A RISK AND VULNERABILITY ONTOLOGY FOR CONSTRUCTION PROJECTS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
THE MIDDLE EAST TECHNICAL UNIVERSITY

BY

GÜLŞAH FİDAN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

AUGUST 2008

Approval of the thesis:

A RISK AND VULNERABILITY ONTOLOGY FOR CONSTRUCTION PROJECTS

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ABSTRACT

A RISK AND VULNERABILITY ONTOLOGY FOR CONSTRUCTION PROJECTS

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August 2008, 116 pages

Risk is an uncertain event which will cause deviation in pre-defined objectives, if it occurs. Risk management aims to identify risks, quantify their impacts and develop strategies to mitigate them to ensure project success. Within the context of risk management studies, risk models are usually designed to simulate the project performance under various scenarios. For risk modeling, the statistical link between the risk events and their consequences is scrutinized. However, this approach has a limitation as the influence of the "system" is neglected during modeling the relation between risk sources and consequences. The term "vulnerability" is used to describe internal characteristics of a system which influence this relationship. Management of vulnerabilities in addition to risks is essential for the success of risk management. However, there is no consensus on an appropriate definition of vulnerability parameters and their influence on construction projects.

One of the aims of the study is to identify the vulnerability factors for construction projects and to propose a framework which portrays the relationship between risk and vulnerability. For this purpose, a detailed literature survey is performed to define the determinants influencing the level of vulnerability. In addition, case studies were conducted with Turkish contractors to explore the relationships between risk events, project vulnerabilities and project performance. Another objective of the study is to propose a risk and vulnerability ontology which provides a definite vocabulary and machine-comprehensible common understanding of the developed framework. Developed ontology will further be used to form a database for risk and vulnerability management.

Keywords: Risk, Vulnerability, Ontology.

ÖZ

İNŞAAT PROJELERİ İÇİN BİR RİSK VE RİSK KIRILGANLIĞI ONTOLOJİSİ

Fidan, Gülşah

Yüksek Lisans, İnşaat Mühendisliği Bölümü

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Ağustos 2008, 116 sayfa

Risk, oluştuğu taktirde önceden belirlenmiş hedeflerde sapmaya neden olan belirsiz bir olaydır. Risk yönetimi, proje başarısını gerçekleştirebilmek için riskleri saptamayı, etkilerini ölçmeyi ve onları hafifletici stratejiler geliştirmeyi amaçlar. Risk yönetimi çalışmaları kapsamında, çeşitli senaryolar altında proje performansını belirlemek için genellikle risk modelleri tasarlanır. Risk modellemesinde, risk olayları ve onların sonuçları arasındaki istatistiksel bağlantı incelenir. Ancak, risk kaynakları ve sonuçları arasındaki ilişki modellenirken "sistem"in etkisi ihmal edilmesinden dolayı bu yaklaşımın bir kısıtlaması vardır. "Risk kırılganlığı" terimi, bu ilişkiyi etkileyen sistemin iç özelliklerini tanımlamak için kullanılır. Risk yönetiminin başarısı için riske ek olarak risk kırılganlıklarının da yönetilmesi zorunludur. Ancak, inşaat projeleri için risk kırılganlık faktörlerinin tanımı ve etkileri üzerine henüz bir fikir birliğine varılamamıştır.

Bu çalışmanın amaçlarından bir tanesi, inşaat projeleri için risk kırılganlığı etkenlerini belirlemek ve risk ve risk kırılganlığı arasındaki ilişkiyi gösteren bir taslak önermektedir. Bu amaçla, risk kırılganlık seviyesini etkileyen etmenleri tanımlayabilmek için detaylı bir literatür taraması yapılmıştır. Ek olarak, Türk müteahhitlerle, risk olayları, risk kırılganlığı ve proje performansı arasındaki bağlantıları araştırmak amacıyla örnek olay incelemeleri yürütülmüştür. Bu çalışmanın bir diğer amacı ise geliştirilen taslak için açık bir sözlük ve bilgisayarca anlaşılabilir ortak bir anlayış oluşmasını sağlayan bir risk ve risk kırılganlığı ontolojisi kurmaktır. Geliştirilen ontoloji ileride risk ve risk kırılganlığı yönetimi için veritabanı oluşturmak amacıyla kullanılacaktır.

Anahtar Kelimeler: Risk, Risk Kırılganlığı, Ontoloji.

To my beloved family

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to my advisors Assoc. Prof. Dr. Irem Dikmen Toker and Prof. Dr. M. Talat Birgönül for their constant encouragement and support throughout my study. I wish to thank Asst. Prof. Dr. Ali Murat Tanyer for his invaluable suggestions. Without their ambition, creative ideas, clear expression and concern of the detail, this thesis would not have been possible.

I would like to thank to my family; Funda, Yeter, İzzet Fidan and Kaan Demiroğlu. Their unconditional love, continued encouragement and belief in my abilities nurtured me through this process.

I wish to thank Ulaş Emiroğlu for his unwavering support during my studies. His love and patience were certainly fundamental to my success.

I would like to thank to all my friends, especially Gizem Bezirci and İnci Narin. I feel lucky to have their friendship. I wish to thank to Dr. Beliz Özorhon for her invaluable help.

Finally, I would like to thank Scientific and Technical Research Council of Turkey (TUBITAK) which financially supported this study under the grant number 107M334.

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AI	Artificial Intelligence
PAR	Pressure and Release
PRM	Project Risk Management
RC	Risk Consequence
RE	Risk Event
RH	Risk and Hazard
RS1	Risk Source Group 1
RS2	Risk Source Group 1
RV	Risk and Vulnerability
USD	United States Dollar
V1	Vulnerability Group 1
V2	Vulnerability Group 2
V3	Vulnerability Group 3
EPC	Engineering, Procurement and Construction
PDS	Project Delivery System
FIDIC	International Federation of Consulting Engineers
OKBC	Open Knowledge Base Connectivity
ISO	International Organization for Standardization
IPCC	Intergovernmental Panel on Climate Change
UNDHA	United Nations Department of Humanitarian Affairs

CHAPTER 1

INTRODUCTION

Construction industry entails project-based undertakings which all include high-risk activities as they are susceptible to external conditions (such as weather, physical, political, economic and socio-cultural conditions) as well as project-related risk factors. Unlike to other sectors, construction industry is subject to more risk because of the high level of uncertainty stemming from external conditions. Therefore, risk management plays a vital role in construction projects. However, since each construction project is unique, it is a difficult process to configure project risks, their causes, consequences, relations between these factors and parameters influencing these interrelations.

Risk is the probability of occurrence of a risk event, which triggers undesirable outcomes. Magnitude of risk depends on its probability and potential consequences (Brooks, 2003). Risk management process mainly comprises of identification of risk events, assessment of their influence on project outcomes and developing response strategies to mitigate them. Since a project risk is a sign of a probable adverse consequence, its analysis almost invariably focuses on the process and causation of its occurrence. Within this process, the consequences are determined only by considering likelihood of risk events. However, as emphasized by Zhang (2007), giving more importance to the statistical link between risk events and risk consequences neglects the effect of "project system" on the process. The rules, structures, actions, behaviors, cultures within the project system have influence on the risk process. Barber (2005) considers these types of risks as internally generated and mentions the fact that imperfect organizations or systems generate new risks. Dikmen et al. (2007) describe the factors that determine the relationship between risk source and consequence as factors about manageability. In this study, the term "vulnerability" will be used to characterize the influence of project system on risk consequences as suggested by Zhang (2007) and Lewis (1999). The main idea of the thesis is that the traditional risk management process should be enhanced to cover vulnerability management, which deals with the fragility of a system to probable risk events.

One of the gaps in the area of construction risk management is that the risk source-event relation is usually not considered in previously developed hierarchical risk breakdowns. In practice, there are cause-effect relationships between the risk factors leading to a network form rather than a one-way hierarchical structure. Han et al. (2008) discuss the significance of those interrelations and propose "risk paths" that show the causal relationships between risk sources and events. It is argued that risk identification should entail identification of risk paths rather than individual sources of risk.

Although there are some studies that mentioned the importance of vulnerabilities and risk paths in risk modeling, there is no research that presents a common structure that combines these terms. Although the researches often share the same objective such as developing a system that considers influence of system on risk, they do not necessarily use the same terminology to communicate in the risk management process. This makes information sharing and reuse tedious. Development of a ontology will be a practical solution for this problem. Ontologies are representations of organized knowledge that give well-defined and explicit semantics which can be computationally processed for more sophisticated functionalities in knowledge management applications.

The aim of this chapter is to give information about the background of the research, the purpose of the study and applied methodologies. The purpose of this study is to investigate the risk paths and vulnerability factors in international construction projects, to develop a framework combining identified risk and vulnerability factors, and to design a frame based ontology for vulnerability integrated risk management process. This study is undertaken as a part of an ongoing research project which aims to develop a multi-agent system for risk management of construction projects. Research project aims to quantify the final impact of risks on each party through the negotiation processes between the project participants on a multi-agent platform. Developed framework will be utilized to create various scenarios and evaluate influence of risks and vulnerabilities on the overall project objectives. Designed ontology will serve for development of a knowledge base system (database) through the utilization of collected information about risk and vulnerability factors experienced in construction projects.

For this purpose, in this study, risk management literature within the construction management research domain has been reviewed to investigate the determinants of risk and vulnerability and to understand whether a ontology will be helpful or not. As a result of literature review, a framework has been developed. Then, case study methodology has been utilized to capture the validity of the parameters and relations within the framework. Finally, an ontology has been designed to properly share or re-use the information related with developed framework. The ontology development methodology included the specification, conceptualization, formalization and implementation phases.

Within the context of this thesis, Chapter 2 reviews the literature relevant to risk and vulnerability management with a special emphasis on definition of the term "vulnerability" and identification of vulnerability parameters. Chapter 3 outlines the literature review on ontology. Chapter 4 presents the methodology to develop the framework as well as its verification. Chapter 5 discusses the ontology development process. Chapter 6 concludes the study by presenting the research contributions, limitations, and future research directions.

CHAPTER 2

LITERATURE REVIEW ON RISK AND VULNERABILITY

This chapter presents the findings of a literature review on risk and vulnerability, with more emphasis on vulnerability. The chapter is divided into three main sections. In the first section, definition and challenges of risk and risk management will be discussed. In the second section, related information about vulnerability including is definition, distinction from risk and list of vulnerability parameters will be presented. In the last section, previously developed vulnerability integrated risk management processes will be reviewed.

2.1 Risk and Risk Management Concept: Definition and Challenges

In literature, most of the risk definitions are probabilistic, in other words, they are all related with the probability of occurrence of a risk event and its likely outcomes. Risk is defined as a function of probability and loss or magnitude of hazard impact (Smith, 1996; IPCC, 2001; Adams, 1995; Downing et al., 2001). It is accepted as "the exposure to the chance of occurrences of events adversely or favorably affecting project objectives as a consequence of uncertainty" (Al-Bahar, 1990). Although the risk outcomes could be a negative or a positive deviation, studies on risk usually choose the negative and unfavorable ones as risk consequences (Zhang, 2007). PMBoK (2000) defines risk as an uncertain event or condition that, if occurs, has a positive or negative effect on project objectives. Risk is a measurable uncertainty, which is originated from the unforeseen future and vagueness in context (Dikmen et al., 2007; Olsson, 2007).

Traditional project risk management process (PRM) is defined as identification of sources of uncertainty (risk identification), estimation of their consequences (risk analysis), and generation of response strategies throughout the life cycle of a project to ensure that there is no deviation from pre-defined objectives. Risk identification necessitates distinguishing and documenting the relevant risk factors. Each identified risk is further examined in risk analysis phase by measuring its magnitude by considering its associated impact on the project. The last stage, risk handling/response development aims to identify, evaluate, select, and implement response strategies to reduce the likelihood of occurrence of risk events and/or lower the negative impact of those risks to an acceptable level (Fan et al., 2008).

Risk identification is the first step of PRM. It has significant importance as risk analysis and response generation is performed based on the pre-defined risks (Al-Bahar and Crandall, 1990). Construction projects are high-risk undertakings as they are susceptible to external conditions as well as internal risk factors. Generic risk checklists and breakdown structures are proposed in order to facilitate and formalize the risk identification process. Using these tools, decision-makers may assess the magnitude of different sources of risk and identify potential risk events that may affect project outcomes. Wideman (1986) generated a risk breakdown structure that has five categories: external-unpredictable, external-predictable but uncertain, internal (non-technical), technical and legal. Flanagan and Norman (1993) classified risk sources as a hierarchy of four layers: the environment, the market or industry, the company and the project. Raftery (1994) defined three separate categories of risk such as risks internal to the project, risks external to the project, and risks regarding the client/the project/project team and project documentation. Han and Diekmann (2001) proposed a structure to classify international construction risks in five categories such as political, economic, cultural/legal, technical/construction, and others. Tah and Carr (2000) pinpointed the importance of a common vocabulary for risk and developed a risk information model that facilitates construction of risk databases to be used during risk identification and information retrieval in forthcoming projects. All the discussed risk categorizations clearly present the risk factors all of which are mainly similar to each other. The previous risk breakdown systems have a potential to help decision-makers in creating risk checklists, however, they have major shortcomings.

First; the risk source-event relation is usually not considered in hierarchical risk breakdowns. In practice, there are cause-effect relationships between the risk factors leading to a network form rather than a one-way hierarchical structure. Han et al. (2008) discuss the significance of those interrelations and propose "risk paths" that show the causal relationships between risk sources and events. They argue that risk identification should entail identification of risk paths instead of individual sources of risk.

Second, risk management can make an imperative contribution to effective project management. Since a project risk is accepted as a kind of possible, critical consequence, the analysis of it invariably focused on the process and causation of its occurrence, such that a project risk assessment process is considered to start with the risk event and end in a risk consequence (Zhang, 2007). In this traditional risk management process the influence of system is usually accepted as less important (Barber, 2005). During the identification phase, a critical issue, which is defined as "controllability/manageability" by Dikmen et al. (2007) and "project vulnerability" by Zhang (2007) should be considered to construct reliable risk models. As mentioned by Atkinson et al. (2006), uncertainty is created in part by the quality and completeness of information, diversity of interests and susceptibility to external influences in a project; all of which makes us vulnerable to the action of others.

To overcome the mentioned issues, and to increase the effectiveness of PRM applications, other factors such as its manageability and risk attitude should be considered during risk assessment in addition to probability and impact. Finally, it is believed that risk paths and system influence should be considered in the risk identification stage.

2.2 Vulnerability Concept

2.2.1 Definition of Vulnerability

In spite of the fact that all companies are exposed to risk, some characteristics of firms and projects will influence the impact of risk in the event of its occurrence (Khattab et al., 2007). The term "vulnerability" is used to explain inborn characteristics of a system. Vulnerability indicates the degree to which a project is susceptible to adverse effects of change (Brooks, 2003). It exists within systems independently of external hazards and depends on organization's capability to manage risks, and can be internally created by organizational, social and economic factors.

The social, political and economic conditions of nations, regions and systems have been investigated considering the concept of vulnerability. However, most authorities concentrate on only one or a limited number of sources of risk, which leads to the emergence of different definitions of vulnerability (Alwang et al., 2002). Table 2.1 presents some of the different definitions of vulnerability within the literature. The investigated disciplines include economics, sociology, disaster management, environmental management, health and so on.

Table 2.1: Definitions of Vulnerability in the Literature

Author(s)	**Definitions**
Agarwal and Blockley (2007)	"Vulnerability is a particular form of hazard- a hazard which is internal to the system".
Allen (2003)	Vulnerability refers to "the set of socio-economic factors that determine people's ability to cope with stress or change".
Alwang et al. (2002)	Vulnerability is "the probability of experiencing a loss in the future relative to some benchmark of welfare. Vulnerability refers to the relationship between adverse results, risk, and efforts to manage risk".
Blaikie et al. (1994)	Vulnerability is "the combination of characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from hazard impacts that threaten their life, well-being and livelihood".
Buchanan (1991)	"Vulnerability refers to the scale and complexity of the problems facing the project manager, the degree of uncertainty and risk involved, and to the anticipated degree of contention and resistance which the change is likely to generate".
Buckle et al. (2001)	"Vulnerability is a measure of the exposure of a person to a hazard and indicates the type and severity of the damage that is possible".
Chambers (2006)	Vulnerability is "defenselessness, insecurity and exposure to risk, shocks and stress".
Council for International Organizations of Medical Sciences cited in Levine (2004)	"Vulnerable persons are those who are relatively or (absolutely) incapable of protecting their own interests because they may have insufficient power, intelligence, education, resources, strength, or other needed attributes".
Dercon (1999)	Vulnerability is defined as: "vulnerability to fall below a particular minimum consumption level".
Einarsson and Rausand (1998)	Vulnerability indicates the properties of a system which makes its ability to survive and fulfill its aim weaker in case of risk presence
Nicholls et al. (1999)	"The likelihood of occurrence and impacts of weather and climate related events".
Öksüz (2003)	Vulnerability assessment is for the prediction and identification of the seismic performance and safety level of the building, which might be exposed to severe damage during an expected earthquake.

In literature, several researchers realized the importance of vulnerability in risk concept and they proposed alternative risk definition by integrating vulnerability into definitions.

