.2389	0.2183	0.1976	0.0944	0.1563
Cost Risk	0.1770	0.0118	0.1150	0.1150	0.1770	0.1976
Quality Risk	0.1150	0.1150	0.0118	0.2389	0.2183	0.1357
Safety Risk	0.0944	0.1770	0.0737	0.0118	0.1976	0.1150
Environmental Sustainability Risk	0.1976	0.0944	0.1976	0.1976	0.0118	0.0944
Human Resources Risk	0.1976	0.1150	0.1150	0.2389	0.0944	0.0118

Table 5.9 The total-relation matrix and the D, R, D + R, D - R values

							D	R	D + R	D-R
Time Risk	**0.5930**	**0.7730**	**0.7251**	**0.8857**	**0.6924**	**0.6754**	**4.3447**	**3.7852**	**8.1298**	**0.5595**
Cost Risk	**0.6765**	**0.5179**	**0.5924**	**0.7465**	**0.6781**	**0.6436**	**3.8550**	**3.6938**	**7.5488**	**0.1612**
Quality Risk	**0.6351**	**0.6220**	**0.5051**	**0.8553**	**0.7330**	**0.6011**	**3.9517**	**3.5300**	**7.4817**	**0.4217**
Safety Risk	**0.5343**	**0.5817**	**0.4847**	**0.5505**	**0.6209**	**0.5072**	**3.2794**	**4.6612**	**7.9406**	**-1.3819**
Environmental Sustainability Risk	**0.6807**	**0.5978**	**0.6539**	**0.8075**	**0.5433**	**0.5585**	**3.8417**	**3.8681**	**7.7097**	**-0.0264**
Human Resources Risk	**0.6655**	**0.6015**	**0.5689**	**0.8157**	**0.6003**	**0.4679**	**3.7197**	**3.4539**	**7.1736**	**0.2659**

It was explained in the previous chapter that the normalized values of the direct-relation matrix can be utilized as an estimation of the internal weight between main criteria in ANP supermatrix. The normalized value of matrix T, which is obtained from dividing the value of each column to the sum of that column, is presented in Table 5.10.

Table 5.10 The internal weight between main risk criteria from the total-relation matrix

	Time Risk	**Cost Risk**	**Quality Risk**	**Safety Risk**	**Environmental Sustainability Risk**	**Human Resources Risk**
Time Risk	0.1567	0.2093	0.2054	0.1900	0.1790	0.1956
Cost Risk	0.1787	0.1402	0.1678	0.1601	0.1753	0.1863
Quality Risk	0.1678	0.1684	0.1431	0.1835	0.1895	0.1740
Safety Risk	0.1412	0.1575	0.1373	0.1181	0.1605	0.1469
Environmental Sustainability Risk	0.1798	0.1618	0.1852	0.1732	0.1405	0.1617
Human Resources Risk	0.1758	0.1628	0.1611	0.1750	0.1552	0.1355

5.2.2 Determination of the Internal Weight of Risk Sub-Criteria

Correspondingly, the mentioned calculations can be performed for sub-criteria of each main criterion, and the internal eight can be computed for each risk sub-criteria. In Tables 5.11 to 5.16, these calculations are performed for all risk sub-criteria. In each table, the internal weight between risk sub-criteria and the D, R, D + R, and D - R values are presented. It must be reminded that the normalized value of matrix T, which is obtained from dividing the value of each column to the sum of that column, reveals the internal weight of risk sub-criteria. These values are used in preparation of the supermatrix in fuzzy ANP.

Table 5.11 The internal weight between time risk sub-criteria and the D, R, D + R, D - R values

			D	R	D + R	D-R
T1	0.4459	0.4891	8.0615	9.2375	17.2990	-1.1761
T2	0.5541	0.5109	9.2375	8.0615	17.2990	1.1761

Table 5.12 The internal weight between cost risk sub-criteria and the D, R, D + R, D - R values

						D	R	D + R	D-R
C1	0.1465	0.1711	0.1677	0.1749	0.1597	4.8413	6.3566	11.1979	-1.5153
C2	0.2172	0.1892	0.2182	0.2178	0.2166	6.2830	5.2064	11.4894	1.0766
C3	0.2270	0.2273	0.2034	0.2263	0.2499	6.7354	5.0057	11.7411	1.7298
C4	0.2083	0.2061	0.2000	0.1744	0.1962	5.8024	6.7539	12.5563	-0.9515
C5	0.2009	0.2063	0.2108	0.2066	0.1776	5.9117	6.2513	12.1629	-0.3396

Table 5.13 The internal weight between quality risk sub-criteria and the D, R, D + R, D - R values

					D	R	D + R	D-R
Q1	0.1902	0.2548	0.2663	0.2651	2.5878	3.3441	5.9320	-0.7563
Q2	0.3417	0.2583	0.3249	0.3483	3.4991	1.8454	5.3446	1.6537
Q3	0.1825	0.2384	0.1498	0.1887	1.9981	2.6790	4.6771	-0.6810
Q4	0.2856	0.2485	0.2589	0.1980	2.6812	2.8976	5.5788	-0.2164

Table 5.14 The internal weight between safety risk sub-criteria and the D, R, D + R, D - R values

				D	R	D + R	D-R
A1	0.3400	0.3843	0.3940	7.3307	6.8418	14.1726	0.4889
A2	0.2769	0.2419	0.2728	5.2041	6.4104	11.6145	-1.2064
A3	0.3831	0.3738	0.3333	7.1662	6.4488	13.6151	0.7174

Table 5.15 The internal weight between environmental sustainability risk sub-criteria and the D, R, D + R, D - R values

					D	R	D + R	D-R
S1	0.1671	0.2627	0.2827	0.2654	1.5527	2.2270	3.7797	-0.6743
S2	0.4194	0.2664	0.3781	0.4269	2.4741	1.6204	4.0946	0.8537
S3	0.1493	0.1655	0.1090	0.1128	0.9063	1.3788	2.2850	-0.4725
S4	0.2642	0.3053	0.2301	0.1948	1.6684	1.3753	3.0436	0.2931

Table 5.16 The internal weight between human resources risk sub-criteria and the D, R, D + R, D - R values

					D	R	D + R	D-R
HR1	0.1448	0.2021	0.1843	0.3129	1.2291	1.8806	3.1097	-0.6516
HR2	0.4115	0.2537	0.4410	0.3820	2.2129	1.1499	3.3628	1.0630
HR3	0.1623	0.2311	0.1187	0.1200	0.9070	1.2183	2.1253	-0.3112
HR4	0.2814	0.3131	0.2560	0.1851	1.4967	1.5969	3.0937	-0.1002

5.3 Results of Fuzzy ANP

In this phase, the supermatrix was formed, and eventually the final weight of risk main criteria and their related sub-criteria were calculated. In order to establish the supermatrix, the normalized matrix T was used for determination of the internal weight between risk main criteria and the internal weight between risk sub-criteria. In addition, the unweighted supermatrix was produced from the weights obtained by pair-wise comparisons between risk main criteria and sub-criteria. This matrix was accordingly normalized with respect to sum of the columns like matrix T. In the final step, in order to obtain the final weights for each criteria or sub-criteria, the unweighted supermatrix was raised to the power of 2k+1, in which k is an arbitrary number, in order to make it rather convergent. Table 5.18 illustrates the convergent matrix or the so-called limited matrix which represents the final weights.