Crichton (1999) defined risk as the probability of a loss, which depends on three elements: hazard, vulnerability and exposure. Changing any one of these three elements changes the risk consequence. According to Agarwal and Blockley (2007), risk is the production of hazard and vulnerability. To illustrate, hazard is the earthquake, exposure is the facility on earthquake zone and vulnerability changes due to the design, construction and maintenance of the facility. It is clear that the combination of a hazard with a vulnerable system results in disasters. Risk should be combine characteristics of a system in addition to probability of occurrence of an event, which leads to risk consequences. (Sarewitz et al., 2003).

Sarewitz et al. (2003) examines risk in two headlines. Event risk is the "risk of occurrence of any particular hazard or extreme event" and outcome risk is "the risk of a particular outcome". They accepted that outcome risk "integrates both the characteristics of a system and the chance of the occurrence of an event that jointly results in losses." According to Stenchion (1997), "risk might be defined simply as the probability of occurrence of an undesired event [but might] be better described as the probability of a hazard contributing to a potential disaster…importantly, it involves consideration of vulnerability to the hazard." UNDHA (1992) demostrated a mathematical model which introduces risk as the product of hazard and vulnerability.

Similar to the previous definitions, in this study, the "vulnerability" term is used to describe all the factors that make the system more susceptible to damage in case of a risk occurrence and risk consequence is accepted as a function of event risk and vulnerability.

2.2.2. Vulnerability Principles and Distinctions from Risk

Vulnerability is often confused with risk (Ezell, 2007). It is considered to be similar to the risk concept (Einarsson and Rausand, 1998). However, management of vulnerability is based on a different perspective than the traditional risk management. Some general principles about vulnerability and its distinctions from the risk are as follows:

Vulnerability is related with robustness and resilience; on the other hand risk is linked with safety (Einarsson and Rausand, 1998). According to the definition of Einarsson and Rausand (1998), robustness and resilience indicates the ability of accept or resist unexpected variations, in which “robustness is a static concept showing the strength of the system and resilience means that the system may change and adapt to the new situation.”

Vulnerability is about being susceptible to a risky situation, whereas risk is used for defining the severity of consequences within a scenario. While risk management is applied to estimate the likelihood and consequences of risks, vulnerability management is used to define the characteristics of a system that will change the possibility for harm. (Ezell, 2007; Brooks, 2003; Adger, 1999).

Project vulnerabilities exist before the occurrence of risk events (Zhang, 2007), but they will not become significant until the risk event happens. For instance, the existence of an escalation clause will not become momentous until there is a change in inflation.

Reducing vulnerability is an important way of managing risk, but any reduction in the impact of a risk is not related with reducing the vulnerability of system. Risk response strategies developed through a risk-based approach will be enough to cover the cost of extreme events, however the success of this application does not depend on reduction of vulnerability (Agarwal and Blockley, 2007; Sarewitz et al., 2003). For example, theft of materials at site will cause both time and money loss. Insurance, as a risk response strategy, will prevent cost overrun. However, insurance will not change the vulnerability of system. Vulnerability can only be reduced by improving site conditions, such as building secure storages at site. It is a fact that, the relation between risk and vulnerability is not inter-changeable. In other words, reducing vulnerability will always reduce risk outcomes, however reducing the risk outcomes will not always means reduced vulnerability. (Sarewitz et al., 2003).

To deal with the consequences of a risk factor, risk based approaches require getting hold of the accurate probabilistic data about the risk events. Vulnerability is also related with the probability, but vulnerability evaluation does not depend on exact quantification of future events. Vulnerability is "forward-looking and defined as the probability of experiencing a loss in the future relative to some benchmark of benefit" (Alwang et al., 2002). In their article, Sarewitz et al. (2003) mention that vulnerability assessment can be done "by history, be general scientific insight (e.g., floods occur on flood plains), by judgment acquired through personal experience, by personal priorities (e.g., "any risk to my child is too much risk"), or other means." Trusting on predictions will lead misleading results. In case the probability of a risk event is underrated in decision process, vulnerability of the system to that risk item should increase and as a result risk consequence will be higher than expected. Vulnerability level of the system may differ due to the applied risk management technique (Sarewitz et al., 2003).

A vulnerability parameter cannot generate a risk consequence without a risk event; however, a risk event may lead to a risk consequence on its own (Zhang, 2007). Vulnerability is the condition or inherent characteristic of a system, which influences the amount of damage. For example, project size will not cause any risk. However, in case of any change in quality of a material, project size will change the degree of cost overrun.

2.2.3. Importance of Vulnerability

Determination of vulnerabilities and managing them is important for increasing the capability to deal with risks and improving adaptation capabilities (Prowse, 2003). Through vulnerability management, the weakness of a project system can be identified and the project may be adapted to probable risks to minimize their impact on project outcomes.

According to Brooks (2003), "adaptation is the adjustments in a system's characteristics that improve its ability to cope with risks and adaptive capacity of a system is the ability of a system to modify or change its characteristics so as to cope better with existing external stresses." Vulnerability will be reduced through adaptation. For example, if a company is not familiar with the construction technology used in the project, then an experienced partner may be found to perform the construction. As a result, the company may reduce the vulnerability generated from the lack of experience and decrease the probability of project failure. As stated by Einarsson and Rausand (1998), "regular testing and analysis of the performance of safety functions and mitigation is one of the major tasks for keeping the vulnerability of a company at an acceptable level."

Managing vulnerability shows the ways of limiting uncertainty through achieving enough capacity to deal with risk and vulnerability (Prowse, 2003). Effective planning for risk consequences requires that the vulnerability associated with specific processes be understood in parallel with understandings of probabilities of risk, so that decisions can be taken by achieving the appropriate balance between risk and vulnerability management (Sarewitz et al., 2003). Integrated vulnerability management into risk management process may help companies to better understand threats, determine acceptable levels of risk, and take action to mitigate identified vulnerabilities. Thus, a framework that consists of vulnerability parameters applicable to construction business should be developed.

2.2.4. Vulnerability Parameters

Although there are several studies to define risk parameters, there is no other study focusing on the determination of vulnerability parameters for international construction projects. Therefore, determination of vulnerability parameters necessitates special emphasis and in this part of the thesis a list of the project vulnerabilities collected through a detailed literature review is presented (Table 2.2). The vulnerability factors are grouped under four categories: contract clauses, project characteristics including country conditions, company characteristics covering project management capabilities and project participant's characteristics. The categorization is revised in further stages of the study considering their relations between risk factors. Revised categorization as well as the relations between risk and vulnerability factors will be discussed in following chapters.

According to Katz (2004), "the contract is the contractor's first line of defense in dealing with risks", because responsibility and risk allocation between project parties are defined through contractual clauses. Ineffective risk sharing or the misunderstanding of risk distribution between project parties generally leads to a dispute after the occurrence of a risk event (Hartman and Snelgrove, 1996). Unfair or poorly defined contract clauses may lead severe risk consequences. Table 2.2 shows the most significant contract clauses that will make the projects more or less vulnerable to project risks.

Project characteristics basically include project requirements, restrictions, standards, project size, duration, site and country conditions (Table 2). Fan et al. (2008) mention that project characteristics could change the impact of risk event by affecting the risk handling strategy. As discussed by Han et al. (2007), many risks of international construction projects are closely related with fairness of construction laws and regulations of host country, local material supplies, the cultural issues and the attitude of government.

Table 2.2: Identified Vulnerability Parameters

FACTORS	SOURCE
CONTRACT CLAUSES	
Rights and obligation of the parties	Atkinson et al. (2006), Chapman (2001), Fortune and White (2006), Hartman and Snelgrove (1996), Hassanein and Afify (2007), Katz (2004), Pinto and Slevin (1987)
Measurement of work and Payment method	Chan et al. (2004), Han et al. (2007), Hartman and Snelgrove (1996), Hassanein and Afify (2007), Katz (2004)
Escalation	Han et al. (2007)
Valuation of variations	Hartman and Snelgrove (1996), Han et al. (2007)
Default of owner	Han et al. (2007), Hartman and Snelgrove (1996), Hassanein and Afify (2007)
Force majeure	Han et al. (2007), Hartman and Snelgrove (1996)
Differing site conditions	Han et al. (2007), Hartman and Snelgrove (1996), Hassanein and Afify (2007), Katz (2004)
Warranty	Han et al. (2007), Hassanein and Afify (2007)
Permissions/approvals	Han et al. (2007), Hassanein and Afify (2007), Hastak and Shaked (2000), Langbein (2005), Pinto and Slevin (1987)
Variation of work	Chan et al. (2004), Hartman and Snelgrove (1996), Hassanein and Afify (2007), Katz (2004), Ling et al. (2004)
Disputes	Chua et al. (1999), Han et al. (2007), Hartman and Snelgrove (1996), Katz (2004), Marrewijk (2007),
Taxation	Hassanein and Afify (2007)
Liquidated damages	Hartman and Snelgrove (1996), Hassanein and Afify (2007), Katz (2004)
Time extension	Hassanein and Afify (2007), Katz (2004)
Cost compensation	Han et al. (2007), Hartman and Snelgrove (1996)
Codes and standards	Atkinson et al. (2006), Caño and Cruz (2002), Chapman (2001), Chan et al. (2004), Hassanein and Afify (2007), Jaafari (2007), Ling et al. (2004)
PROJECT CHARACTERISTICS	
Size	Baloi and Price (2003), Caño and Cruz (2002), Chan et al. (2004), Chua et al. (1999), Fan et al. (2008), Fortune and White (2006), Han et al. (2007), Han et al. (2008), Ling (2004), Ling et al. (2004), Zin et al. (2006)
Contract type	Chan et al. (2004), Han et al. (2007), Hastak and Shaked (2000), Ling (2004), Ling et al. (2004), Torp et al. (2005)
Project delivery method	Jaafari (2007)
Design quality	Atkinson et al. (2006), Baloi and Price (2003), Chapman (2001), Chan et al. (2004), Jaafari (2007), Ling (2004), Ling et al. (2004), Olsson (2007), Zin et al. (2006)

Table 2.2: Identified Vulnerability Parameters (continued)

FACTORS	**SOURCE**
Technical requirement	Atkinson et al. (2006), Baloi and Price (2003), Barber (2005), Busby and Hug hes (2004), Caño and Cruz (2002), Chan et al. (2004), Fan et al. (2008), Han et al. (2007), Han et al. (2008), Hastak and Shaked (2000), Jaafari (2007), Ling (2004), Ling et al. (2004), Olsson (2007), Özorhon (2007), Pinto and Mantel (1990), Pinto and Slevin (1987), Zin et al. (2006)
Managerial requirement	Baloi and Price (2003), Zin et al. (2006)
Constructability requirement	Atkinson et al. (2006), Busby and Hughes (2004), Chua et al. (1999), Fortune and White (2006), Langbein (2005), Melton (2007), Pinto and Slevin (1987)
Duration	Atkinson et al. (2006), Caño and Cruz (2002), Chapman (2001), Chan et al. (2004), Fan et al. (2008), Han et al. (2007), Ling (2004), Ling et al. (2004)
Quality standards	Atkinson et al. (2006), Chapman (2001)
Environmental standards	Atkinson et al. (2006), Chapman (2001), Hartman and Snelgrove (1996), Fortune and White (2006)
Budget	Atkinson et al. (2006), Chapman (2001), Chan et al. (2004), Jaafari (2007), Ling (2004), Ling et al. (2004)
Innovation level	Chapman (2001), Jaafari (2007), Torp et al. (2005)
Project location	Baloi and Price (2003), Han et al. (2008)
Site conditions (site access, site security, site location)	Baloi and Price (2003), Caño and Cruz (2002), Chapman (2001), Chua et al. (1999), Han et al. (2007), Han et al. (2008), Hassanein and Afify (2007)
Design quality	Atkinson et al. (2006), Chapman (2001), Chan et al. (2004), Chua et al. (1999), Han et al. (2007), Han et al. (2008), Hastak and Shaked (2000), Jaafari (2007), Ling (2004)
Advance payment	Hassanein and Afify (2007)
Scope clarity	Atkinson et al. (2006), Baloi and Price (2003), Caño and Cruz (2002), Chan et al. (2004), Han et al. (2007), Langbein (2005), Ling (2004), Ling et al. (2004), Melton (2007), Özorhon (2007), Perminova et al. (2008), Pinto and Mantel (1990), Pinto and Slevin (1987), PMBoK (2000)
Contract language(clarity of contract document)	Dikmen et al. (2007), Han et al. (2007), Hartman and Snelgrove (1996), Hastak and Shaked (2000), Katz (2004), Langbein (2005), Torp et al. (2005)
Country Conditions	
Local construction material	Atkinson et al. (2006), Baloi and Price (2003), Caño and Cruz (2002), Chapman (2001), Han et al. (2007), Han et al. (2008), Hastak and Shaked (2000), Melton (2007), Torp et al. (2005)
Local construction labor	Atkinson et al. (2006), Baloi and Price (2003), Caño and Cruz (2002), Han et al. (2008), Hastak and Shaked (2000), Khattab et al.(2007), Melton (2007), Torp et al. (2005)

Table 2.2: Identified Vulnerability Parameters (continued)

FACTORS	SOURCE
Local construction equipment	Atkinson et al. (2006), Baloi and Price (2003), Caño and Cruz (2002), Han et al. (2008), Hastak and Shaked (2000), Melton (2007), Torp et al. (2005)
Local subcontractor	Han et al. (2007), Ling (2004), Melton (2007)
Professional services other than construction (infrastructure)	Chapman (2001), Han et al. (2007), Hastak and Shaked (2000)
Maturity of legal system	Baloi and Price (2003), Bing et al. (1999), Fan et al. (2008), Han et al. (2007), Han et al. (2008), Hastak and Shaked (2000)
Government attitude toward foreign investors	Han et al. (2007), Han et al. (2008), Hastak and Shaked (2000)
Import/export quota	Bing et al. (1999), Han et al. (2008), Khattab et al. (2007)
Taxation restrictions/tax rates	Baloi and Price (2003), Hassanein and Afify (2007), Hastak and Shaked (2000), Khattab et al. (2007)
Cultural differences	Atkinson et al. (2006), Bing et al. (1999), Chapman (2001), Han et al. (2008), Hastak and Shaked (2000), Özorhon (2007), Zin et al. (2006)
Linguistic differences	Bing et al. (1999), Han et al. (2007), Hastak and Shaked (2000), Özorhon (2007), Zin et al. (2006)
Religious differences	Bing et al. (1999), Hastak and Shaked (2000), Özorhon (2007), Zin et al. (2006)
Bribery	Baloi and Price (2003)
Mafia power	Baloi and Price (2003), Hastak and Shaked (2000
International relations	Baloi and Price (2003), Hastak and Shaked (2000)
Bureacracy	Chapman (2001), Chua et al. (1999), Hartman and Snelgrove (1996), Hastak and Shaked (2000), Torp et al. (2005)
Significance of the project for the country	Baloi and Price (2003), Han et al. (2007), Han et al. (2008), Hastak and Shaked (2000), Ling (2004)
Requirements for working in country	Baloi and Price (2003), Fan et al. (2008), Khattab et al. (2007)
Political stability	Baloi and Price (2003), Fan et al. (2008), Fortune and White (2006), Hastak and Shaked (2000), Marrewijk(2007), Özorhon (2007)
Economical stability	Baloi and Price (2003), Bing et al. (1999), Fan et al. (2008), Han et al. (2007), Hastak and Shaked (2000), Khattab et al. (2007), Özorhon (2007)
Geography and climate conditions	Baloi and Price (2003), Chapman (2001), Han et al. (2007), Han et al. (2008), Hastak and Shaked (2000)
COMPANY CHARACTERISTICS	
Project manager competency /experience	Barber (2005), Caño and Cruz (2002), Chua et al. (1999), Fortune and White (2006), Han et al. (2007), Han et al. (2008), Ling (2004), Torp et al. (2005), Zin et al. (2006)

Table 2.2: Identified Vulnerability Parameters (continued)

FACTORS	SOURCE
Project manager leadership/authority	Atkinson et al. (2006), Caño and Cruz (2002), Chua et al. (1999), Fortune and White (2006), Han et al. (2007), Zin et al. (2006)
Project manager	Chua et al. (1999), Han et al. (2007), Zin et al. (2006)
Team experience/commitment/ motivation	Atkinson et al. (2006), Baloi and Price (2003), Caño and Cruz (2002), Chapman (2001), Chan et al. (2004), Fortune and White (2006), Han et al. (2007), Han et al. (2008), Jaafari (2007), Kutsch and Hall (2005), Ling et al. (2004), Melton (2007), Torp et al. (2005), Zin et al. (2006)
Openness and trust between team	Atkinson et al. (2006), Bing et al. (1999), Chan et al. (2004), Ling (2004), Ling et al. (2004), Marrewijk (2007), Melton (2007)
Team turnoandr possibility	Atkinson et al. (2006), Chapman (2001), Chua et al. (1999), Langbein (2005)
Team and Company workload	Atkinson et al. (2006), Fan et al. (2008), Han et al. (2008), Langbein (2005), Perminova et al. (2008)
Cultural diandrsity within team	Caño and Cruz (2002), Chapman (2001), Han et al. (2007), Torp et al. (2005)
Experience in similar projects	Atkinson et al. (2006), Caño and Cruz (2002), Chan et al. (2004), Fan et al. (2008), Fortune and White (2006), Han et al. (2008), Langbein (2005), Ling (2004), Ling et al. (2004)
Experience in the country	Chan et al. (2004), Han et al. (2008), Ling (2004), Ling et al. (2004), Özorhon (2007)
Experience about PDS	Chan et al. (2004), Ling (2004), Ling et al. (2004)
Experience with client	Chan et al. (2004), Ling et al. (2004)
Experience with partner	Chan et al. (2004), Ling et al. (2004)
Senior management support	Baloi and Price (2003), Chua et al. (1999), Fortune and White (2006), Pinto and Mantel (1990), Pinto and Slevin (1987), Torp et al. (2005)
Firm business style (Process vs. results-oriented , employee vs. job-oriented)	Marrewijk (2007), Özorhon (2007)
Firm management style (family oriented-professional) /methods	Fortune and White (2006), Marrewijk (2007), Özorhon (2007)
Location of management (headquarter vs regional branch)	Han et al. (2007)
Financial strength	Chapman (2001), Chan et al. (2004), Jaafari (2007), Han et al. (2008), Ling et al. (2004), Özorhon (2007), Torp et al. (2005)