Other calculation processes include formation of the unweighted supermatrix, weighted supermatrix and computation of the final weights, which are all illustrated in Tables 5.17 to 5.20.

Table 5.17 The unweighted supermatrix

	T	C	Q	A	S	HR	T1	T2	C1	C2	C3	C4	C5	Q1	Q2	Q3	Q4
T	0.157	0.209	0.205	0.190	0.179	0.196	0	0	0	0	0	0	0	0	0	0	0
C	0.179	0.140	0.168	0.160	0.175	0.186	0	0	0	0	0	0	0	0	0	0	0
Q	0.168	0.168	0.143	0.183	0.190	0.174	0	0	0	0	0	0	0	0	0	0	0
A	0.141	0.157	0.137	0.118	0.161	0.147	0	0	0	0	0	0	0	0	0	0	0
S	0.180	0.162	0.185	0.173	0.140	0.162	0	0	0	0	0	0	0	0	0	0	0
HR	0.176	0.163	0.161	0.175	0.155	0.135	0	0	0	0	0	0	0	0	0	0	0
T1	0.829	0	0	0	0	0	0.446	0.489	0	0	0	0	0	0	0	0	0
T2	0.171	0	0	0	0	0	0.554	0.511	0	0	0	0	0	0	0	0	0
C1	0	0.371	0	0	0	0	0	0	0.147	0.171	0.168	0.175	0.160	0	0	0	0
C2	0	0.169	0	0	0	0	0	0	0.217	0.189	0.218	0.218	0.217	0	0	0	0
C3	0	0.088	0	0	0	0	0	0	0.227	0.227	0.203	0.226	0.250	0	0	0	0
C4	0	0.326	0	0	0	0	0	0	0.208	0.206	0.200	0.174	0.196	0	0	0	0
C5	0	0.046	0	0	0	0	0	0	0.201	0.206	0.211	0.207	0.178	0	0	0	0
Q1	0	0	0.231	0	0	0	0	0	0	0	0	0	0	0.190	0.255	0.266	0.265
Q2	0	0	0.126	0	0	0	0	0	0	0	0	0	0	0.342	0.258	0.325	0.348
Q3	0	0	0.569	0	0	0	0	0	0	0	0	0	0	0.182	0.238	0.150	0.189
Q4	0	0	0.074	0	0	0	0	0	0	0	0	0	0	0.286	0.249	0.259	0.198
A1	0	0	0	0.626	0	0	0	0	0	0	0	0	0	0	0	0	0
A2	0	0	0	0.274	0	0	0	0	0	0	0	0	0	0	0	0	0
A3	0	0	0	0.100	0	0	0	0	0	0	0	0	0	0	0	0	0
S1	0	0	0	0	0.283	0	0	0	0	0	0	0	0	0	0	0	0

S2	0	0	0	0	0.186	0	0	0	0	0	0	0	0	0	0	0	0
S3	0	0	0	0	0.417	0	0	0	0	0	0	0	0	0	0	0	0
S4	0	0	0	0	0.114	0	0	0	0	0	0	0	0	0	0	0	0
HR1	0	0	0	0	0	0.351	0	0	0	0	0	0	0	0	0	0	0
HR2	0	0	0	0	0	0.152	0	0	0	0	0	0	0	0	0	0	0
HR3	0	0	0	0	0	0.426	0	0	0	0	0	0	0	0	0	0	0
HR4	0	0	0	0	0	0.070	0	0	0	0	0	0	0	0	0	0	0
Goal	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1

	A1	**A2**	**A3**	**S1**	**S2**	**S3**	**S4**	**HR1**	**HR2**	**HR3**	**HR4**	**Goal**
T	0	0	0	0	0	0	0	0	0	0	0	0.343
C	0	0	0	0	0	0	0	0	0	0	0	0.233
Q	0	0	0	0	0	0	0	0	0	0	0	0.092
A	0	0	0	0	0	0	0	0	0	0	0	0.208
S	0	0	0	0	0	0	0	0	0	0	0	0.065
HR	0	0	0	0	0	0	0	0	0	0	0	0.059
T1	0	0	0	0	0	0	0	0	0	0	0	0
T2	0	0	0	0	0	0	0	0	0	0	0	0
C1	0	0	0	0	0	0	0	0	0	0	0	0
C2	0	0	0	0	0	0	0	0	0	0	0	0
C3	0	0	0	0	0	0	0	0	0	0	0	0
C4	0	0	0	0	0	0	0	0	0	0	0	0

C5	0	0	0	0	0	0	0	0	0	0	0	0
Q1	0	0	0	0	0	0	0	0	0	0	0	0
Q2	0	0	0	0	0	0	0	0	0	0	0	0
Q3	0	0	0	0	0	0	0	0	0	0	0	0
Q4	0	0	0	0	0	0	0	0	0	0	0	0
A1	0.340	0.384	0.394	0	0	0	0	0	0	0	0	0
A2	0.277	0.242	0.273	0	0	0	0	0	0	0	0	0
A3	0.383	0.374	0.333	0	0	0	0	0	0	0	0	0
S1	0	0	0	0.167	0.263	0.283	0.265	0	0	0	0	0
S2	0	0	0	0.419	0.266	0.378	0.427	0	0	0	0	0
S3	0	0	0	0.149	0.166	0.109	0.113	0	0	0	0	0
S4	0	0	0	0.264	0.305	0.230	0.195	0	0	0	0	0
HR1	0	0	0	0	0	0	0	0.145	0.202	0.184	0.313	0
HR2	0	0	0	0	0	0	0	0.411	0.254	0.441	0.382	0
HR3	0	0	0	0	0	0	0	0.162	0.231	0.119	0.120	0
HR4	0	0	0	0	0	0	0	0.281	0.313	0.256	0.185	0
Goal	1	1	1	1	1	1	1	1	1	1	1	1