Table 2.2: Identified Vulnerability Parameters (continued)

FACTORS	SOURCE
Project Management Capabilities	
Cost&contingency estimation	Baloi and Price (2003), Barber (2005), Chapman (2001), Chan et al. (2004), Fortune and White (2006), Han et al. (2007), Jaafari (2007), Ling et al. (2004), Melton (2007), Pinto and Slevin (1987), PMBoK (2000), Zin et al. (2006)
Schedule deandlopment	Atkinson et al. (2006), Barber (2005), Han et al. (2007), Hastak and Shaked (2000), Fortune and White (2006), Jaafari (2007), Melton (2007), Pinto and Slevin (1987), Pinto and Mantel (1990), PMBoK (2000), Torp et al. (2005), Zin et al. (2006)
Procurement strategy	Atkinson et al. (2006), Barber (2005), Chapman (2001), Fortune and White (2006), Han et al. (2007), Jaafari (2007), Melton (2007), PMBoK (2000), Zin et al. (2006)
QA/QC	Chapman (2001), Barber (2005), Han et al. (2007), Jaafari (2007), Ling (2004), PMBoK (2000), Zin et al. (2006)
Organization structure/responsibility allocation	Atkinson et al. (2006), Barber (2005), Busby and Hughes (2004), Caño and Cruz (2002), Chapman (2001), Chan et al. (2004), Fortune and White (2006), Langbein (2005), Ling et al. (2004), Melton (2007), Perminova et al. (2008), Torp et al. (2005), Zin et al. (2006)
Communication & feedback system	Atkinson et al. (2006), Barber (2005), Busby and Hughes (2004), Chapman (2001), Chan et al. (2004), Chua et al. (1999), Fan et al. (2008), Fortune and White (2006), Han et al. (2007), Hastak and Shaked (2000), Jaafari (2007), Ling et al. (2004), Marrewijk (2007), Olsson (2007), Perminova et al. (2008), Pinto and Mantel (1990), Pinto and Slevin (1987), PMBoK (2000), Torp et al. (2005), Zin et al. (2006)
Documentation system	Barber (2005), Chapman (2001), Fortune and White (2006), Han et al. (2007), Katz (2004), Langbein (2005)
Subcontractors/supplier selection	Barber (2005), Caño and Cruz (2002), Chan et al. (2004), Han et al. (2007), Hastak and Shaked (2000), Jaafari (2007)
Partner selection	Han et al. (2007)
Health and safety management	Barber (2005), Han et al. (2007), Hastak and Shaked (2000), Ling (2004), Zin et al. (2006)
Enviromental management	Barber (2005), Han et al. (2007), Hastak and Shaked (2000), Zin et al. (2006)
Change management	Atkinson et al. (2006), Baloi and Price (2003), Barber (2005), Chapman (2001), Fortune and White (2006), Han et al. (2007), Jaafari (2007), Melton (2007), Torp et al. (2005)
Risk management system	Atkinson et al. (2006), Barber (2005), Caño and Cruz (2002), Chapman (2001), Fortune and White (2006), Jaafari (2007), Kutsch and Hall (2005), Melton (2007), PMBoK (2000), Torp et al. (2005)

Table 2.2: Identified Vulnerability Parameters (continued)

FACTORS	SOURCE
Control&monitoring system (cost, schedule, performance)	Atkinson et al. (2006), Barber (2005), Busby and Hughes (2004), Chapman (2001), Chan et al. (2004), Chua et al. (1999), Fortune and White (2006), Han et al. (2007), Jaafari (2007), Ling et al. (2004), Marrewijk (2007), Melton (2007), Pinto and Mantel (1990), Pinto and Slevin (1987), Torp et al. (2005), Zin et al. (2006)
Claim management	Baloi and Price (2003), Barber (2005), Ling (2004)
PROJECT PARTIES	
Owner	
Experience	Atkinson et al. (2006), Chan et al. (2004), Chapman (2001), Dikmen et al. (2007), Han et al. (2007), Ling (2004), Ling et al. (2004), Zin et al. (2006)
Team workload	Caño and Cruz (2002), Ling (2004), Perminova et al. (2008)
Team turnover	Chapman (2001), Chua et al. (1999), Langbein (2005)
Significance of the project for the owner	Caño and Cruz (2002), Chua et al. (1999), Langbein (2005), Ling (2004), Pinto and Mantel (1990), Pinto and Slevin (1987)
Funding capacity	Caño and Cruz (2002), Bing et al. (1999), Chapman (2001), Han et al. (2007), Jaafari (2007), Hastak and Shaked (2000), Langbein (2005), Melton (2007), Özorhon (2007)
Attitude & trust	Atkinson et al. (2006), Bing et al. (1999), Caño and Cruz (2002), Chan et al. (2004), Fortune and White (2006), Hastak and Shaked (2000), Langbein (2005), Ling et al. (2004), Marrewijk (2007), Özorhon (2007)
Objectives clarity	Bing et al. (1999), Caño and Cruz (2002), Chapman (2001), Chan et al. (2004), Kutsch and Hall (2005), Langbein (2005), Ling et al. (2004), Han et al. (2007), Perminova et al. (2008), Pinto and Slevin (1987), Torp et al. (2005), Zin et al. (2006)
Bureacracy	Torp et al. (2005)
Cultural differences	Atkinson et al. (2006), Barber (2005)
Relations with contractor	Atkinson et al. (2006), Bing et al. (1999), Chan et al. (2004), Chua et al. (1999), Han et al. (2008), Hastak and Shaked (2000), Kutsch and Hall (2005), Ling et al. (2004), Melton (2007), Torp et al. (2005)
Risk handling strategies	Barber (2005), Caño and Cruz (2002), Dikmen et al. (2007)
Local Partner	
Experience	Atkinson et al. (2006), Caño and Cruz (2002), Han et al. (2007), Özorhon (2007)
Technical competency	Atkinson et al. (2006), Caño and Cruz (2002), Dikmen et al. (2007), Han et al. (2007), Özorhon (2007), Torp et al. (2005)
Team workload	Caño and Cruz (2002), Perminova et al. (2008)
Significance of the project for the partner	Han et al. (2007)

Table 2.2: Identified Vulnerability Parameters (continued)

FACTORS	SOURCE
Strength of the relations with client	Baloi and Price (2003), Han et al. (2007)
Trust between partner and contractor	Atkinson et al. (2006), Bing et al. (1999), Hastak and Shaked (2000), Marrewijk (2007), Özorhon (2007)
Financial strength	Bing et al. (1999), Melton (2007), Özorhon (2007)
Level of partnership	Han et al. (2007), Hassanein and Afify (2007), Jaafari (2007), Özorhon (2007)
Cultural differences	Barber (2005), Han et al. (2007), Özorhon (2007)
Relations with contractor	Bing et al. (1999), Chan et al. (2004), Chua et al. (1999), Hastak and Shaked (2000), Ling et al. (2004), Melton (2007), Torp et al. (2005)
Risk handling strategies	Barber (2005), Caño and Cruz (2002), Dikmen et al. (2007)
Other parties (Subcontractor/ supplier/ designer /consultant)	
Experience	Atkinson et al. (2006), Baloi and Price (2003), Bing et al. (1999), Caño and Cruz (2002), Chan et al. (2004), Fortune and White (2006), Han et al. (2007), Hastak and Shaked (2000), Ling (2004), Ling et al. (2004)
Tecnical competency	Baloi and Price (2003), Chua et al. (1999), Dikmen et al. (2007), Han et al. (2007), Ling (2004), Özorhon (2007), Torp et al. (2005)
Workload	Perminova et al. (2008)
Financial strength	
Relations with contractor	Bing et al. (1999), Chua et al. (1999), Chan et al. (2004), Hastak and Shaked (2000), Ling et al. (2004), Melton (2007), Torp et al. (2005)
Risk handling strategies	Barber (2005), Caño and Cruz (2002), Dikmen et al. (2007)

Company characteristics such as project management system's maturity, project managers and team's abilities, experience and strength have also influence on the risk consequences. Chan et al. (2004) mention that the project managers should be able to plan and execute their construction projects to maximize the project's chances of success. They should use management tools effectively, which include adequate communication, control mechanisms, feedback capabilities, monitoring, project organization structure, plan and schedule followed, etc.

Key project participants include client, partner, subcontractor, supplier, designer and engineer. As Chan et al. (2004) state, "a construction project requires team spirit; therefore team building is important among different parties." Thus, the abilities, workload, financial strength of each party and the relations between these parties will influence project outcomes.

2.3. Previously Developed Vulnerability Integrated Risk Management Processes

To open up the link between risk event and consequence, vulnerability should be taken into account. In literature there are some studies that pinpoint the importance of the vulnerability assessment in traditional risk management process.

Dikmen et al. (2007) defined the influence of system as "controllability/ manageability issue. In their study, they mention the fact that probabilistic relationships between risk events and consequences are not enough to describe the project risks as they fail to capture the influence of project systems. The actual consequences of risk events depend on an organisation's capability to manage risks, thus, the company factors as well as the project characteristics that affect project vulnerability should be taken into account as shown in Figure 2.1. Although they emphasized the importance of system influence on risk consequences, they did not give any detail about how to integrate vulnerabilities with risk consequences moreover they do not present a detailed list of vulnerability parameters.

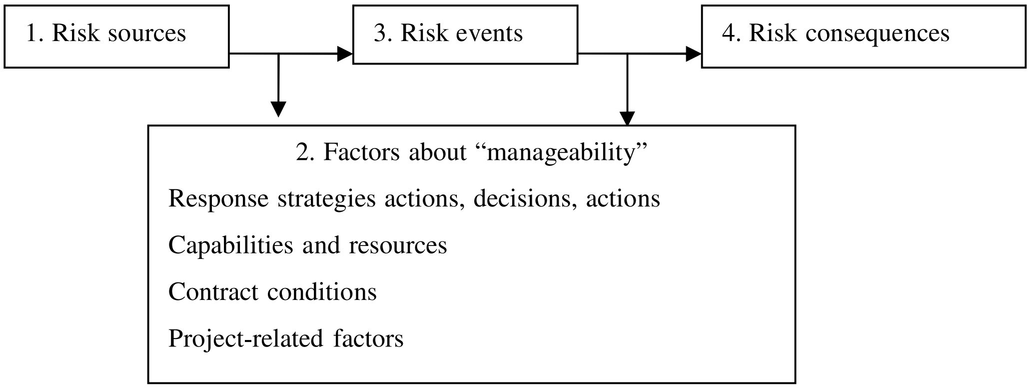

Figure 2.1: Risk Information Model Developed by Dikmen et al. (2007)

Busby and Hughes (2004) demonstrated a study that investigated how significant errors occurred in projects, and how hidden conditions in project organizations influence the generation of such error. In their study, they named these conditions as pathogens by influencing from the similarity with the development of disease in natural organisms. They are vulnerabilities whose significance is generally unclear to project participants until significant error has occurred. They suggested that, risk identification be supported by considering pathogens and incubation processes, and might be followed by a risk assessment to prioritize and quantify the identified risks (Figure 2.2).

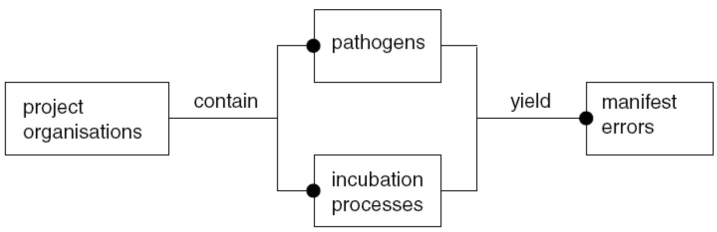

Figure 2.2: Risk Model by Busby and Hughes (2004)

In their study Turner, et al. (2003) introduced two frameworks for vulnerability analysis (risk-hazard (RH) and pressure-and-release (PAR) models) and discuss their shortcomings. Foundational RH models (Figure 2.3) indicates that the impact of a hazard depends on exposure to the hazard event and the dose–response (sensitivity) of the entity exposed. However, there are inadequacies in the model revealed out by various lines of investigation. For example, how the systems in question increase the impacts of the hazard is not discussed and the distinctions among exposed subsystems and components that lead to significant variations in the consequences of the hazards are not mentioned.

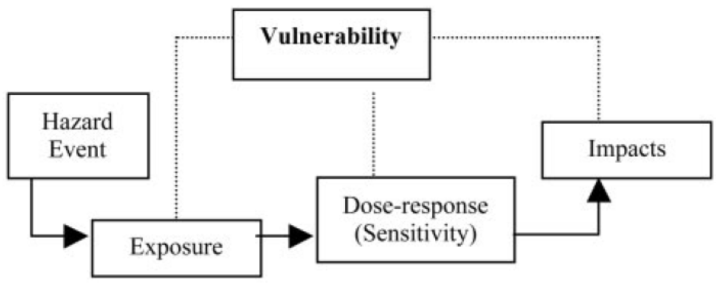

Figure 2.3: RH Framework Discussed by Turner et al. (2003)

The second model is the PAR model (Figure 2.4), in which risk is clearly defined as a function of the perturbation (hazard) and the vulnerability of the exposed unit. Although vulnerability is clearly highlighted, the PAR model is considered to be insufficiently comprehensive for the broader concerns of sustainability science. It provides little detail on the structure of the hazard's causal sequence, and it tends to underemphasize reaction beyond the system of analysis that integrative RH models include.

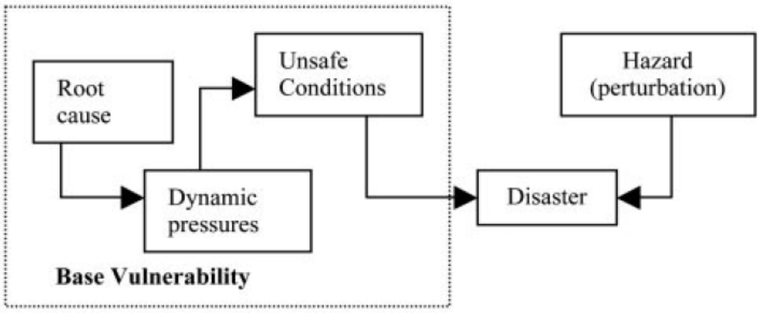

Figure 2.4 PAR Framework Discussed by Turner et al. (2003)

Zhang (2007) also suggested that the notion of vulnerability to characterize the influence of project system in risk processes, as shown in Figure 2.5. However, in his study, the details of the relation and vulnerability parameters are not discussed.

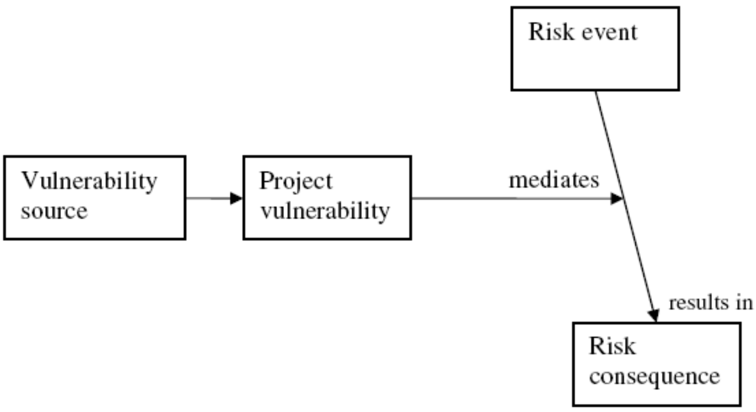

Figure 2.5. Risk process suggested by Zhang (2007)

To fill the research gaps by developing a framework and an ontology for risk and vulnerability assessment constitutes the major motivation of this study.

CHAPTER 3

LITERATURE REVIEW ON ONTOLOGY

This chapter conceives “ontologies” from the perspectives of knowledge representation. After brief information about what an ontology is, the tools and languages used for the development and implementation of ontologies, and the methodologies of building ontologies will be discussed. In addition, some examples of previously developed ontologies will be presented.

3.1. Definition of Ontology

The literature contains an overwhelming number of definitions of the notion of ontology and the methodologies for developing an ontology. Ontology is a term that comes from philosophy, used to define a systematic explanation of the order and structure of reality. The necessity of sharing the knowledge related with a domain influence the foundational theory of ontological commitment. As a result, ontology term is started to be used widely in knowledge engineering community (Goldman, 1969; Severens, 1974; Holsapple and Joshi, 2002; Rayo, 2008).

The mostly cited one from the ontology definitions is given by Gruber (1993), who defines ontology as “an explicit specialization of a conceptualization”. Conceptualization indicates a simplified view of the world and specification refers to a formal representation which means that ontology should be machine-readable. Gruninger and Lee (2002) describe conceptualization as a conceptual model of how people think of things that belong to a particular subject area.

According to Sowa (2000), ontology is the study of categories of things that exist or may exist in some domain. Guarino (1995) explained ontology as the study of the organization. Hendler (2001) and Chandrasekaran et al. (1999) define ontology as a set of knowledge terms, which is a representation vocabulary and the semantic interconnections specialized to a domain. From the conceptualizing and structuring knowledge point of view, ontology implies the collection of data that clearly represents semantics of data in a computer processable manner (Tang et al., 2004). Gašević et al. (2004) give a more formal definition that, "to someone who wants to discuss topics in a domain D using a language L, an ontology provides a catalog of the types of things assumed to exist in D; the types in the ontology are represented in terms of the concepts, relations, and predicates of L."

Ontology is accepted as the basic structure in the development of a knowledge base (Swartout and Tate, 1999). Ontologies define an agreed common terminology by specifying the concepts and relationships between the concepts. The main aim in constructing ontology is to give a common language that is computationally utilizable, sharable, and reusable by humans or machines (Holsapple and Joshi, 2002; Gruninger and Lee, 2002). In order to capture semantic properties of relations and concepts, ontology also provides a set of axioms, which are expressions in some logical language (Roman et al., 2005).

Although there are many definitions exist in literature, all of them pinpoint the same idea that, ontology aims to model knowledge to develop a machine-legible common understanding of the domain that the terms indicate.

3.2. Importance of Ontology

Ontology is the hearth of knowledge representation, because of the fact that, without ontology there would be no knowledge representation and no practical way to share it (Chandrasekaran et al., 1999). Ontology has been proposed as an important mean of representing real world knowledge. They are thought to provide a natural means for representing information for database management systems by providing the needed domain knowledge. This domain knowledge has two main usages. First, domain knowledge, as stored in an ontology, can help in creating a database because it presents what terms might appear in an application domain and how they are related to other terms. In addition, the constraints settled in the ontology will reveal the rules in an application domain which guides the formalization of constraints in database design. Second, comparing the concepts in a system with those in an ontology can highlight missing constructs (Sugumaran and Storey, 2002).

Gašević et al. (2004) clearly list the most useful features of ontology such that:

- Vocabulary: Ontology provides a finite list of terms related with a subject. But it is different than those human-oriented ones, because it presents logical statements describing the terms, their interrelations as well as the rules for combining the terms to define extensions to the vocabulary.
- Taxonomy: A hierarchical classification of entities within a domain can be achieved through ontology.
- Content theory: Ontologies are typically content theories, since ontology identify classes of objects, interrelations, and concept hierarchies that exist in some domain.
- Knowledge Sharing and Reuse: In ontology, the developed system, containing concepts and relations in a field, can be shared and reused among knowledge-based systems like intelligent agents and applications.

Usage of ontology will vary. A number of fields of artificial intelligence (AI) and computing use ontologies, such that knowledge representation, knowledge engineering, qualitative modeling, language engineering, database design, information retrieval and extraction, and knowledge management and organization (McGuinness, 2002). In this study, developed ontology will serve for database development.

As Cullot et al. (2003) mention, ontologies will be designed for simply explanatory purposes and serve as a common base for sharing the understanding of discussion. In this case, the developed ontology can be utilized to support the design of a database schema. Another use of ontologies is to enable data management services, such that ontologies are populated with instances stored in a database and they are used to facilitate access to data by enabling the management of incomplete data (Pattuelli, 2007).

With the developed ontology, which is a kind of knowledge model, one can also facilitate for accessing knowledge bases stored in knowledge representation systems. As mentioned by Noy and McGuinness (2001), “the ontology is designed to be domain-specific, allowing domain experts to easily and naturally enter their knowledge of the area. The resulting knowledge base can then be used with a problem-solving method to answer questions and solve problems regarding the domain. Finally, an application is the end product created when the knowledge base is used in solving an end-user problem employing appropriate problem-solving, expert-system, or decision-support methods.”

The Figure 3.1 shows typical use of ontology (Protégé 2000 User’s Guide) . The solid arrows indicate the forward progression through the process, while the dotted arrows show places where revisions are usually necessary.

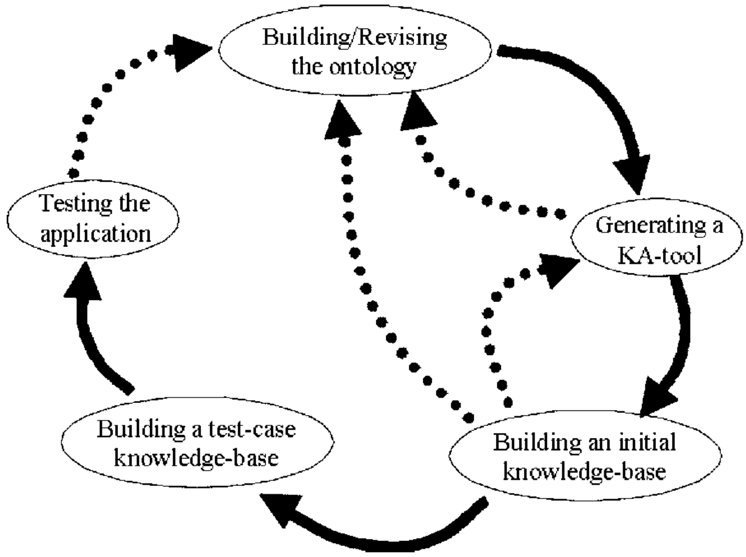

Figure 3.1: Usage of Ontology

3.3. Ontology Representation Languages and Development Tools

Gašević et al. (2004) stated that ontology development requires a lot of engineering effort, discipline, and rigor. Ontological engineering requires various design principles, development processes and activities, supporting technologies, and systematic methodologies that assist ontology development and use throughout its life cycle.

In ontology development process, one can use any one of the representation languages like XML Schema, RDF, RDF Schema, SHOE, DAML-ONT, OIL, DAML+OIL, OWL, SWRL etc.

As the ontology development tool, Protégé 2000 is selected in for this study among the several ontology-editing environments, like Ontolingua (Ontolingua, 1997), and Chimaera (Chimaera, 2000). Protégé 2000 is the leading ontology development editor and environment, developed at Stanford University. Protégé is available from Stanford University site at http://protege.stanford.edu/download.html and detailed information about how to use the software can be obtained from Protégé 2000 User's Guide (2000).

As mentioned by Gašević et al. (2004), Protégé facilitates "the defining of concepts (classes) in ontology, properties, taxonomies, and various restrictions, as well as class instances (the actual data in the knowledge base)." Protégé supports several ontology representation languages, including RDF (Protégé Frames) and OWL (Protégé-OWL). In this study, a frame-based ontology will be designed by the utilization of Protégé-Frames.

Hayes (1980) argued that "most of frames are just a new syntax for parts of first order logic." Although this means that frames do not offer anything new in expressiveness, there are two important points in which frame-based systems may have an advantage over systems using first-order logic. Firstly, they offer a concise way to express knowledge in an object-oriented way (Fikes and Kehler, 1985). Secondly, by using only a fragment of first order logic, frame-based systems may offer more efficient means for reasoning.

As stated in Protégé 2000 User's Guide, Protégé-Frames permits an integration of "(1) the modeling of an ontology of classes describing a particular subject, (2) the creation of a knowledge-acquisition tool for collecting knowledge, (3) the entering of specific instances of data and creation of a knowledge base, and (4) the execution of applications."

With knowledge model developed through Protégé, one can also facilitate conformance to the Open Knowledge Base Connectivity (OKBC) protocol for accessing knowledge bases stored in knowledge representation systems (Protégé 2000 User's Guide).

Basic terms used in Protégé-Frames through this study are as follows (Sachs, 2006):

- Class: Classes will correspond to objects, or types of objects, in the domain.
- Slot: Class attributes and relations are described using slots.
- Slot facet: Facets indicates the properties and restrictions of slots.
- Instance: Instances are the actual data in the knowledge base.

3.3. Ontology Development Methods

Ontology development is a tough process. Gašević et al. (2004) pinpoint the fact that, even with the most sophisticated ontology development languages, environments, and methodologies; the collection of concepts and relations in a domain, achieving consensus on them among the domain experts and other interested parties, is still a major problem. Moreover, there is no one correct way to develop an ontology, the best solution changes due to the requirements of the domain users. An ontology development methodology consists of several principles, processes, methods, and activities for designing, constructing and evaluating ontologies. In literature, there are several methodologies containing these issues. The book written by Gašević et al. (2004) includes a survey on methodologies concluding that, "there is no one best methodology, because there is no one "correct" way to model a domain. Also, ontology development is necessarily an iterative process."

Gruber (1993) outlines a set of design criteria to guide ontology development. These criteria are:

- Clarity: Definitions should be objective, free of social or computational context, and documented with natural language.
- Coherence: The defining axioms should be logically consistent.
- Extendibility: The ontology should anticipate new used of the shared vocabulary.

- Minimal encoding bias: The conceptualization should be specified at the knowledge level without depending on a particular symbol-level encoding.
- Minimal ontological commitment: An ontology should make a minimal number of claims about the world being modelled.

There are various studies that have focused on methodological issues (Bouaud et al., 1995; Gruber, 1993; Noy and McGuinness, 2001; Uschold and Gruninger, 1996). The detailed information on the ontology development procedures is out of the scope of this study (for detailed information about mostly applied ontology development procedures, please view Breitman et al., 2007). Instead, only applied ontology development method, methontology, will be described in detailed in the extent of this research. Methontology is one of the mostly applied well established ontological framework developed in the Laboratory of Artificial Intelligence of the Polytechnic University of Madrid (Fernandéz-Lopéz et al.,1997). The details and application of the method will be discussed in Chapter 5.

3.5. Previous Studies

In recent years, in recognition of the importance of ontologies in collaborative working, there is an increase in ontology engineering studies proposed in the literature. Many researches try to develop their own ontology according to their needs. However, as Ferreira et al. (2007) mention, "none of these developed ontology has been accepted as a standard or so heavily tested that it covers all possible ontology engineering development related processes or so commonly used that it is foreseeable to be adopted as a standard in a near future." Therefore, there is still a huge gap in Ontology Engineering research area. Currently various areas and application (like knowledge management, virtual organizations, semantic web, agents, biology, medicine, natural language, information integration, and so on) necessitate the development of a common terminology (Ferreira et al., 2007).

Woestenek (1998) describes the development of a common vocabulary for the storage and exchange of information in manufacturing concepts and terms to deal with manufacturing systems integration problem. The aim of the developed system is to make information interpretable among systems and people within and across networked organizations.

Ugwu et al. (2001) develop an ontology for agent-based collaborative design of portal structures, using knowledge acquisition techniques and tools (Figure 3.2). They illustrated the application of the ontology in the development of a multi-agent systems. Their study shows that a common ontology facilitates interaction and negotiation between agents.

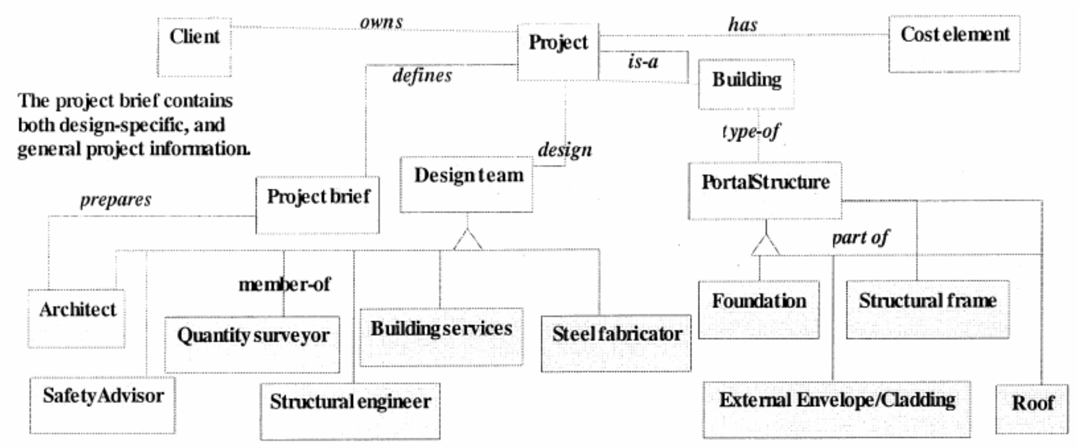

Figure 3.2: Frame ontology developed by Ugwu et al. (2001)

In their paper, Falbo et al. (2004) demonstrate an ontology-based knowledge management approach to maintain organizational learning in risk management.

In the study, ontologies are used to develop the organizational memory and to support the main knowledge services. The develop ontology contains both risk concepts and relations as illustrated in Figure 3.3.

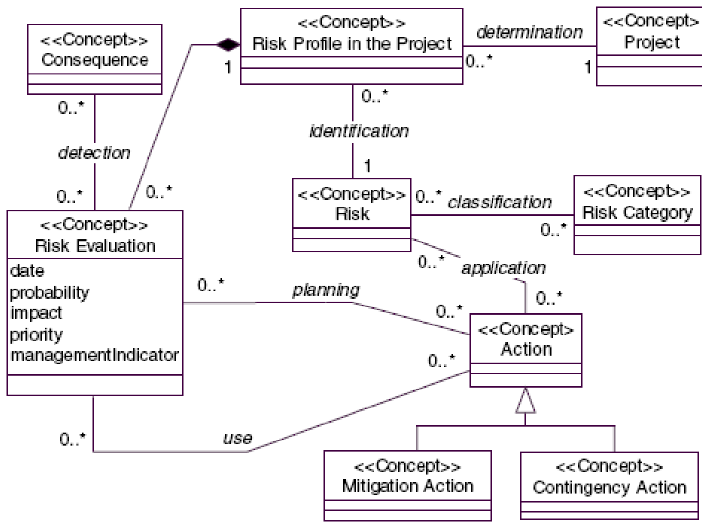

Figure 3.3: Risk ontology developed by Falbo et al. (2004)

In their study, Ferreira et al. (2007) propose risk analysis ontology which is developed by taking Riskit method as the base of the categorization (Figure 3.4). The risk parameters are grouped under 4 categories: risk factor, risk event, reaction and risk effect. In their study, the risk ontology is developed through risk scenarios generation by connecting these 4 elements in a single logic sequence that describes a problem that can occur in a project and by identifying the interdependencies and influences between these groups.

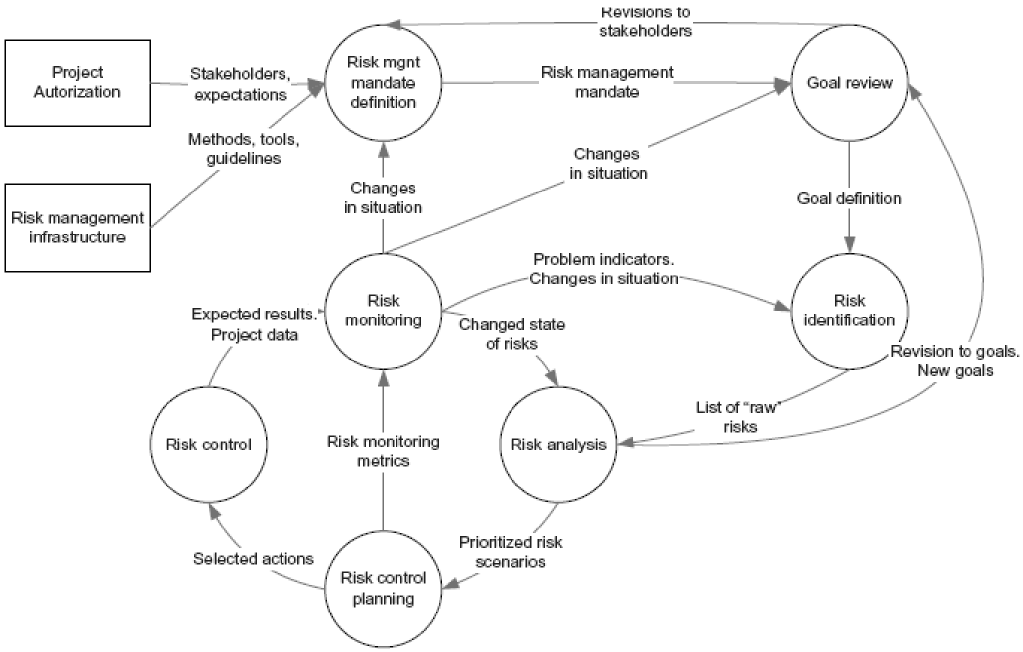

Figure 3.4: Riskit management process given in Ferreira et al. (2007)

Assali et al. (2008) try to develop a knowledge database of industrial safety based on ontologies as a part of an ongoing study that aims to develop an industrial risk analysis support system. In addition, they presented the usage the mind maps as a practical and efficient way to produce the conceptual model of ontologies.