Table 5.18 The weighted supermatrix

	T	**C**	**Q**	**A**	**S**	**HR**	**T1**	**T2**	**C1**	**C2**	**C3**	**C4**	**C5**	**Q1**	**Q2**	**Q3**	**Q4**
T	0.078	0.105	0.103	0.095	0.090	0.098	0	0	0	0	0	0	0	0	0	0	0
C	0.089	0.070	0.084	0.080	0.087	0.093	0	0	0	0	0	0	0	0	0	0	0
Q	0.084	0.084	0.072	0.092	0.095	0.087	0	0	0	0	0	0	0	0	0	0	0
A	0.070	0.079	0.069	0.059	0.081	0.074	0	0	0	0	0	0	0	0	0	0	0
S	0.090	0.081	0.093	0.087	0.070	0.081	0	0	0	0	0	0	0	0	0	0	0
HR	0.088	0.082	0.081	0.088	0.078	0.068	0	0	0	0	0	0	0	0	0	0	0
T1	0.414	0	0	0	0	0	0.223	0.245	0	0	0	0	0	0	0	0	0
T2	0.085	0	0	0	0	0	0.277	0.256	0	0	0	0	0	0	0	0	0
C1	0	0.186	0	0	0	0	0	0	0.074	0.086	0.084	0.087	0.080	0	0	0	0
C2	0	0.085	0	0	0	0	0	0	0.109	0.095	0.109	0.109	0.108	0	0	0	0
C3	0	0.044	0	0	0	0	0	0	0.114	0.114	0.102	0.113	0.125	0	0	0	0
C4	0	0.163	0	0	0	0	0	0	0.104	0.103	0.100	0.087	0.098	0	0	0	0
C5	0	0.023	0	0	0	0	0	0	0.101	0.103	0.106	0.103	0.089	0	0	0	0
Q1	0	0	0.116	0	0	0	0	0	0	0	0	0	0	0.095	0.128	0.133	0.133
Q2	0	0	0.063	0	0	0	0	0	0	0	0	0	0	0.171	0.129	0.163	0.174
Q3	0	0	0.285	0	0	0	0	0	0	0	0	0	0	0.091	0.119	0.075	0.095
Q4	0	0	0.037	0	0	0	0	0	0	0	0	0	0	0.143	0.125	0.130	0.099
A1	0	0	0	0.313	0	0	0	0	0	0	0	0	0	0	0	0	0
A2	0	0	0	0.137	0	0	0	0	0	0	0	0	0	0	0	0	0
A3	0	0	0	0.050	0	0	0	0	0	0	0	0	0	0	0	0	0
S1	0	0	0	0	0.141	0	0	0	0	0	0	0	0	0	0	0	0
S2	0	0	0	0	0.093	0	0	0	0	0	0	0	0	0	0	0	0

S3	0	0	0	0	0.208	0	0	0	0	0	0	0	0	0	0	0	0
S4	0	0	0	0	0.057	0	0	0	0	0	0	0	0	0	0	0	0
HR1	0	0	0	0	0	0.176	0	0	0	0	0	0	0	0	0	0	0
HR2	0	0	0	0	0	0.076	0	0	0	0	0	0	0	0	0	0	0
HR3	0	0	0	0	0	0.213	0	0	0	0	0	0	0	0	0	0	0
HR4	0	0	0	0	0	0.035	0	0	0	0	0	0	0	0	0	0	0
Goal	0	0	0	0	0	0	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500

	A1	**A2**	**A3**	**S1**	**S2**	**S3**	**S4**	**HR1**	**HR2**	**HR3**	**HR4**	**Goal**
T	0	0	0	0	0	0	0	0	0	0	0	0.172
C	0	0	0	0	0	0	0	0	0	0	0	0.117
Q	0	0	0	0	0	0	0	0	0	0	0	0.046
A	0	0	0	0	0	0	0	0	0	0	0	0.104
S	0	0	0	0	0	0	0	0	0	0	0	0.033
HR	0	0	0	0	0	0	0	0	0	0	0	0.030
T1	0	0	0	0	0	0	0	0	0	0	0	0
T2	0	0	0	0	0	0	0	0	0	0	0	0
C1	0	0	0	0	0	0	0	0	0	0	0	0
C2	0	0	0	0	0	0	0	0	0	0	0	0

C3	0	0	0	0	0	0	0	0	0	0	0	0
C4	0	0	0	0	0	0	0	0	0	0	0	0
C5	0	0	0	0	0	0	0	0	0	0	0	0
Q1	0	0	0	0	0	0	0	0	0	0	0	0
Q2	0	0	0	0	0	0	0	0	0	0	0	0
Q3	0	0	0	0	0	0	0	0	0	0	0	0
Q4	0	0	0	0	0	0	0	0	0	0	0	0
A1	0.170	0.192	0.197	0	0	0	0	0	0	0	0	0
A2	0.139	0.121	0.137	0	0	0	0	0	0	0	0	0
A3	0.192	0.187	0.167	0	0	0	0	0	0	0	0	0
S1	0	0	0	0.084	0.132	0.141	0.133	0	0	0	0	0
S2	0	0	0	0.210	0.133	0.189	0.214	0	0	0	0	0
S3	0	0	0	0.075	0.083	0.055	0.057	0	0	0	0	0
S4	0	0	0	0.132	0.153	0.115	0.098	0	0	0	0	0
HR1	0	0	0	0	0	0	0	0.073	0.101	0.092	0.157	0
HR2	0	0	0	0	0	0	0	0.206	0.127	0.221	0.191	0
HR3	0	0	0	0	0	0	0	0.081	0.116	0.060	0.060	0
HR4	0	0	0	0	0	0	0	0.141	0.157	0.128	0.093	0
Goal	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500

Table 5.19 The limited supermatrix

	T	C	Q	A	S	HR	T1	T2	C1	C2	C3	C4	C5	Q1	Q2	Q3	Q4
T	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088
C	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
Q	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
A	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058
S	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
HR	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
T1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
T2	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
C1	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
C2	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
C3	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
C4	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
C5	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Q1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Q2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Q3	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
Q4	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
A1	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
A2	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
A3	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
S1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010

S2	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
S3	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
S4	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
HR1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
HR2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
HR3	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
HR4	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Goal	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333

	A1	**A2**	**A3**	**S1**	**S2**	**S3**	**S4**	**HR1**	**HR2**	**HR3**	**HR4**	**Goal**
T	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088
C	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
Q	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
A	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058
S	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
HR	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
T1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
T2	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
C1	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
C2	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
C3	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010

C4	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
C5	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Q1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Q2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Q3	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
Q4	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
A1	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
A2	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
A3	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
S1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
S2	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
S3	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
S4	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
HR1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
HR2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
HR3	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
HR4	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Goal	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333

The final weight of main risk criteria and sub-criteria can be exploited from the limited supermatrix. These weights are listed in Table 5.20.