In their study, Wang et al. (2008) presented an ontology for knowledge about news regarding financial instruments. The developed ontology contains two parts. First part is a hierarchy framework for the domain knowledge that primarily includes classes of news, classes of financial instrument markets participants, classes of financial instruments, and primary relations between these classes. In the second part, a how classes of news are causally related with classes of financial instruments are demonstrated. The ontology aims to make the knowledge about news in financial instrument markets understandable and to build trading models based on news in the financial instrument markets.

Gilmour (2004) create a knowledge base for the area of hazard identification in risk management. Knowledge base is represented in ontology form which is created for intelligent software agents who need a formal structure and language to be able to share and think logically with information. This study involves research in the area of hazard identification and then the construction of an ontology to represent this knowledge.

In risk management literature, although there are several developed software programs to provide a process to risk management, what is actually needed is a universal vocabulary to improve and support all process information to easily refer to it and made contributions (Gusmão and Moura, 2006). Therefore, this research aims to develop ontology for the risk management framework which considers risk source-event-consequence relations in addition to the vulnerabilities which will serve for database development. The developed ontology will be employed in the design of a database for the usage of intelligent-agents.

CHAPTER 4

RESEARCH METHODOLOGY FOR RISK-VULNERABILITY FRAMEWORK

As mentioned in Chapters 2 and 3, the literature review on risk and vulnerability forms the basis of framework and ontology development. It is seen that, very detailed studies have been conducted to define, categorize and manage risk in international construction projects. However, it is realized that, in most of the studies, risks were grouped without considering the causal relation within risk elements. Moreover, although there are some proposals to integrate vulnerability into risk management process, there is no reported study that discusses the details of how to manage this integration. There is no consensus on the definition, parameters and the interaction of vulnerability with risk. Moving from this point, first, an initial framework comprising of risk and vulnerability parameters is developed. At this stage, the factors collected through literature review are categorized. Risks are grouped in order to form a cause-effect relation and vulnerabilities are grouped considering their influences on this cause-effect link. Then, seven case studies are conducted to understand the actual risks and vulnerabilities experienced in real construction projects and to validate the developed framework. Cognitive map technique is used to summarize the knowledge gained during the interviews and to represent the actual relations between risk and vulnerability factors. In this chapter, details of these phases will be discussed.

4.1. Risk and Vulnerability Framework Design

4.1.1. Definition of Risk-Related Terms Used in the Framework

As Dikmen et al. (2007) mention, to discuss the roots of a negative event, its probability of occurrence or consequences, researches usually uses the same term, “risk”. However, this leads to the development of inconsistent and wrong models for risk management. The sources of an event should be examined separately than its consequences. A risk consequence like cost overrun shouldn’t be in the same level with a source like changes in project scope, because there is a cause-effect relationship between these notions. Han et al. (2008) defined risk paths as the combination of risk variables and their cause-and-effect scenarios which leads the construction of a tree structure for risk concepts. The interrelations between risk sources-event and consequences, risk paths, should be defined for a realistic risk model.

Risk source is accepted as something that has potential to cause harm to project. Risk event is the occurrence of negative happening and risk consequence implies the outcome of the occurred event which causes deviation in the project objectives (Australian standard AS 4360, 2004). Collected risk items through a detailed literature review are categorized questioning whether they have potential to cause problem (risk source) or it is itself a problem (risk event) or they are the actual consequence of a negative effect (risk consequence).

- The risk sources are investigated under two groups, considering their origins: adverse change (RS1) and unexpected event (RS2). Adverse change implies a negative variation from the initial conditions of the project, like change in performance, change in client attitude, etc. The second category is the unexpected events (usually acts of God) that happen suddenly and cause problems in a project, such as force majeure events and accidents.

- Risk events (RE) are mainly about "variations (decrease or increase)" about productivity, quantity of work, relations etc.

- Risk consequence (RC) is defined based on the assumption that there are two project success criteria: cost and schedule. It is clear that the contents of this category can be revised by incorporating other success criteria (such as quality issues etc.) applicable for particular project cases.

4.1.2. Definition of Vulnerability Parameters Used in the Framework

As Twigg (2001) mentioned, in order to understand the factors that increase a system's vulnerability, one should diverge from the risk event itself and consider a set of influences. For international construction projects the factors related with the contract, company, project and project participants come together to create the influencing factors. The vulnerability factors, which were identified as a part of this study, are given in Chapter 2. Through this research, the collected vulnerability factors are categorized considering their influence on risk paths. Some of the vulnerability factors affect the probability of occurrence of risks whereas the others affect only the relations between risk sources, events and consequences. Vulnerability factors may influence the level of risk in three ways:

- Vulnerability (V1), "robustness", refers to the factors that affect the probability of occurrence of risk. For example, if the owner's objectives are not clear, this will increase the risk of "change in scope". The factors affecting project robustness (V1) are mainly grouped under four main categories: country, project, parties and company.

- Vulnerability (V2), "resilience", refers to the factors that affect manageability of risk. For instance, "change in construction technology" may lead to a less significant risk event (such as delay) if the company has the necessary know-how and an adequate change management system. Factors forming the "resilience" contain the issues related with contractor/company such as the experience, resources and managerial capability of the company.

- Vulnerability (V3), "sensitivity", refers to the factors that influence the impact of risk events on project success. In other words, those are the factors which affect the magnitude of risk consequences. For instance, if there is an increase in the quantity of work due to change in scope, the implications for the contractor are different in case the contract/payment type is unit-price or lump-sum. Sensitivity factors contain several project related parameters such as, project delivery system, payment type, etc.

4.1.3 Risk-Vulnerability Framework

After the risk and vulnerability parameters are decided, a generic structure that encompasses the risk-vulnerability paths was constructed. The proposed structure is depicted in Figure 4.1. The detailed taxonomy of risk and vulnerability factors is given in Table 4.1. In Table 4.1, factors are given with their notations/abbreviations in bracket, which will be used and referred in the following section, during analysis of case studies.

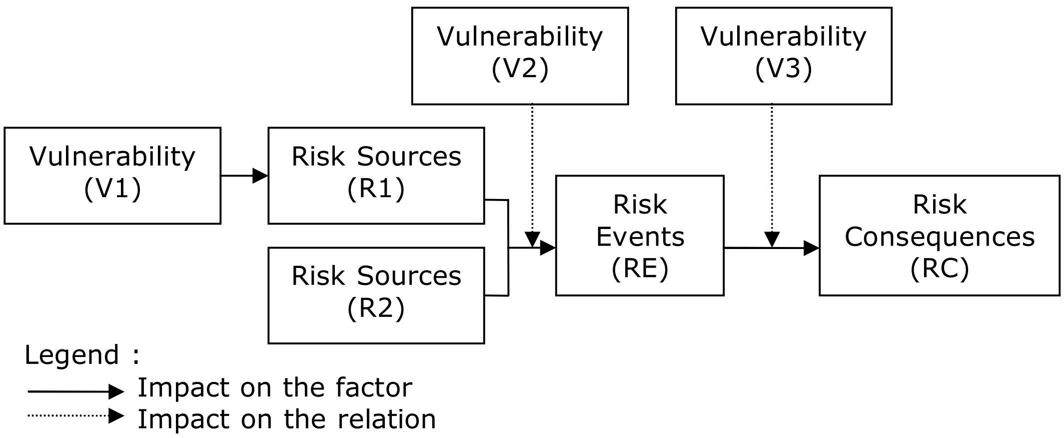

Fig 4.1: Risk-Vulnerability paths

Table 4.1: Risk and Vulnerability Factors

Category	Sub-category	Factors
Vulnerability (V1)	Strict project-requirements	Quality management (V1.1), health and safety management (V1.2), environmental management (V1.3), project management (V1.4)
	Project-conditions	Complexity of design (V1.5), incomplete design (V1.6), low constructability (V1.7), design errors (V1.8), complexity of construction method (V1.9), poor accessibility of site (V1.10), inadequate geotechnical investigation (V1.11), inadequate climate conditions (V1.12), vagueness of contract clauses (V1.13), contract errors (V1.14)
	Country- market conditions	Unavailability of material (V1.15), equipment (V1.16), labor (V1.17), subcontractor (V1.18), infrastructure (V1.19)
	Country-conditions	Instability of economic conditions (V1.20), government (V1.21), international relations (V1.22), level of bureaucracy (V1.23), level of bribery (V1.24), level of mafia power (V1.25), , instability of social conditions (V1.26), immaturity of legal system (V1.27), restrictions for foreign companies (V1.28)
	Company-resources	Lack of financial resources (V1.29), technical resources (V1.30), staff (V1.31), lack of managerial capability (scope (V1.32), time (V1.33), cost (V1.34), quality (V1.35), human resources (V1.36), communication (V1.37), risk (V1.38), procurement (V1.39)) , experience (in similar projects (V1.40), in country (V1.41), in project delivery system (PDS) (V1.42), with client (V1.43), with partner (V1.44))
	Client-conditions	Unclear objectives (V1.45), level of bureaucracy (V1.46), negative attitude (V1.47), poor staff profile (V1.48), unavailability of financial resources (V1.49), technical incompetency (V1.50), poor managerial/organizational ability(V1.51)
	Partner	Technical incompetence (V1.52), managerial incompetence (V1.53), lack of financial resources (V1.54), cultural differences with the company/contractor (V1.55)
	Designer	Technical incompetence (V1.56), managerial incompetence (V1.57), lack of financial resources (V1.58), cultural differences with the company/contractor (V1.59)
	Consultant	Technical incompetence (V1.60), managerial incompetence (V1.61), lack of financial resources (V1.62), cultural differences with the company/contractor (V1.63)

Table 4.1: Risk and Vulnerability Factors (continued)

Category	**Sub-category**	**Factors**
Risk Sources (RS1)	Economic	Adverse change in currency rates (RS1.1), inflation (RS1.2), tax rates (RS1.3)
	Legal	Adverse change in laws and regulations (RS1.4)
	Political	Adverse change in relations with the government (RS1.5)
	Market	Adverse change in availability of labor (RS1.6), availability of material (RS1.7), availability of equipment (RS1.8), availability of subcontractor (RS1.9)
	Client	Adverse change in staff (RS1.10), financial situation of the client (RS1.11), attitude (RS1.12), relations (RS1.30)
	Technical	Adverse change in technology/method (RS1.13), design (RS1.14), original schedule/sequence (RS1.15), scope (RS1.16), work quality/rework (RS1.17)
	Company	Adverse change in performance (RS1.18), financial conditions (RS1.19), top management (RS1.20), project team (RS1.21), site organization (RS1.22), communication with parties (RS1.35)
	Partner	Adverse change in performance (RS1.23), financial conditions (RS1.24), relations (RS1.25)
	Designer	Adverse change in performance (RS1.26), relations (RS1.27)
	Consultant	Adverse change in performance (RS1.28), relations (RS1.29)
	External conditions	Adverse change in site conditions (RS1.31), weather conditions (RS1.32), geological conditions (RS1.33), public reaction (RS1.34)
Risk Sources (RS2)	Force majeure	War/hostilities (RS2.1), rebellion/terrorism (RS2.2), social unrest (RS2.3), national catastrophes (RS2.4), historical findings (RS2.5), epidemic disease (RS2.6)
	Unexpected conditions	Accidents (RS2.7), damage to site (RS2.8), breakdown of machinery (RS2.9), theft (RS2.10), strikes/labor problems (RS2.11)
Vulnerability (V2)	Company	Management capability (V2.1), resources (technical, financial, staff) (V2.2), experience (V2.3)

Table 4.1: Risk and Vulnerability Factors (continued)

Category	Sub-category	Factors
Risk events (RE)	Productivity	Decrease in productivity (RE.1)
	Quantity	Increase in quantity of work (RE.2)
	Quality	Decrease in quality (RE.3)
	Unit cost of resources	Increase in unit cost of resources (RE.4)
	Delay	Delay in bureaucracy (RE.5), site handover (RE.6), logistics (RE.7), progress payments (RE.8)
Vulnerability (V3)	Project	Size (V3.1), duration (V3.2), payment type (V3.3), project delivery system (V3.4), partnership type (V3.5), contract clauses (V3.6)
Risk Consequence (RC)	Cost	Impact on cost (RC.1)
	Schedule	Impact on duration (RC.2)

Finally, it should be noted that, all factors under a specific category are not necessarily affected from all factors given under the preceding category. For example, all of the factors under R1 are not influenced by all V1. There are individual relations between the factors leading to a number of risk-vulnerability paths some of which coincide whereas others are completely independent. Also, the risk-vulnerability factors are defined from the perspective of the contractor.

4.2 Verification of Framework

In this research, case study methodology is selected in order to understand and verify the basic relations between the factors of risk, vulnerability and project performance. As mentioned by Feagin et al. (1991), case study is an ideal method when a holistic, in-depth investigation is needed.

To better understand the relations between risk and vulnerability factors and to capture the main properties of these factors seven case studies were conducted.

Turkish contractors in international markets were selected as the target population and selected experts from this population were interviewed. Detailed information about the project and reasons of failure were collected through an interview with people that took part in the project, each lasting for 1-1.5 hours. The participants are requested for permission to audiotape the interview sessions for detailed investigation of speech. During the interview, the participants are requested to talk about completed projects that they took part in. For the confidentiality purposes the name of the project, and the parties are withheld..

4.2.1. Cognitive Mapping Technique

Cognitive mapping technique is used to identify an individual's beliefs about a particular domain and to depict these diagrammatically; cognitive maps are the visual representation of an individual's subjective data which help in the understanding and analysis of specific elements of an individual's thoughts rather than thinking (Edkins et al., 2007).

Cognitive mapping technique has been used in several studies in the field of risk management such as research about modeling complex projects (Williams, 2002), discovering risks in projects (Williams et al., 1997), exploring the process of risk identification (Maytorena et al., 2004) and delay analysis (Eden et al., 2000).

During the face-to-face interviews, cognitive mapping technique was used to summarize the risk-related information and a software entitled as Cognizer was utilized to draw the cognitive map of the interviewees. The guideline of using Cognizer is out of the scope of the study (for detailed information about the program, see Clarkson and Hodgkinson, 2005).

All the concepts mentioned by the interviewee are presented in cognitive maps with their notations used in the map. The expressions/concepts mentioned by the expert are tried to be matched with the factors that are included in the RV framework. The concepts mentioned by the interviewee do not fully comply with the pre-defined factors because of the fact that the factors given in Table 4.1 are the general names used widely in the literature, which would be implied by different expressions in each case study. The factors defined in the ontology are broader concepts rather than specific factors so that the ontology is generic and can be used to represent all conditions.

The demonstrated cognitive maps present all concepts and their interrelations mentioned by the interviewee. The strengths of the relations are shown by the values on the arrows which can be either a positive or negative value within the range of -3 to 3. The strengths of relations are decided according to the opinions of the interviewee. For example, V1 parameters tend to increase the probability of the RS1 occurrence; therefore their relations are represented with positive numbered arrows. On the other hand, in some cases V2 parameters decreases the impact of the RS1, thus their interrelations are shown with minus values. In addition, the strength of the relations are demonstrated by values 1,2,3 which indicate the low, medium and high influence respectively.

4.2.2. Case Studies

After brief information about each project, cognitive map showing details of project progress as well as table presenting concepts and notations used in cognitive map are presented for each project. The notations used in each map are the same with the ones given in Table 4.1.

4.2.2.1. Project A: OverHead Transmission Line Project in South Iraq

The initial cases (Project A and B) are chosen so that they are carried out in the same country by same company and the projects are technically very similar. This enables the investigation of impacts of contract and country conditions as well as the parties involved in the project.

The Company that carried out both of the projects has been designing, manufacturing and undertaking the construction works of steel structures for energy and telecommunication industries. The Company employs around 1 000 personnel and exports to more than 100 countries in five continents. In 2007, the total sales of the Company were around 180 million USD and the Company exported nearly 70 000 metric tons of towers. The projects investigated were technically very similar and performed in different regions of the same country in the same year.

One of the most significant issues of Project A was that, the company did not have any experience with Client (V1.43) and they were unfamiliar to the strict management requirements (V1.4). Therefore, it took their much time to prepare the required documents (RS1.18), which cause delays in progress payments (RS.8). Since they could not get money, they had to slow down the construction which leads to delays (RC.2). Another issue was the managerial (V1.53) and technical insufficiency (V1.52) of the Partner. Since the Partner could not perform the job as expected (RS1.15), the Company decided to perform the construction on his own as the Company had enough experience in similar projects (V2.3). Since Company's high level of experience decreases the impact of risk source, it is indicated with a minus degree on the map.

All other issues, their relations with each other and their influence levels can be clearly observed from Figure 4.2. The expressions used by the interviewee to discuss these issues are given in Table 2.2.

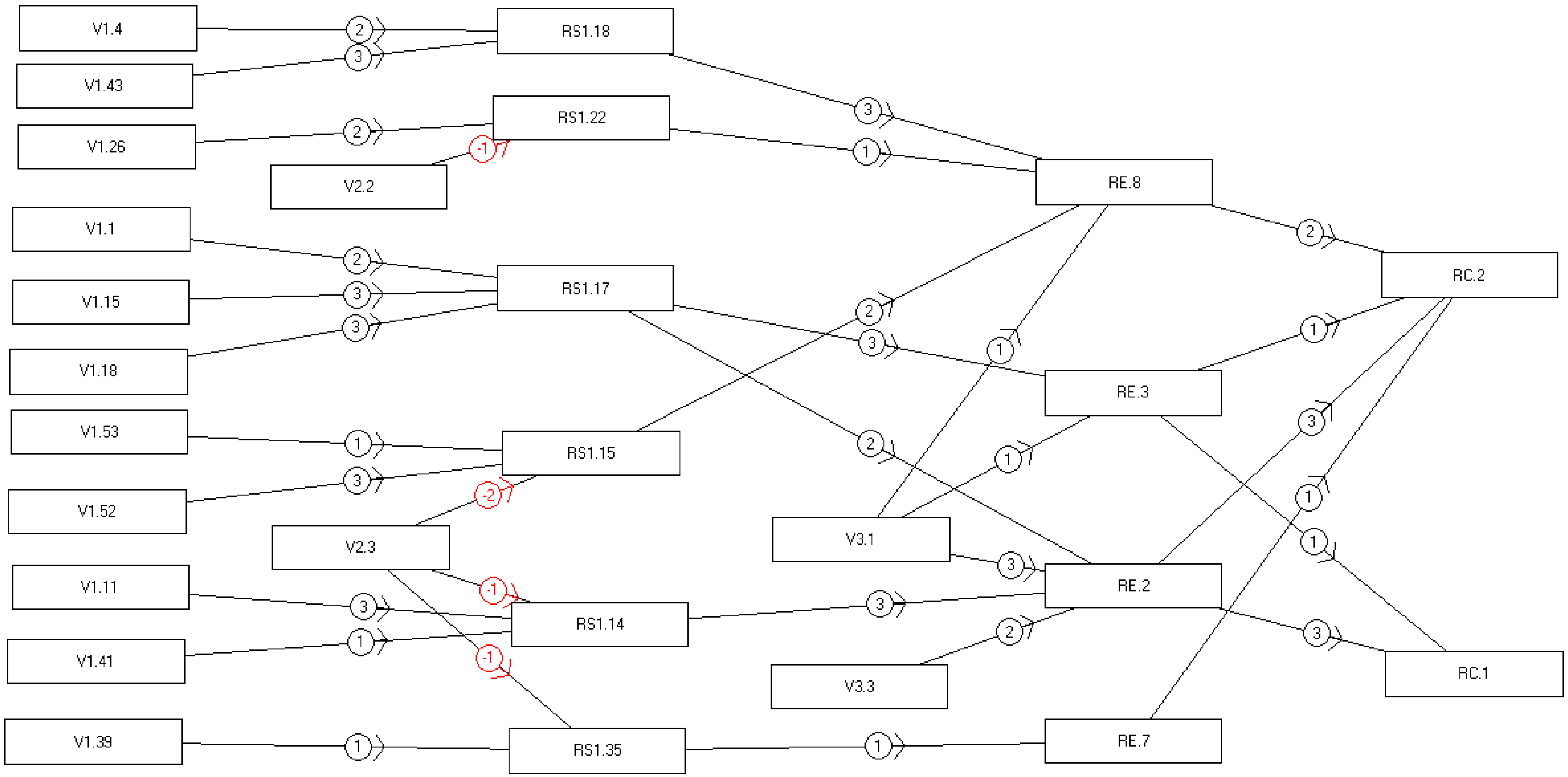

Figure 4.2: Cognitive Map of Project A

Table 4.2 : Concepts and notations used in the cognitive map of Project A

Category	Notation	Expression used by the interviewee	Corresponding factor in the framework
V1	V1.4	Heavy progress reporting requirements	Strict project management requirements
	V1.43	This was the first project performed for this Client	Lack of experience with client
	V1.26	There was conflict between different ethnic groups	Instability of social conditions
	V1.1	Quality standards were mentioned in the Contract, there was no chance to change them	Strict quality management requirements
	V1.15	There were no local supplier that can sell material having required quality	Unavailability of material
	V1.18	There were no local subcontractor	Unavailability of subcontractor
	V1.53	Partner neither develops a schedule nor submits required reports and tests	Managerial incompetence of partner
	V1.52	Partner was inexperienced in transmission line construction projects	Technical incompetence of partner
	V1.11	Because of the time limit in tender stage, we couldn't do a detailed geotechnical investigation	Inadequate geotechnical investigation
	V1.41	This was the first project performed in South Iraq	Lack of experience in country
	V1.39	Strict quality requirements necessitate several suppliers from different countries; this was the first project that we have worked with this much supplier at a time	Lack of project procurement management
V2	V2.2	When partner couldn't perform construction, we allocate our site team to project	Sufficient company resources
	V2.3	We have performed several similar projects	Sufficient company experience
RS1	RS1.18	We couldn't submit required documents on time	Adverse change in performance of contractor
	RS1.22	Team turnover rate was high	Adverse change in site organization
	RS1.17	Material purchased from local companies cause changes in work quality	Adverse change in work quality/rework

Table 4.2: Concepts and notations used in the cognitive map of Project A (continued)

Category	Notation	Expression used by the interviewee	Corresponding factor in the framework
RS1	RS1.15	Partner couldn't start the project at time stated in schedule	Adverse change in original schedule/sequence
	RS1.14	We have to revise all the foundation designs	Adverse change in design
	RS1.35	Communication and coordination with all the suppliers were difficult	Adverse change in communication with parties
V3	V3.1	There were more than a hundred towers which require different treatment	Project size
	V3.3	It was a lump-sum contract	Project payment type
RE	RE.8	We couldn't get payments on planned times	Delay in progress payments
	RE.3	There were variations in quality	Decrease in quality
	RE.2	Instead of the Partner, we performed the construction. Additional tests were conducted and foundations were strengthened	Increase in quantity of work
	RE.7	Material supply took much time	Delay in logistics
RC	RC.1	Project was completed with a less profit than expected	Impact on cost
	RC.2	Project was completed with a delay of two months	Impact on duration

4.2.2.2. Project B: Over Head Transmission Line Project in North Iraq

The project was performed by the same company, performing Project A. Same company and similar characteristics makes it easy to observe the impact of contract, project parties and country conditions.

All the concepts mentioned by the interviewee are presented in Figure 4.3. Table 4.3 illustrates the notations used in the map with their meanings. As can be understood from the map, Project B is a less problematic project when compared to Project A, although it has very similar technical characteristics with Project A.

This time, the Company was responsible for design, manufacturing and construction. The Company did not have any partner. The Company had previously completed several projects for the same client and agreed with subcontractors and suppliers that they worked together before. Therefore, material supply (V1.15) and subcontractor availability (V1.18) were less significant issues in this project. The project manager, who was an expert in this type of projects, controlled the project at site, which eliminate the communication problems with parties and accelerate the approval process. The project was performed in the North side of the same country, where there was more stability in social life. The company performed several projects in this region and was familiar with ground conditions so did not face with any severe unexpected geotechnical conditions (V1.11). There were only some additional works (RE.2) due to the strengthening of some foundations (RS1.14). The managerial complexity of the project was lower when compared with Project A. Team turnover rate in the project was very low. The most critical issue was the consulting company who assigned only one engineer to the project. The engineer did not have enough technical and managerial capacity (V1.60, V1.61); therefore, he couldn't fulfill his requirements on time and slowed down the process (RS1.28). In spite of some variations, the project was delivered with a little cost and duration increase which is considered as negligible by the company.

It is clear that although the company is the same, different strategies were utilized in the projects. Different parties involved in the projects and contract clauses significantly affected the level of vulnerability.

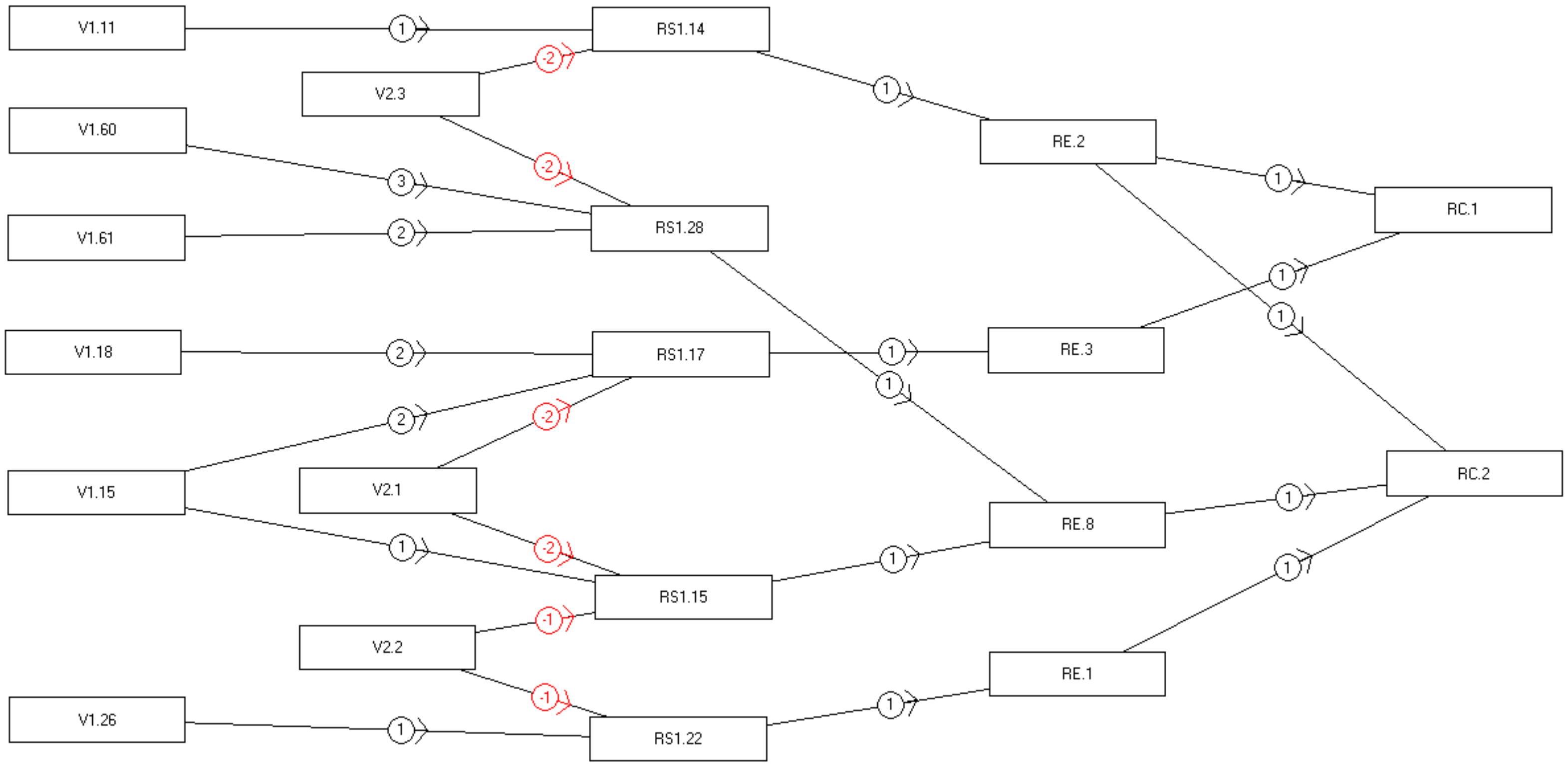

Figure 4.3: Cognitive map of Project B

Table 4.3: Concepts and notations used in the cognitive map of Project B

Category	Notation	Expression used by the interviewee	Corresponding factor in the framework
V1	V1.11	The soil survey couldn't be completed before tendering	Inadequate geotechnical investigation
	V1.60	Consultant didn't have necessarily experience	Technical incompetence of consultant
	V1.61	Consultant could not obey the approval schedule	Managerial incompetence of
	V1.18	There were very few subcontractors to be employed in country	Unavailability of subcontractor
	V1.15	It was difficult to find material	Unavailability of
	V1.26	The war at country influences social life but the North side was more stable	Instability of social conditions
V2	V2.3	Company performed several projects at North side	Sufficient company experience
	V2.1	The communication, coordination and control mechanism were well established	Sufficient company managerial capability
	V2.2	The project and site team well capable enough	Sufficient company resources
RS1	RS1.14	Some foundation designs were revised	Adverse change in design
	RS1.28	Consultant slowed down the progress	Adverse change in performance of
	RS1.17	Some foundations were not safe enough	Adverse change in work quality/rework
	RS1.15	Construction had started a bit later than expected	Adverse change in original schedule
	RS1.22	We had re-arranged site team at once	Adverse change in site organization
RE	RE.2	Previous foundations were got strengthen according to revised design	Increase in quantity of work
	RE.3	There were some variations in quality, but precautions were taken on time	Decrease in quality
	RE.8	Consultant approvals affect the payment schedule	Delay in progress payments
	RE.1	Team motivation decreased	Decrease in productivity
RC	RC.1	Project is completed approximately within estimated budget	Impact on cost
	RC.2	There was not a significant delay	Impact on duration

4.2.2.3 Project C: Housing project in the United Arab Emirates

Project C is a villa type residential construction project performed in Dubai. The villas mainly had four different types and planned to be completed in 580 days with more than 3500 staff. There were three main parties: owner, contractor and consultant. The design process was under the responsibility of Consultant and the construction was performed by a Turkish Contractor.

The interview was made with the engineer working in Turkish company as project scheduler. Risk-related information of the project is summarized in Figure 4.4 by cognitive map technique. All the concepts mentioned by the interviewee are presented in Table 4.4 with the notations used in the map.

The project necessitated a well-established and properly-followed project schedule because of the fact that tower cranes were utilized for the construction of buildings and the movement of cranes cause idle time (V1.4). In case of any change in the original schedule, the cranes had to be moved from one place to another which causes delays as well as additional expenditure. The work sequence was clearly stated in contract however, as a result of the managerial insufficiency (V1.53), Partner (designer/consultant) couldn't submit designs on time in the planned order (RS1.23) and cause changes in original schedule (RS1.15). Since the contractor couldn't complete the villas on planned days (RS1.18), payments could not be taken (RE.8). One other issue is the unavailability of material (V1.15) due to high level of construction projects in the country. However, the company has a well established procurement management system, so that they purchased material from 5 different suppliers which decreased delays in logistics (V2.1).

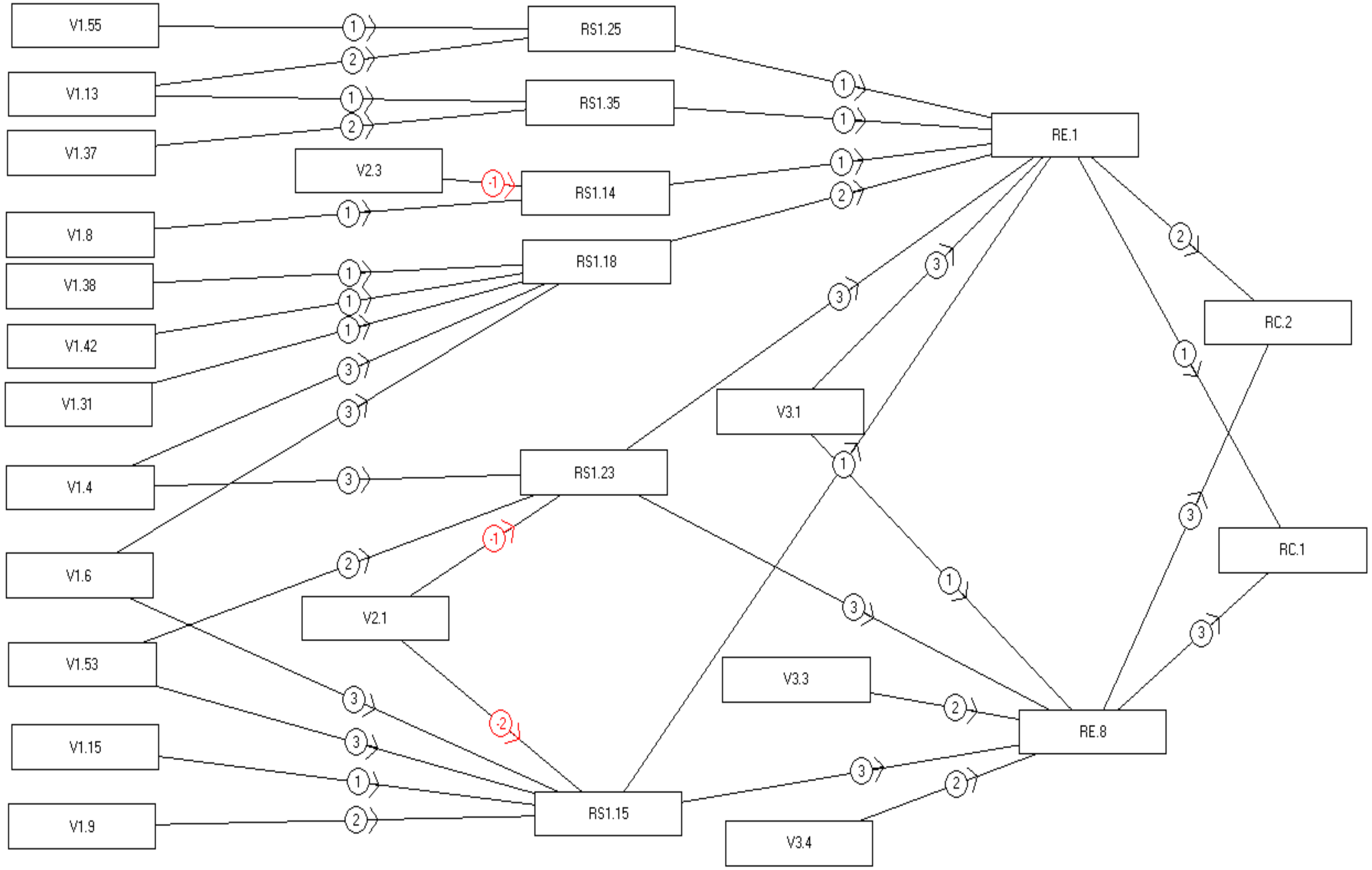

Figure 4.4: Cognitive Map of Project C

Table 4.4 : Concepts and notations used in the cognitive map of Project C

Category	Notation	Expression used by the interviewee	Corresponding factor in the framework
V1	V1.55	The business style of Partner was different than Contractor	Cultural differences between partner and
	V1.13	The responsibilities were not clear enough	Vagueness of contract clauses
	V1.37	The meetings with Partner were not frequent enough	Lack of communication management
	V1.8	The water depot was designed improperly	Design errors
	V1.38	Contingency was underestimated	Lack of project risk management
	V1.42	Designed was not usually performed by Consultant	Lack of experience in PDS
	V1.31	There were not much staff familiar with FIDIC requirements	Lack of staff
	V1.6	Design was not completed in the expected order	Incomplete design
	V1.4	A detailed schedule should be developed and updated properly	Strict project management requirements
	V1.53	Partner didn't obey the schedule	Managerial incompetence of Partner
	V1.15	The workload of local suppliers were very high	Unavailability of material
	V1.9	The construction requires frequent movement of cranes	Complexity of construction method
V2	V2.3	Company performed several similar projects	Sufficient company experience
	V2.1	Company has a well established control and coordination mechanism	Sufficient company managerial capability
RS1	RS1.25	The relations with partner got worse	Adverse change in relations with partner
	RS1.35	Regular meetings were not enough to discuss the issues	Adverse change in communication with parties
	RS1.14	The location of water depot was changed	Adverse change in design
	RS1.18	Contractor couldn't perform construction in expected rapidity.	Adverse change in performance of contractor
	RS1.23	Partner did not submit design in proper schedule	Adverse change in performance of partner
	RS1.15	Delay in design submission cause changes in construction schedule	Adverse change in original schedule