Table 5.20 Main criteria and sub-criteria Weights (W)

Row	Risk Factors (Main Criteria)	W-Main Criteria	Sub-Criteria	W-Sub-Criteria
1	**Time Risk (T)**	0.088	Weakness in Construction Schedules **(T1)**	0.057
			Delay in Supply of Materials **(T2)**	0.031
2	**Cost Risk (C)**	0.067	High Bid Price **(C1)**	0.018
			Increase in Price of the Materials **(C2)**	0.013
			Increase in the Work Cost **(C3)**	0.010
			Delay in Payment of Costs in Accordance with the Contract **(C4)**	0.017
			Financial Problems **(C5)**	0.008
3	**Quality Risk (Q)**	0.044	Choosing Inappropriate Apparatus and Equipment **(Q1)**	0.010
			Choosing Unsuitable Materials **(Q2)**	0.010
			Machinery Failure **(Q3)**	0.016
			Poor Quality of Work **(Q4)**	0.007
4	**Safety Risk (A)**	0.058	Collapse (Deficiency) of Construction **(A1)**	0.029
			Workers' Safety **(A2)**	0.016
			Unforeseen Disasters During the Work, such as Fire **(A3)**	0.014
5	**Environmental Sustainability Risk (S)**	0.039	Disturbance toResidents Near the Construction Site **(S1)**	0.010
			Physical Injury to the Workers **(S2)**	0.011
			Environmental Constraints **(S3)**	0.011
			Noise **(S4)**	0.007
6	**Human Resource Risk (HR)**	0.037	Lack of Management Competency **(HR1)**	0.010
			Lack of Experienced Professional Consultants **(HR2)**	0.010
			Key Personnel Changes **(HR3)**	0.011
			Workers' Strike **(HR4)**	0.006

5.4 Results of Fuzzy TOPSIS

In this phase, the results of step by step implementation of fuzzy TOPSIS will be explained. In the first step, ten experts' opinions about evaluation of the alternatives on the basis of risk sub-criteria have been gathered and represented in the form of fuzzy numbers according to Table 4.4. Afterwards, these opinions were aggregated on the basis of the mean, and were reported in Table 5.21. Rows of this table represent the alternatives, which are the six civil construction projects including: Balarood Reservoir Dam Project (P1), Karun IV Reservoir Dam Project (P2), Doyraj Reservoir Dam Project (P3), Siazakh Reservoir Dam Project (P4), Shahre Bijar Resevoir Dam Project (P5), and Gadir Reservoir Dam Project (P6). Columns of the table, however, represent the risk sub-criteria. The questionnaire which relates to the fuzzy TOPSIS method is given in Appendix A.

Table 5.21 The aggregated fuzzy scores of the alternatives in relation with risk sub-criteria, based on ten experts' opinions

	T1			T2			C1		
P1	0.43	0.61	0.77	0.28	0.38	0.54	0.29	0.45	0.63
P2	0.38	0.52	0.64	0.45	0.65	0.79	0.38	0.46	0.66
P3	0.50	0.66	0.78	0.15	0.31	0.51	0.34	0.42	0.56
P4	0.29	0.47	0.65	0.20	0.38	0.56	0.47	0.50	0.64
P5	0.35	0.53	0.71	0.35	0.53	0.71	0.39	0.41	0.55
P6	0.23	0.37	0.55	0.27	0.45	0.65	0.24	0.39	0.55
	C2			**C3**			**C4**		
P1	0.48	0.66	0.80	0.50	0.70	0.82	0.43	0.59	0.75
P2	0.30	0.46	0.66	0.26	0.42	0.60	0.44	0.62	0.74
P3	0.31	0.45	0.61	0.17	0.31	0.49	0.43	0.61	0.77
P4	0.42	0.60	0.74	0.32	0.50	0.68	0.34	0.48	0.64
P5	0.28	0.40	0.56	0.36	0.46	0.60	0.48	0.66	0.80
P6	0.36	0.54	0.68	0.28	0.48	0.64	0.37	0.55	0.71
	C5			**Q1**			**Q2**		
P1	0.47	0.63	0.75	0.30	0.46	0.66	0.26	0.40	0.58
P2	0.41	0.53	0.65	0.34	0.48	0.64	0.49	0.63	0.73
P3	0.53	0.73	0.85	0.45	0.63	0.77	0.28	0.42	0.58
P4	0.31	0.43	0.59	0.36	0.52	0.66	0.34	0.50	0.66
P5	0.35	0.47	0.59	0.33	0.47	0.61	0.57	0.77	0.91
P6	0.38	0.56	0.68	0.26	0.40	0.58	0.38	0.56	0.68
	Q3			**Q4**			**A1**		
P1	0.39	0.55	0.69	0.42	0.60	0.74	0.14	0.28	0.46
P2	0.32	0.52	0.70	0.33	0.45	0.59	0.28	0.44	0.60
P3	0.38	0.52	0.64	0.35	0.49	0.61	0.31	0.45	0.61
P4	0.26	0.38	0.56	0.33	0.47	0.61	0.32	0.52	0.70
P5	0.36	0.56	0.70	0.55	0.75	0.91	0.40	0.58	0.74
P6	0.37	0.57	0.73	0.33	0.45	0.59	0.38	0.58	0.76
	A2			**A3**			**S1**		
P1	0.48	0.68	0.82	0.29	0.45	0.63	0.26	0.40	0.58
P2	0.32	0.52	0.70	0.31	0.45	0.61	0.26	0.42	0.60
P3	0.38	0.52	0.70	0.18	0.34	0.54	0.46	0.66	0.82
P4	0.20	0.34	0.52	0.28	0.46	0.62	0.34	0.52	0.68
P5	0.30	0.44	0.58	0.35	0.55	0.73	0.41	0.55	0.67
P6	0.31	0.49	0.65	0.12	0.26	0.46	0.39	0.55	0.69
	S2			**S3**			**S4**		
P1	0.24	0.40	0.60	0.28	0.42	0.58	0.34	0.48	0.64
P2	0.38	0.56	0.74	0.36	0.56	0.70	0.20	0.34	0.52
P3	0.44	0.60	0.72	0.56	0.76	0.88	0.25	0.43	0.59
P4	0.34	0.50	0.66	0.15	0.31	0.51	0.36	0.52	0.66
P5	0.15	0.33	0.53	0.28	0.44	0.60	0.49	0.65	0.75
P6	0.14	0.30	0.48	0.29	0.45	0.63	0.43	0.59	0.75

	HR1			HR2			HR3		
P1	0.48	0.68	0.82	0.40	0.58	0.74	0.06	0.16	0.36
P2	0.27	0.43	0.57	0.36	0.52	0.66	0.25	0.37	0.53
P3	0.42	0.62	0.82	0.18	0.32	0.52	0.42	0.60	0.74
P4	0.45	0.61	0.75	0.41	0.59	0.71	0.40	0.58	0.74
P5	0.37	0.55	0.71	0.19	0.35	0.51	0.22	0.34	0.50
P6	0.41	0.61	0.79	0.42	0.62	0.76	0.35	0.51	0.69
	HR4								
P1	0.41	0.59	0.77						
P2	0.43	0.61	0.77						
P3	0.40	0.56	0.72						
P4	0.43	0.59	0.75						
P5	0.29	0.41	0.59						
P6	0.47	0.63	0.75						

In the next step of fuzzy TOPSIS method, the normalized fuzzy matrix was obtained through equation 4.18. After this step, the weighted fuzzy normal decision matrix was obtained through equation 4.19. A point to bear in mind is that the weights of risk sub-criteria have been already obtained from the second phase of the proposed model, i.e. fuzzy ANP, and were reported in Table 5.20. Table 5.22 illustrates the weighted fuzzy normal decision matrix.