Table 4.4 : Concepts and notations used in the cognitive map of Project C (continued)

Category	Notation	Expression used by the interviewee	Corresponding factor in the framework
RE	RE.1	Motivation of the site team got worse	Decrease in productivity
	RE.8	Payments were taken later than planned dates	Delay in progress payments
V3	V3.1	Crane movements took much time due to high number of villas	Project size
	V3.3	It was a lump-sum contract	Project payment type
	V3.4	Construction will not start before design is completed	Project delivery system
RC	RC.1	Cost overrun	Impact on cost
	RC.2	Delay	Impact on duration

4.2.2.4 Project D: Building project in Afghanistan

Project D was a building construction project performed by an experienced Turkish Contractor in the consultant of an American firm in Afghanistan. The client was a governmental entity. Although the project was very simple, the company could not complete it and the project was terminated.

The main problem was the country conditions, such that because of the ongoing war there were not any established government (V1.21) and legal system (V1.27). In addition to security problems (V1.26), adverse weather conditions (V1.12) made the accessibility of site impossible for the Company (RS1.31). The Company faced difficulties in customs procedures (V1.23) and company's inability in the procurement management (V1.39) cause unavailability of material at site (RS1.7) which lead unavoidable delays in logistics (RE.7). The financial situation of the company was not good (V1.29) and improper estimation of bidding price (V1.34) influence changes in performance of contractor (RS1.18). All other problematic issues are presented in Figure 4.5 with the causal relation between factors. Table 4.4 presents the definition of each notation used in the cognitive map.

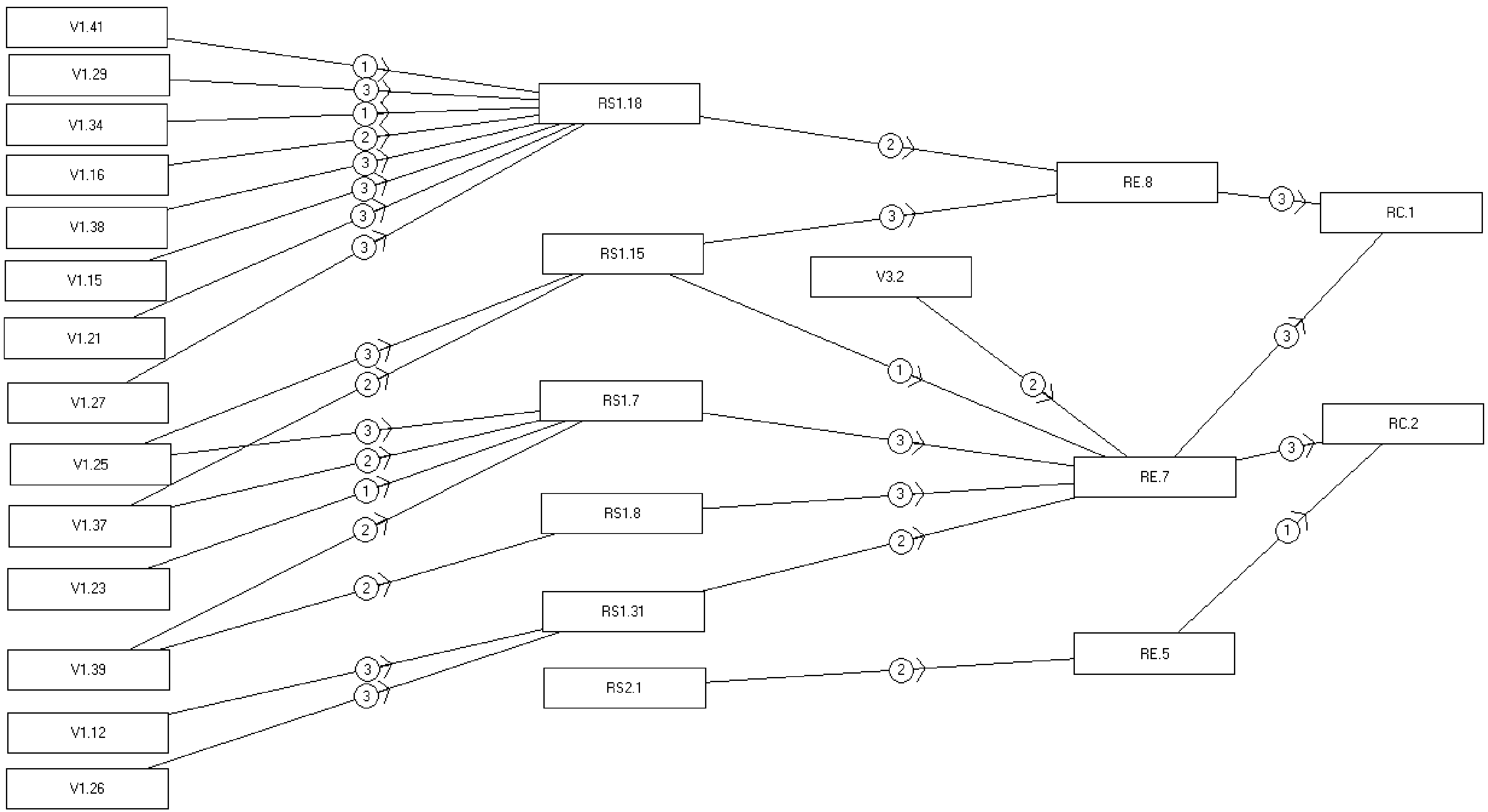

Figure 4.5: Cognitive Map of Project D

Table 4.5 : Concepts and notations used in the cognitive map of Project D

Category	Notation	Expression used by the interviewee	Corresponding factor in the framework
V1	V1.41	It was the first project performed in Afghanistan	Lack of experience in country
	V1.29	The financial situation of the company was bad	Lack of company financial resources
	V1.34	The bidding was given with a very low contingency to get the job	Lack of project cost management
	V1.16	There were not enough equipment at the country	Unavailability of equipment
	V1.38	Necessary insurances were not made	Lack of project risk management
	V1.15	The suppliers were not sufficient	Unavailability of material
	V1.21	There was not any stable government	Instability of government
	V1.27	The regulations and laws were not definite	Immaturity of legal system
	V1.25	Mafia was very powerful	Level of mafia power
	V1.37	Coordination within company was not proper	Lack of project communication
	V1.23	Custom procedures	Level of bureaucracy
	V1.39	Coordination in logistics couldn't be maintained.	Lack of project procurement management
	V1.12	Weather conditions were bad, especially in winter	Inadequate climate conditions
	V1.26	There were security problems	Instability of social conditions
RS1	RS1.18	Company couldn't execute the project as planned	Adverse change in company performance
	RS1.15	Delays occurred in activities	Adverse change in original schedule
	RS1.7	Material couldn't be obtained	Adverse change in availability of material
	RS1.8	Necessary machines were stuck in roads due to weather conditions	Adverse change in availability of equipment
	RS1.31	Sometimes site accessibility becomes impossible	Adverse change in site conditions
RS2	RS2.1	There was an ongoing war	War/hostilities
V3	V3.2	Strict project duration	Project duration
RE	RE.8	Payments couldn't be taken on time	Delay in payments
	RE.7	Material couldn't be delivered on time	Delay in logistics
	RE.5	Custom clearance procedures took time	Delay in bureaucracy

Table 4.5 : Concepts and notations used in the cognitive map of Project D (continued)

Category	Notation	Expression used by the interviewee	Corresponding factor in the framework
RC	RC.1	Project couldn't be completed within budget	Impact on cost
	RC.2	Project couldn't be completed within schedule	Impact on duration

4.2.2.5 Project E: Process Plant Project in Jordan

Project B is an 80 million USD process plant project performed in Jordan by a Turkish company by establishing a joint venture with a Canadian contractor. It was an EPC (Engineering, procurement, construction) contract which was awarded on a lump-sum turnkey basis. Design of the project was performed by the Canadian partner and procurement and construction stages were under the responsibility of the Turkish contractor. Although both of the companies had enough experience in design and construction, the project could not be completed on time and within budget. After an approximately one year of delay, the contract was terminated by the Client and the project was given to a new contractor.

A civil engineer that took part in the management team of the Turkish company was interviewed for 1-1.5 hours. The interviewee worked in the company starting from the initial stages of the project until the termination; therefore he was assumed to have enough knowledge about the project.

As can be revealed from the map, the most significant factors regarding the case study project are unfamiliarity of the parties to EPC projects (V1.42), high managerial requirements of EPC projects (V1.4), improper schedule development (V1.33), the complexity (V1.9) and the vagueness of design at tendering stage (V1.6), and the payment mechanism of project (V3.3), as they are highly connected to other factors with a relationship strength of "3". Since the party responsible from the design of the structure was unfamiliar with EPC projects, he did not realize the importance of a properly developed schedule at the initial stages, and improperly developed schedule (V1.53) influenced the performance of the contractor (RS1.18) and consequently caused adverse changes in the attitude of the client (RS1.12). In addition, the incomplete design drawings at the preliminary stages led to several variations in the expected conditions such as changes in design (RS1.14) and changes in work sequence (RS1.15) which further resulted in delay. To cope with the delay, the company decided to accelerate the project and assigned additional staff to the project (V2.2), but it was not sufficient enough to prevent delays in logistics (RE.7) and delay on the cash flow (RE.8). Risk events resulted in cost overrun (RC.2) and delay in project completion date (RC.1).

Other issues with their influence strengths can be observed from the causal map (Figure 4.6) and the explanation of notations used in map can be obtained from Table 4.6.

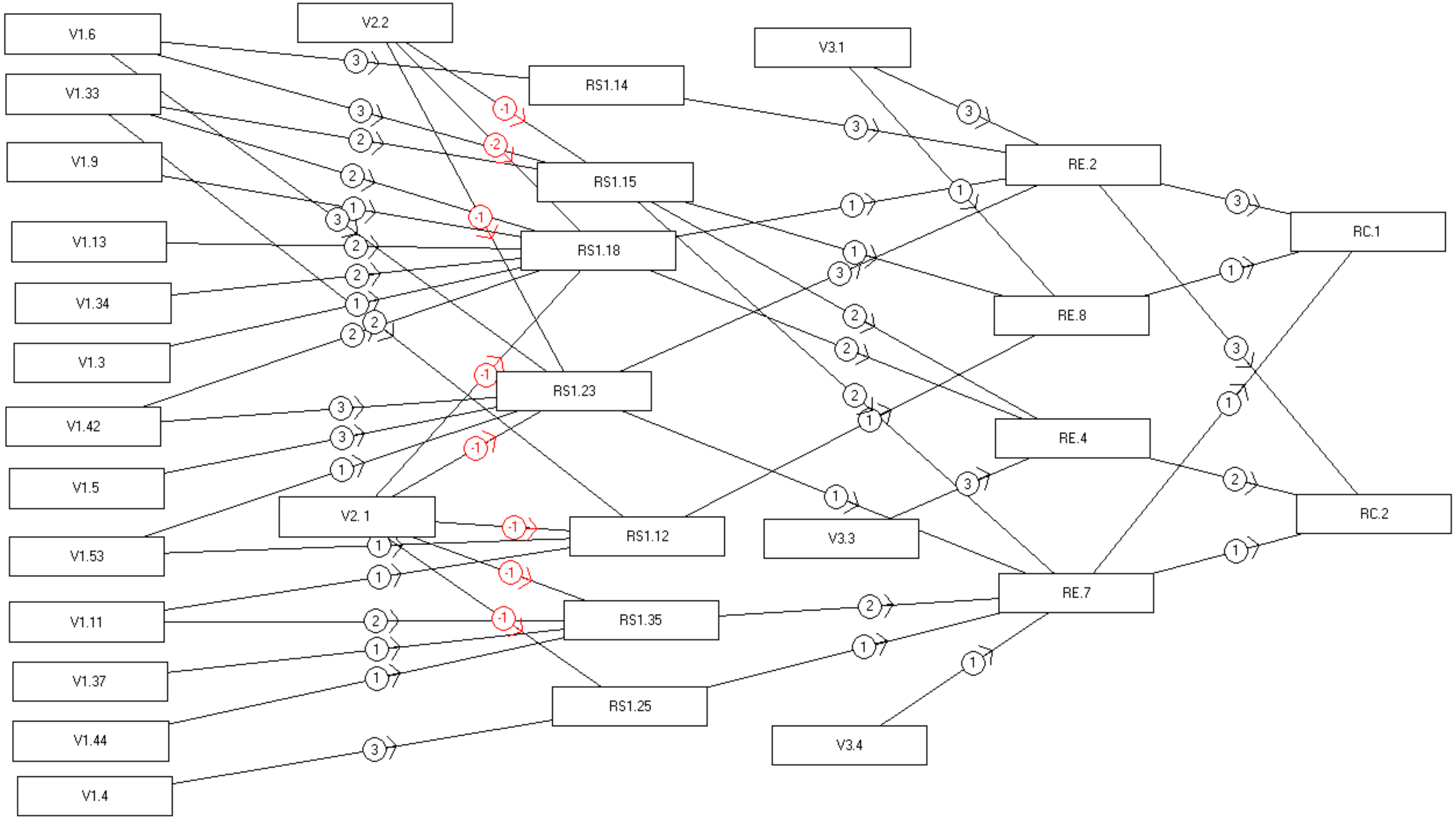

Figure 4.6: Cognitive Map of Project E

Table 4.6: Concepts and notations used in the cognitive map of Project E

Category	Notation	Expression used by the interviewee	Corresponding factor in the framework
V1	V1.6	Vagueness in design	Incomplete design
	V1.33	Improper schedule	Lack of time management capability
	V1.9	Complexity of construction	Complexity of construction method
	V1.13	Vagueness in responsibilities	Vagueness of contract clauses
	V1.34	Improper cost estimation	Lack of cost management capability
	V1.3	Enviromental issues	Strict environmental management requirements
	V1.42	Unfamilarity to EPC structure	Lack of experience in PDS
	V1.5	High design requirements	Complexity of design
	V1.53	Improper control of partner	Managerial incompetence of partner
	V1.11	Insufficient communication	Lack of communication management capability
	V1.37	Cultural issues	Cultural differences with partner
	V1.44	First project with partner	Lack of experience with partner
	V1.4	High managerial requirement	Strict project management requirements
V2	V2.2	Assign more staff	Company resources
	V2.1	Improve control and additional meeting	Company management capability
RS1	RS1.14	Design changes	Adverse change in design
	RS1.15	Change in work sequence	Adverse change in original schedule/sequence
	RS1.18	Performance get worse	Adverse change in performance of contractor
	RS1.23	Partner incompetence	Adverse change in performance of the partner
	RS1.12	Negative client attitude	Adverse change in attitude of the client
	RS1.35	Communication problems	Adverse change in communication between the parties
	RS1.25	Relations get worse	Adverse change in relations with the partner

Table 4.6: Concepts and notations used in the cognitive map of Project E (continued)

Category	Notation	Expression used by the interviewee	Corresponding factor in the framework
V3	V3.1	Huge project scale	Project size
	V3.3	Lump-sum contract	Payment type
	V3.4	EPC requirements	Project delivery system
RE	RE.2	Additional work	Increase in work quantity
	RE.8	Late payments	Delay in progress payments
	RE.4	Increase in unit costs	Increase in unit cost of
	RE.7	Delay in material supply	Delay in logistics
RC	RC.1	Delay in project completion date	Impact on duration
	RC.2	Cost overrun	Impact on cost

4.2.2.6 Project F: Hydropower Plant Project in Turkey

The project was performed by a consortium established by six companies. The design and construction phases were under the responsibility of a Turkish Contactor and an Austrian Firm. The owner was a governmental entity. The project type is lump sum but in case there are extra works, the cost compensation is guaranteed.