Table 5.22 The weighted fuzzy normal decision matrix

	T1			T2			C1		
P1	0.017	0.021	0.030	0.009	0.012	0.017	0.007	0.010	0.015
P2	0.020	0.025	0.034	0.006	0.007	0.010	0.007	0.009	0.012
P3	0.017	0.020	0.026	0.009	0.015	0.031	0.008	0.010	0.013
P4	0.020	0.028	0.045	0.008	0.012	0.023	0.007	0.009	0.009
P5	0.018	0.025	0.037	0.007	0.009	0.013	0.008	0.011	0.011
P6	0.024	0.035	0.057	0.007	0.010	0.017	0.008	0.011	0.018
	C2			**C3**			**C4**		
P1	0.004	0.005	0.007	0.002	0.003	0.004	0.008	0.010	0.014
P2	0.005	0.008	0.012	0.003	0.004	0.007	0.008	0.010	0.013
P3	0.006	0.008	0.011	0.004	0.006	0.010	0.008	0.010	0.014
P4	0.005	0.006	0.008	0.003	0.004	0.006	0.009	0.012	0.017
P5	0.006	0.009	0.013	0.003	0.004	0.005	0.007	0.009	0.012
P6	0.005	0.007	0.010	0.003	0.004	0.006	0.008	0.011	0.016
	C5			**Q1**			**Q2**		
P1	0.003	0.004	0.005	0.004	0.006	0.009	0.004	0.006	0.010
P2	0.004	0.005	0.006	0.004	0.006	0.008	0.003	0.004	0.005
P3	0.003	0.004	0.005	0.004	0.004	0.006	0.004	0.006	0.009
P4	0.004	0.006	0.008	0.004	0.005	0.008	0.004	0.005	0.007
P5	0.004	0.005	0.007	0.004	0.006	0.008	0.003	0.003	0.004
P6	0.004	0.005	0.007	0.005	0.007	0.010	0.004	0.005	0.007
	Q3			**Q4**			**A1**		
P1	0.006	0.008	0.011	0.003	0.004	0.006	0.009	0.014	0.029
P2	0.006	0.008	0.013	0.004	0.005	0.007	0.007	0.009	0.014
P3	0.007	0.008	0.011	0.004	0.005	0.007	0.007	0.009	0.013
P4	0.008	0.011	0.016	0.004	0.005	0.007	0.006	0.008	0.013
P5	0.006	0.008	0.012	0.003	0.003	0.004	0.005	0.007	0.010
P6	0.006	0.008	0.012	0.004	0.005	0.007	0.005	0.007	0.011
	A2			**A3**			**S1**		
P1	0.009	0.013	0.016	0.003	0.004	0.006	0.005	0.007	0.010
P2	0.006	0.010	0.013	0.003	0.004	0.005	0.004	0.006	0.010
P3	0.007	0.010	0.013	0.003	0.005	0.009	0.003	0.004	0.006
P4	0.004	0.007	0.010	0.003	0.004	0.006	0.004	0.005	0.008
P5	0.006	0.008	0.011	0.002	0.003	0.005	0.004	0.005	0.007
P6	0.006	0.009	0.013	0.004	0.006	0.014	0.004	0.005	0.007
	S2			**S3**			**S4**		
P1	0.003	0.004	0.006	0.003	0.004	0.006	0.002	0.003	0.004
P2	0.002	0.003	0.004	0.002	0.003	0.004	0.003	0.004	0.007
P3	0.002	0.003	0.003	0.002	0.002	0.003	0.002	0.003	0.006
P4	0.002	0.003	0.004	0.003	0.005	0.011	0.002	0.003	0.004
P5	0.003	0.005	0.010	0.003	0.004	0.006	0.002	0.002	0.003
P6	0.003	0.005	0.011	0.003	0.004	0.006	0.002	0.002	0.003
	HR1			**HR2**			**HR3**		
P1	0.003	0.004	0.006	0.002	0.003	0.004	0.002	0.004	0.011
P2	0.005	0.006	0.010	0.003	0.003	0.005	0.001	0.002	0.003

P3	0.003	0.004	0.007	0.003	0.005	0.010	0.001	0.001	0.002
P4	0.004	0.005	0.006	0.002	0.003	0.004	0.001	0.001	0.002
P5	0.004	0.005	0.007	0.003	0.005	0.009	0.001	0.002	0.003
P6	0.004	0.005	0.007	0.002	0.003	0.004	0.001	0.001	0.002
		HR4							
P1	0.002	0.003	0.004						
P2	0.002	0.003	0.004						
P3	0.003	0.003	0.005						
P4	0.002	0.003	0.004						
P5	0.003	0.004	0.006						
P6	0.002	0.003	0.004						

After establishing the weighted fuzzy normal decision matrix, it is time to determine the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS). In order to determine these solutions, the weighted fuzzy normal decision matrix was used. Let $\tilde{v}_{ij} = (v_{ij}^{p}, v_{ij}^{m}, v_{ij}^{o})$ be the element which is related to alternative *i* and the sub-criteria *j* of the weighted fuzzy normal decision matrix, then the j^{th} sub-criteria of the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) were obtained from the equation 5.1.

$$\begin{aligned} &FPIS: A^{*}: \tilde{v}_{j}^{*} = (\max_{i} v_{ij}^{p}, \max_{i} v_{ij}^{m}, \max_{i} v_{ij}^{o}) \quad \forall j \\ &FNIS: A^{-}: \tilde{v}_{j}^{-} = (\min_{i} v_{ij}^{p}, \min_{i} v_{ij}^{m}, \min_{i} v_{ij}^{o}) \quad \forall j \end{aligned} \qquad \text{Eq. 5.1}$$

According to equation 5.1, the fuzzy positive-ideal solution and fuzzy negative-ideal solution were determined and reported in Table 5.23.

Table 5.23 The Fuzzy Positive-Ideal Solution (FPIS) and Fuzzy Negative-Ideal Solution (FNIS)

	T1			**T2**			**C1**		
A^*	0.024	0.035	0.057	0.009	0.015	0.031	0.008	0.011	0.018
A^-	0.017	0.020	0.026	0.006	0.007	0.010	0.007	0.009	0.009
	C2			**C3**			**C4**		
A^*	0.006	0.009	0.013	0.004	0.006	0.010	0.009	0.012	0.017
A^-	0.004	0.005	0.007	0.002	0.003	0.004	0.007	0.009	0.012
	C5			**Q1**			**Q2**		
A^*	0.004	0.006	0.008	0.005	0.007	0.010	0.004	0.006	0.010
A^-	0.003	0.004	0.005	0.004	0.004	0.006	0.003	0.003	0.004
	Q3			**Q4**			**A1**		
A^*	0.008	0.011	0.016	0.004	0.005	0.007	0.009	0.014	0.029
A^-	0.006	0.008	0.011	0.003	0.003	0.004	0.005	0.007	0.010
	A2			**A3**			**S1**		
A^*	0.009	0.013	0.016	0.004	0.006	0.014	0.005	0.007	0.010
A^-	0.004	0.007	0.010	0.002	0.003	0.005	0.003	0.004	0.006
	S2			**S3**			**S4**		
A^*	0.003	0.005	0.011	0.003	0.005	0.011	0.003	0.004	0.007
A^-	0.002	0.003	0.003	0.002	0.002	0.003	0.002	0.002	0.003
	HR1			**HR2**			**HR3**		
A^*	0.005	0.006	0.010	0.003	0.005	0.010	0.002	0.004	0.011
A^-	0.003	0.004	0.006	0.002	0.003	0.004	0.001	0.001	0.002
	HR4								
A^*	0.003	0.004	0.006						
A^-	0.002	0.003	0.004						

In this step, the alternatives' distance from the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) were calculated by equations 4.21 and 4.22. Afterwards, using equation 4.23, the similarity or closeness coefficient was obtained, and the alternatives were prioritized on the basis of this index. The final results are reported in Table 5.24.

Table 5.24 Results of implementation of the compound fuzzy DEMATEL, fuzzy ANP, and fuzzy TOPSIS method

	d_i^*	d_i^-	CC_i	**Rank**
P1	0.068	0.052	0.434	6
P2	0.064	1.267	0.952	2
P3	0.075	1.262	0.944	4
P4	0.070	1.258	0.947	3
P5	0.084	0.127	0.602	5
P6	0.058	1.247	0.956	1

According to closeness coefficient, the alternative with higher value acquires better rank. Hence, prioritization of the alternatives on the basis of this index is as follows:

$$P6 > P2 > P4 > P3 > P5 > P1$$

After presenting the prioritization results to senior managers of Mahab Ghodss Company, they stated that in terms of efficiency of the mentioned projects on the basis of risk factors, P3 and P4 and P6 projects had better output in comparison with P1 according to the company's registered records. They also remarked that they could not continue their cooperation in P5 project, and they could not also obtain the necessary scores in the bid for cooperation in P2 project.

Considering these issues, it can be concluded that the obtained results of the new model which for the first time has used a combination of fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS for the evaluation and prioritization of construction projects.it can provide great assistance for selection of the best alternative on the basis of risk factors in uncertainty. Also in this method the decision makers are enabled, according to their personal viewpoints, to express their opinions about risk factors weights, relationships and dependencies of risk factors. Thus each construction project's score in realization of risk sub-criteria and also to apply their opinions in them.

Chapter6

CONCLUSION AND RECOMMENDATIONS FOR FURTHER RESEARCH

6.1 Conclusion

Prioritization of construction projects on the basis of risk factors is a complicated issue, with so many qualitative indices which should be taken into account in this important task. In addition, these indices are not equal in importance. Moreover, many of these indices can have an influence on each other. These indices make the evaluation and prioritization process more difficult and vague, and lead to more complication.

In the present thesis, first the literature review of risks, risk management, and risk management in construction projects were addressed as well as methods of risk evaluation. In the reviewed literature, many factors and indices for risk analysis had been studied by various researchers. Through investigating risk criteria and indices of different researches of the literature and adjustment of them, by the experts, with the conditions and settings of the study, 6 groups of these factors were selected as main risk criteria, including time risk, cost risk, quality risk, safety risk, environmental sustainability risk, and human resources risk. Afterwards, the sub-criteria of each main risk criteria were also identified.

Since evaluation and prioritization of construction projects has been a complicated task, and network structure is an appropriate approach for describing complex systems, this structure was utilized for describing and modeling the issue. On the other hand, in deterministic and real conditions, we are faced with lack of sufficient data; moreover, experts' opinions and judgments are usually mathematically vague, and they are expressed in terms of linguistic variables instead of numerical expressions. Owing to the fact that fuzzy logic is used for expression of vagueness and uncertainty, formulizing the experts' opinion in the form of fuzzy numbers seems to be an appropriate approach. In other words, evaluation and prioritization of construction projects in real world is a complicated task, with so many vague qualitative characteristics. In this project, for the first time a combination of fuzzy DEMATEL, fuzzy ANP, and fuzzy TOPSIS was used for evaluation and prioritization of construction projects, in which the decision makers are able to express their own points of view about risk factors weights, relationships and dependencies between risk criteria, as well as the score of each construction project in realization of risk sub-criteria, and also to apply their opinions in them.

From among the common methods of solving the multi-criteria decision-making issues in uncertainty conditions, fuzzy ANP can be enumerated. However, this method does not consider the relationships and dependencies between risk factors. On the other hand, the proposed model of the present thesis does consider all such conditions. The proposed fuzzy combinational method of this research eliminates the incapabilities of uncertainty measurement. In addition to simplicity and understandability, other significant benefits of the proposed model include: supporting the network structure (describing complex systems), considering the relationships and dependencies between risk main criteria and sub-criteria, supporting the fuzzy concept (expressing the vagueness and uncertainty), and ability of rating (aiding better decision-making). In fact the proposed model helps decision makers to make more accurate decisions and to appropriately manage the prioritization of construction projects, which is from among the important strategies of some organizations. This proposed model has been used for evaluation and prioritization of six construction projects in Mahab Ghodss Consulting Engineering Company.

6.2 Suggestions for Further Research

Certainly, there are many capacities for further research related to the present thesis, some of which include:

- The use of this model in other areas of civil construction and industrial applications.
- Developing a model for solving larger scale issues.
- The use of more practical normalization methods.
- Comparison of this method’s results with the results of other multi-criteria decision-making methods such as ELECTRE and DEA in uncertainty and fuzzy conditions.
- Developing a decision support system on basis of proposed model for evaluation and prioritization of construction projects.

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APPENDICES

Appendix A: Sample Questionnaire

Dear Respondent,

Greetings,

I MEHRDAD ABKENARI, M.Sc. level student of the major CIVIL ENGINNERING, of the EASTERN MEDITERRANEAN UNIVERSITY, am working on my master thesis entitled “Evaluation and Prioritization of Construction Projects, on the Basis of Risk Factors by ANP-DEMATEL-TOPSIS Integrated Approach in Fuzzy Conditions”.

Please take your time to fill up the following questionnaire. Thanks in advance for your sincere cooperation.

The questionnaire below is part of my research on the evaluation and prioritization of construction projects, on the basis of risk factors. The risk factors (main criteria and the sub-criteria) of construction projects are presented in the following table.

QUESTIONNAIRE

1- Gender: Male ☐ Female ☐

2- Education: Associate degree ☐ B.Sc. ☐ M.Sc. ☐ Ph.D. ☐

3- Work Experience in Construction Management:

Less than 2 Years ☐ 2 to 5 Years ☐ 5 to 10 Years ☐

More than 10 Years ☐

Table 1: Risk Factors of Construction Projects Analysis

Row	Risk Factors (Main Criteria)	Sub-Criteria
1	Time Risk	Weakness in Construction Schedules
		Delay in Supply of Materials
2	Cost Risk	High Bid Price
		Increase in Price of the Materials
		Increase in the Work Cost
		Delay in Payment of Costs in Accordance with the Contract
		Financial Problems
3	Quality Risk	Choosing Inappropriate Apparatus and Equipment
		Choosing Unsuitable Materials
		Machinery Failure
		Poor Quality of Work
4	Safety Risk	Collapse (Deficiency) of Construction
		Workers' Safety
		Unforeseen Disasters During the Work, such as Fire
5	Environmental Sustainability Risk	Disturbance to Residents Near the Construction Site
		Physical Injury to the Workers
		Environmental Constraints
		Noise
6	Human Resources Risk	Lack of Management Competency
		Lack of Experienced Professional Consultants
		Key Personnel Changes
		Workers' Strike

PART A) FUZZY ANP

Please read the following questions and put ✓ in the pairwise comparison matrix in the following way:

If you consider the factor on the **right** side of the matrix as more important than the factor on the left side of the matrix (right in front), put ✓ at the **right** of the **Equal Importance** column and just under the level of importance you believe in. If you consider the factor on the **right** side of the matrix as **less important** than the factor on the **left** side of the matrix, put ✓ at the left of the **Equal Importance** column and just under the level of importance you believe in (for the factor on the left).

Notice 1: the empty space between 2 levels of importance in pairwise comparison tables represents the **intermediate level of importance** between the other two levels.

Notice 2: from right to left, **the level of importance of the right side factor decreases in comparison with the left side factor.**

Notice 3: In case you need **more explanations** about each of the factors, you can find a summary of the factor in the table attached to the questionnaire.

Notice 4: please pay attention to the **logical consistency** of the answers. For example, if in **Table 1** you evaluate the role of **"Time Risk" criteria** as absolutely more important than the **"Cost Risk" criteria**, and the role of **"Cost Risk"** as absolutely more important than the **"Quality Risk",** this means that your analysis of the role of **"Time Risk" criteria** in comparison with **"Quality Risk"** criteria as absolutely more important.

1. How do you analyze the importance and role of each of the factors on the right side of the pairwise comparisons table No.1, in comparison with the factors on the left side in **“Construction Projects Evaluation”**? (For instance you should answer the following question in the first row of the table: How do you analyze the importance and role of **“Time Risk”** criteria in comparison with **“Cost Risk”** for **evaluation of universities performance**?)

For more information about each of the factors, refer to the factors table attached to the questionnaire. The empty space between 2 levels of importance in the table represents the intermediate level of importance between the other two levels.

Pairwise Comparison Table 1

Factor	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	Factor
Cost Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Time Risk
Quality Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Time Risk
Safety Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Time Risk
Environmental Sustainability Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Time Risk
Human Resources Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Time Risk
Quality Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cost Risk
Safety Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cost Risk
Environmental Sustainability Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cost Risk
Human Resources Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Cost Risk
Safety Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Quality Risk
Environmental Sustainability Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Quality Risk
Human Resources Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Quality Risk
Environmental Sustainability Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Safety Risk
Human Resources Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Safety Risk
Human Resources Risk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Environmental Sustainability Risk

2. Each of the factors on the right and left side of the pairwise comparison table 2 are sub-criteria of **"Time Risk".** How do you analyze the importance and role of each of the factors on the right side of the pairwise comparisons table No.2, in comparison with the factors on the left side in **"Time Risk"**? (For instance you should answer the following question in the first row of the table: How do you analyze the importance and role of **"Weakness in Construction Schedule"** criteria in comparison with **"Delay in Supply of Materials"** for **Time Risk of Construction Projects**?)

Pairwise Comparison Table 2

Factor	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	Factor
Delay in Supply of Materials	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Weakness in Construction Schedule

3. Each of the factors on the right and left side of the pairwise comparison table 3 are sub-criteria of **"Cost Risk".** How do you analyze the importance and role of each of the factors on the right side of the pairwise comparisons table No.3, in comparison with the factors on the left side in **"Cost Risk"**? (For instance you should answer the following question in the first row of the table: How do you analyze the importance and role of **"High Bid Price"** criteria in comparison with **"Increase in Price of the Materials"** for **Cost Risk of Construction Projects**?)

Pairwise Comparison Table 3

Factor	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	Factor
Increase in Price of the Materials	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High Bid Price
Increase in the Work Cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High Bid Price
Delay in Payment of Costs in Accordance with the Contract	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High Bid Price
Financial Problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	High Bid Price
Increase in the Work Cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Increase in Price of the Materials
Delay in Payment of Costs in Accordance with the Contract	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Increase in Price of the Materials
Financial Problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Increase in Price of the Materials
Delay in Payment of Costs in Accordance with the Contract	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Increase in the Work Cost
Financial Problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Increase in the Work Cost
Financial Problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Delay in Payment of Costs in Accordance with the Contract

4. Each of the factors on the right and left side of the pairwise comparison table 4 are sub-criteria of **"Quality Risk".** How do you analyze the importance and role of each of the factors on the right side of the pairwise comparisons table No.4, in comparison with the factors on the left side in **"Quality Risk"**? (For instance you should answer the following question in the first row of the table: How do you analyze the importance and role of **"Choosing Inappropriate Apparatus and Equipment"** criteria in comparison with **"Choosing Unsuitable Materials"** for **Quality Risk of Construction Projects**?)

Pairwise Comparison Table 4

Factor	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	Factor
Choosing Unsuitable Materials	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Choosing Inappropriate Apparatus and Equipment
Machinery Failure	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Choosing Inappropriate Apparatus and Equipment
Poor Quality of Work	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Choosing Inappropriate Apparatus and Equipment
Machinery Failure	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Choosing Unsuitable Materials
Poor Quality of Work	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Choosing Unsuitable Materials
Poor Quality of Work	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Machinery Failure

5. Each of the factors on the right and left side of the pairwise comparison table 5 are sub-criteria of **"Safety Risk".** How do you analyze the importance and role of each of the factors on the right side of the pairwise comparisons table No.5, in comparison with the factors on the left side in **"Safety Risk"**? (For instance you should answer the following question in the first row of the table: How do you analyze the importance

and role of **“Collapse (Deficiency) of Construction”** criteria in comparison with **“Workers’ Safety”** for **Safety Risk of Construction Projects**?)

Pairwise Comparison Table 5

Factor	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	Factor
Workers’ Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Collapse (Deficiency) of Construction
Unforeseen Disasters During the Work, such as Fire	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Collapse (Deficiency) of Construction
Unforeseen Disasters During the Work, such as Fire	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Workers’ Safety

6. Each of the factors on the right and left side of the pairwise comparison table 6 are sub-criteria of **“Environmental Sustainability Risk”.** How do you analyze the importance and role of each of the factors on the right side of the pairwise comparisons table No.6, in comparison with the factors on the left side in **“Environmental Sustainability Risk”**? (For instance you should answer the following question in the first row of the table: How do you analyze the importance and role of **“Disturbance of Residents near the Construction Site”** criteria in comparison with **“Physical Injury to the Workers”** for **Environmental Sustainability Risk of Construction Projects**?)

Pairwise Comparison Table 6

Factor	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	Factor
Physical Injury to the Workers	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disturbance of Residents near the Constructio n Site**
Environmen tal Constraints	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disturbance of Residents near the Constructio n Site**
Noise	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Disturbance of Residents near the Constructio n Site**
Environmen tal Constraints	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Physical Injury to the Workers**
Noise	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Physical Injury to the Workers**
Noise	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Environmen tal Constraints**

7. Each of the factors on the right and left side of the pairwise comparison table 7 are sub-criteria of **"Human Resources Risk".** How do you analyze the importance and role of each of the factors on the right side of the pairwise comparisons table No.7, in comparison with the factors on the left side in **"Human Resources Risk"**? (For instance you should answer the following question in the first row of the table: How do you analyze the importance and role of **"Lack of Management Competency"** criteria in comparison with **"Lack of Experienced Professional Consultants"** for **Human Resources Risk of Construction Projects**?)

Pairwise Comparison Table 7

Factor	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	Factor
Lack of Experienced Professional Consultants	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Lack of Management Competency
Key Personnel Changes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Lack of Management Competency
Workers' Strike	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Lack of Management Competency
Key Personnel Changes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Lack of Experienced Professional Consultants
Workers' Strike	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Lack of Experienced Professional Consultants
Workers' Strike	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Key Personnel Changes

PART B) FUZZY DEMATEL

Criteria Relationship Form:

Please show the rate of impact of the criteria in each row on the criteria in each column by the numerical values (**Very High = 5 , High = 4 , Low = 3 , Very Low = 2 , No Effect = 1**). Notice that it is assumed that the criteria don't have any effect on themselves.

For example in the table below, "High" in the shaded cell represents the high impact of the cost risk on the quality risk.

Table 1. Evaluation of the Relationships among the Main Risk Criteria of Construction Projects

Evaluation of the Relationships among the Main Risk Criteria of Construction Projects	Time Risk	Cost Risk	Quality Risk	Safety Risk	Environmental Sustainability Risk	Human Resources Risk
Time Risk	*					
Cost Risk		*				
Quality Risk			*			
Safety Risk				*		
Environmental Sustainability Risk					*	
Human Resources Risk						*

Table 2: Evaluation of the Relationship among Sub-criteria of Time Risk

Evaluation of the Relationship between Sub-criteria of Time Risk	Weakness in Construction Schedule	Delay in Supply of Materials
Weakness in Construction Schedule	*	
Delay in Supply of Materials		*

Table 3. Evaluation of the Relationship among Sub-criteria of Cost Risk

Evaluation of the Relationship between Sub-criteria of Cost Risk	High Bid Price	Increase in Price of the Material s	Increase in the Work Cost	Delay in Payment of Costs in Accordance with the Contract	Financial Problems
High Bid Price	*				
Increase in Price of the Materials		*			
Increase in the Work Cost			*		
Delay in Payment of Costs in Accordance with the Contract				*	
Financial Problems					*

Table 4. Evaluation of the Relationship among Sub-criteria of Quality Risk

Evaluation of the Relationship between Sub-criteria of Quality Risk	Choosing Inappropriate Apparatus and Equipment	Choosing Unsuitable Materials	Machinery Failure	Poor Quality of Work
Choosing Inappropriate Apparatus and Equipment	*			
Choosing Unsuitable Materials		*		
Machinery Failure			*	
Poor Quality of Work				*

Table 5. Evaluation of the Relationship among Sub-criteria of Safety Risk

Evaluation of the Relationship between Sub-criteria of Safety Risk	Collapse (Deficiency) of Construction	Workers' Safety	Unforeseen Disasters During the Work, such as Fire
Collapse (Deficiency) of Construction	*		
Workers' Safety		*	
Unforeseen Disasters During the Work, such as Fire			*

Table 6. Evaluation of the Relationship among Sub-criteria of Environmental Sustainability Risk

Evaluation of the Relationship between Sub-criteria of Environmental Sustainability Risk	Disturbance of Residents Near the Construction Site	Physical Injury of the Workers	Environmental Constraints	Noise
Disturbance of Residents Near the Construction Site	*			
Physical Injury of the Workers		*		
Environmental Constraints			*	
Noise				*

Table 7. Evaluation of the Relationship among Sub-criteria of Human Resources Risk

Evaluation of the Relationship between Sub-criteria of Human Resources Risk	Lack of Management Competency	Lack of Experienced Professional Consultants	Key Personnel Changes	Workers' Strike
Lack of Management Competency	*			
Lack of Experienced Professional Consultants		*		
Key Personnel Changes			*	
Workers' Strike				*

PART C) Fuzzy TOPSIS

In the Name of God

Dear Respondent,

The below table illustrates the risk factors that influence the evaluation of construction projects. How do you analyze the level of importance (or influence) of each of the risk factors in the following table on the success of civil construction projects? Please mark ✓ in the appropriate place for the level of influence of the risk sub-criteria on the success of the civil construction project you are engaged in. For example, if you consider the level of influence of "*Weakness in Construction Schedules*" on the success of the civil construction project to be low, you may mark ✓ in the low importance column, or if you consider this level of influence to be high, you may mark ✓ in the high importance column.

The six studied civil construction projects are respectively:

- **P1- Balarood Reservoir Dam Project**
- **P2- Karun IV Reservoir Dam Project**
- **P3- Doyraj Reservoir Dam Project**
- **P4- Siazakh Reservoir Dam Project**
- **P5- Shahre Bijar Reservoir Dam Project**
- **P6- Gadir Reservoir Dam Project**

Project: P1☐ P2 ☐ P3 ☐ P4 ☐ P5 ☐ P6 ☐

Row	Risk Sub-Criteria	Very High	High	Average	Low	Very Low
1	Weakness in Construction Schedules	☐	☐	☐	☐	☐
2	Delay in Supply of Materials	☐	☐	☐	☐	☐
3	High Bid Price	☐	☐	☐	☐	☐
4	Increase in Price of the Materials	☐	☐	☐	☐	☐
5	Increase in the Work Cost	☐	☐	☐	☐	☐
6	Delay in Payment of Costs in Accordance with the Contract	☐	☐	☐	☐	☐
7	Financial Problems	☐	☐	☐	☐	☐
8	Choosing Inappropriate Apparatus and Equipment	☐	☐	☐	☐	☐
9	Choosing Unsuitable Materials	☐	☐	☐	☐	☐
10	Machinery Failure	☐	☐	☐	☐	☐
11	Poor Quality of Work	☐	☐	☐	☐	☐
12	Collapse (Deficiency) of Construction	☐	☐	☐	☐	☐
13	Workers' Safety	☐	☐	☐	☐	☐
14	Unforeseen Disasters During the Work, such as Fire	☐	☐	☐	☐	☐
15	Disturbance of Residents Near the Construction Site	☐	☐	☐	☐	☐
16	Physical Injury to the Workers	☐	☐	☐	☐	☐
17	Environmental Constraints	☐	☐	☐	☐	☐
18	Noise	☐	☐	☐	☐	☐
19	Lack of Management Competency	☐	☐	☐	☐	☐
20	Lack of Experienced Professional Consultants	☐	☐	☐	☐	☐
21	Key Personnel Changes	☐	☐	☐	☐	☐
22	Workers' Strike	☐	☐	☐	☐	☐