The most significant issue was the unfamilarity of Partner to country conditions and lack of experience wih Client (V1.53). In addition, the relations between Austria and Turkey were not stable (V1.22) which influence the change in relations with client (RS1.30). One other issue was the inadequate weather conditions (V1.12) which not only cause changes in site conditions (RS1.31), but also necissitate revisions in design of the structure (RS1.14). As a result, quantity of work is increased (RE.2). There were also some contract errors, such that the escalation formula was not defined clearly (V1.14) which also cause some problems between parties. The details of all issues are demostrated in Figure 4.7 and explanation of map is given in Table 4.7.

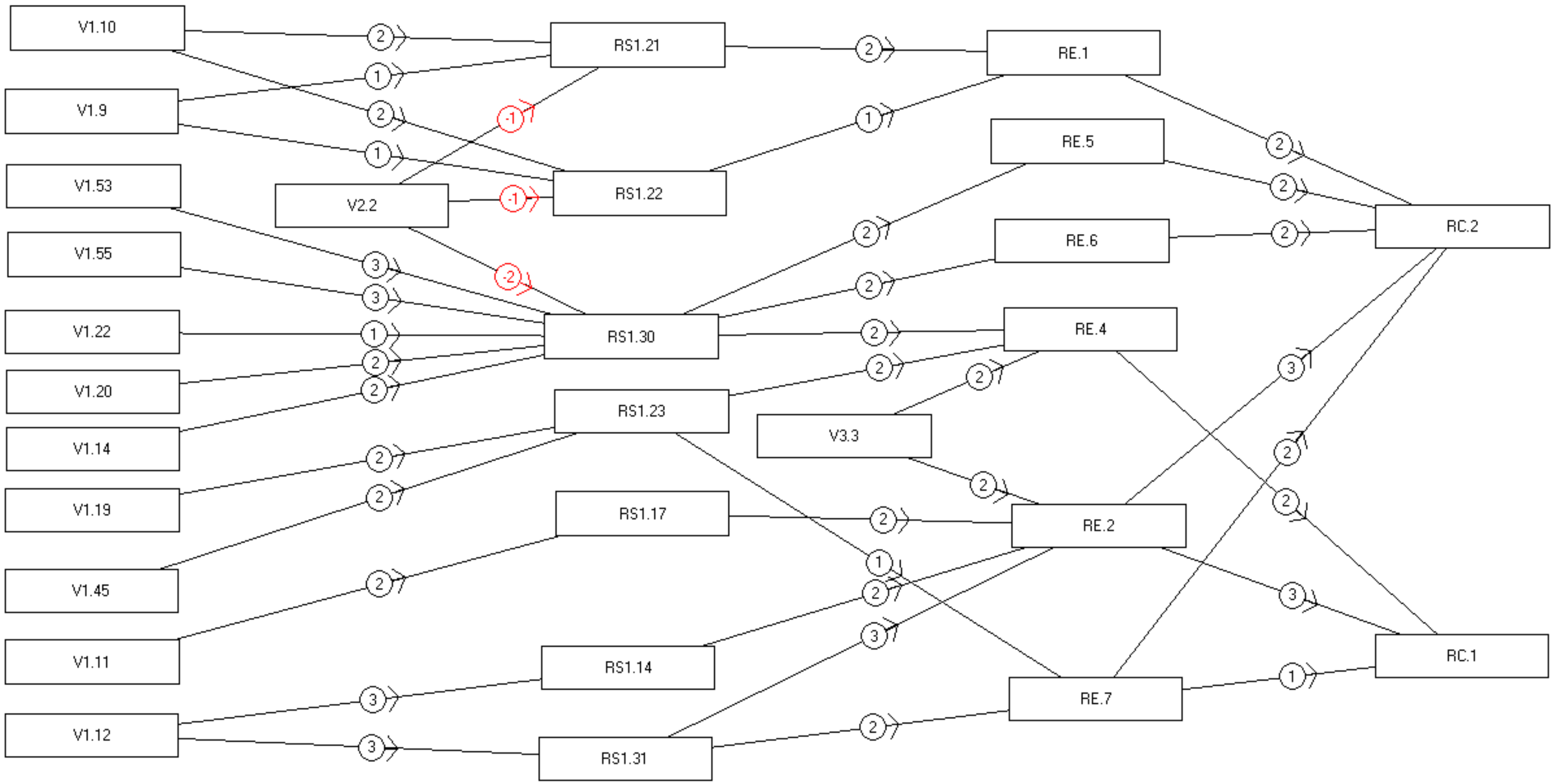

Figure 4.7: Cognitive Map of Project F

Table 4.7: Concepts and notations used in the cognitive map of Project F

Category	Notation	Expression used by the interviewee	Corresponding factor in the framework
V1	V1.10	Project was at the North side of Turkey, frontier to Georgia, where transportation was difficult	Poor accessibility of site
	V1.9	Project was complicated	Complexity of construction method
	V1.53	Partner was unfamiliar to the Turkish regulations	Managerial incompetence of partner
	V1.55	Several terms used in contract were different than their usage in Austria	Cultural differences
	V1.22	Relations between Austria and Turkey were not stable	Instability of international relations
	V1.20	Austrian currency rate experienced negative variation	Instability of economic conditions
	V1.14	Escalation clause was not well defined	Contract errors
	V1.19	Electricity was not provided by the government as planned	Unavailability of infrastructure
	V1.45	Client changed pre-determined suppliers	Unclear objectives of Client
	V1.11	Soil investigation was not done up to the required depth	Inadequate geotechnical investigation
	V1.12	Heavy rains affected the project execution	Adverse weather conditions
V2	V2.2	Partner provided necessary financial resources	Sufficient Company resources
RS1	RS1.21	Project team changed frequently	Adverse change in project team
	RS1.22	Austrian partner changed several staff	Adverse change in site organization
	RS1.30	Relations with client had gone bad	Adverse change in relations with Client
	RS1.23	Partner couldn't perform the job as planned	Adverse change in performance of Partner
	RS1.17	Inadequate soil investigation result in unsafe foundations	Adverse change in work quality
	RS1.14	Weather conditions required revisions in the height of the structure.	Adverse change in design
	RS1.31	Site accessibility was changed.	Adverse change in site conditions
V3	V3.3	Payment type was not certain	Payment type

Table 4.7: Concepts and notations used in the cognitive map of Project F (continued)

Category	Notation	Expression used by the interviewee	Corresponding factor in the framework
RE	RE.1	Motivation of workers decreased	Decrease in productivity
	RE.5	Governmental paperwork took time	Delay in bureaucracy
	RE.6	Government couldn't handover the site on time	Delay in site handover
	RE.4	It cost much than estimated unit prices	Increase in unit cost of resources
	RE.2	Foundations required rework	Increase in work quantity
	RE.7	Delay in material supply	Delay in logistics
RC	RC.1	Project did not completed on time	Impact on duration
	RC.2	Cost increases were claimed	Impact on cost

4.2.2.7 Project G: Infrastructure Project in the United Arab Emirates

The project was performed by a Turkish contractor and an Arabian company for a governmental entity in Dubai. Arabian company was the leader of the joint venture, and he was responsible from the communication with Client. The project could be completed with 4 months delay and cost overrun. The reasons of these variations are as follows:

The most significant issue was that linguistic differences between the contractor and other parties (V1.55) which lead communication problems with client. Moreover, the contractor did not have translator (V1.13) which result in several misunderstandings and affect the contractor's performance adversely (RS1.18). The other significant issues were mainly related with the partner, such that partner's lack of experience (V1.52) and lack of financial resources (V1.54) influence the occurrence of changes in partner's performance (RS1.23). As a result, partner didn't make the payments to the company on planned days (RE.8, although he took money from Client. Other discussed issues can be observed from Figure 4.8 and Table 4.8.

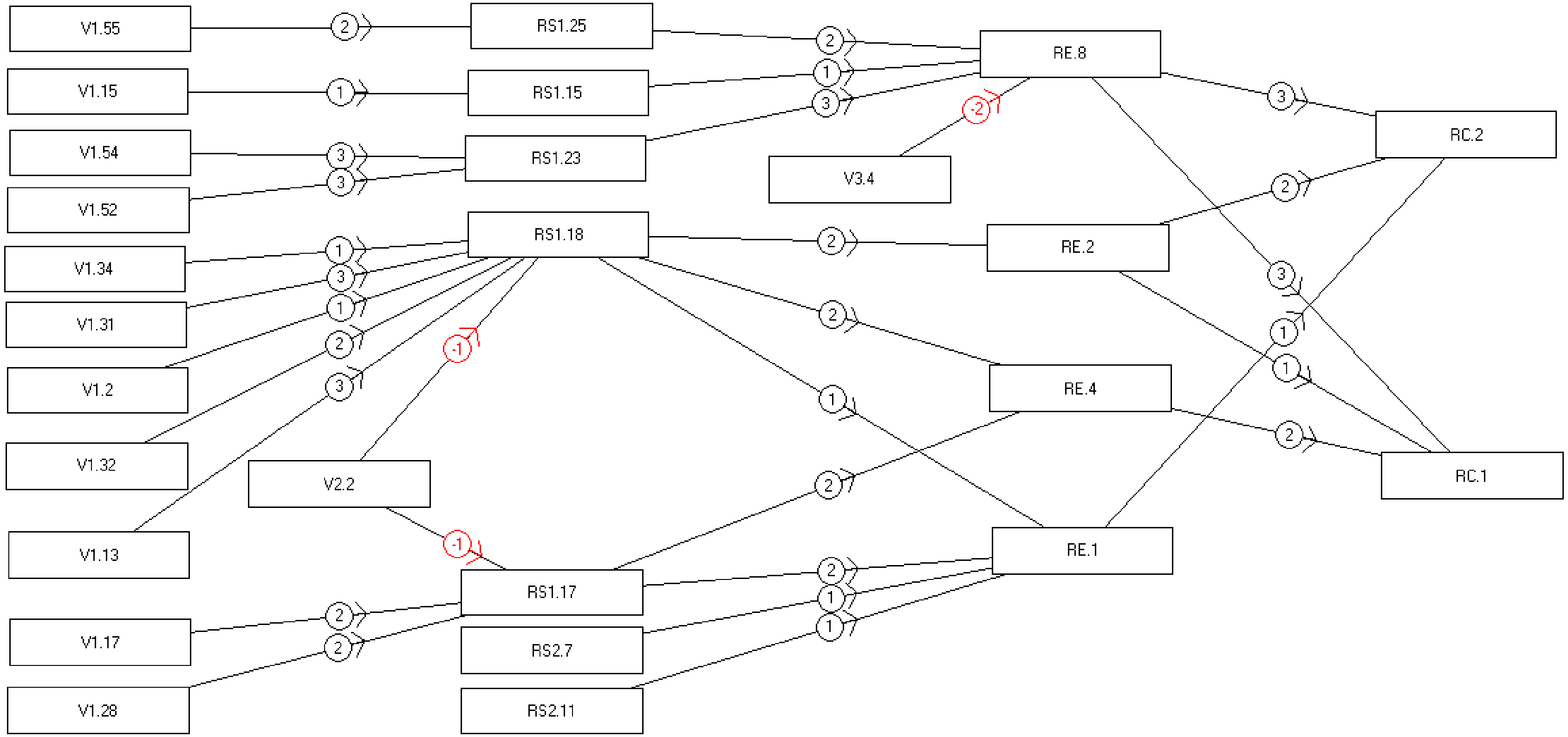

Figure 4.8: Cognitive Map of Project G

Table 4.8: Concepts and notations used in the cognitive map of Project G

Category	Notation	Expression used by the interviewee	Corresponding factor in the framework
V1	V1.55	Lack of communication	Cultural differences
	V1.15	There were several ongoing construction projects in country, finding supplier was problematic	Unavailability of material
	V1.54	Partner couldn't get his payments from his other projects, so has some financial problems	Lack of financial resources of Partner
	V1.52	Partner did not have sufficient experience	Technical incompetence of Partner
	V1.34	Cost flow couldn't be maintained	Lack of cost management
	V1.31	Company did not have any translator	Lack of staff
	V1.2	Project requires to take several safety precautions	Strict health and safety requirements
	V1.32	Company did not read the contract in detail, so did not know his responsibilities	Lack of scope management
	V1.13	Turkish and English versions of the contract were not compatible to each other	Vagueness of contract clauses
	V1.17	Finding high qualified staff was not possible	Lack of labor
	V1.28	Foreign companies had to employ local staff	Country restrictions for foreign companies
V2	V2.2	We have experienced engineers in infrastructure projects	Sufficient company resources
RS1	RS1.25	Relations with partner got worse	Adverse change in relations with Partner
	RS1.15	Late delivery of material caused delays in construction phase	Adverse change in original schedule
	RS1.23	Partner couldn't maintained the coordination between client and company	Adverse change in performance of the Partner
	RS1.18	Project couldn't be executed as planned	Adverse change in performance of the company
	RS1.17	Required work quality couldn't be maintained	Adverse change in work quality
RS2	RS2.7	An accident happened and a worker died	Accidents
	RS2.11	Workers stopped working for a week	Strikes/labor problems

Table 4.8: Concepts and notations used in the cognitive map of Project G (continued)

Concept	Notation	Expression used by the interviewee	Corresponding factor in the framework
V3	V3.4	Client made the payments to Partner who is the leader of the partnership	Partnership type
RE	RE.8	Payments couldn't be received on time	Delay in progress payments
	RE.2	There were several rework	Increase in quantity of work
	RE.4	Revisions increased the unit prices of activities	Increase in unit cost of resources
	RE.1	Productivity got worse	Decrease in productivity
RC	RC.1	Project couldn't be completed on time	Impact on duration
	RC.2	Cost was higher than expected	Impact on cost

4.2.3. Brief Summary and Discussion of Case Studies

It is clear from the case studies that there is a causal relationship between the risk sources, events, their consequences and vulnerability factors. Some vulnerability parameters affect the probability of risk occurrence. For example, high design requirements of the project (complexity of design) strongly increased the probability of change in partner's (design company) performance. Some vulnerability factors affect manageability of risk. For instance, the control mechanism, in other words the managerial capability of the company, made the partner to realize the problematic issues and accelerate the design which reduced delay risk for the company. Vulnerabilities may also influence the impact of risk events on project success. In other words, those are the factors, which affect the magnitude of risk consequences. For instance, vast quantity variations due to changes in design caused severe financial losses since the payment type was lump sum.

4.3. Reformulation of the Framework through Case Studies

The outcome of the interviews revealed that some re-arrangements should be made in the basic structure by considering the requirements of ontology. The main revisions made are as follows:

1) New categories are created and groups are revised. For instance, some groups under V1 are divided into subcategories like country conditions. Moreover, during the interviews, it is recognized that investigating "country conditions" under one concept may lead misleading results in the database development stage. Therefore, country conditions are divided into several categories including market conditions, legal condition, social conditions, economic conditions, etc. Similarly, "project conditions" concept is divided into sub categories, including design, management, construction and contract conditions.

2) Some subclasses are removed. By considering the aim of the developed framework and future studies, some factors are eliminated from the framework, such as contract clauses. It is believed contract clauses will be added to the system in the "negotiation process".

3) Some factors that are pointing out a single concept are merged. Interviews reveal that examining some concepts with several sub-categories is unnecessary since all of them have similar characteristics and grouping them will not provide any additional benefit in the framework. For example, dividing "risk source" into several sub categories is not necessary. Instead this concept will be examined under two headings: adverse change and unexpected event.

4) Some factors are renamed. In the developed structure, the concepts were named with some numbers such as V1, V2, and V3. However, it is

realized that naming the concepts with this notations will make it difficult to understand for users. Therefore, instead of V1, V2 and V3 notations robustness, resilience and sensitivity terms are decided to be used respectively in the developed system.

5) It is decided that some “values” should be attached to different factors appearing in . During the interviews, it is recognized that the strength of the causal relationship between concepts will be different from project to project. Therefore, it will be useful to determine a value partition for all concepts to better understand the relationship. A similar system is used in cognitive maps (range from -3 to 3), but this division is decided to be revised for ontology by considering future study requirements. All of the concepts, except risk consequence, will be rated in a scale having range from 1 to 5 indicating very low, low, medium, high and very high rates respectively. Risk consequence will be given in percentage. In addition, it is realized that some cases are not following the presented sequence. This is due to the fact that, the influence of the factor at that stage is almost negligible. Therefore, to cover these issues, an extra section about “value” should be added (such as zero or one) to define negligible or not existing influence.

Since there is no change in the established relations and the sequence of the concepts, the structure is not presented again. The revised categorization will be represented in a more structured manner in the next chapter.

CHAPTER 5

RESEARCH METHODOLOGY FOR THE DEVELOPMENT OF ONTOLOGY

As discussed in literature review related with ontology, one of the main challenges in the ontology development is that there is no ISO standard for ontology development yet (Ceusters et al., 2005). There are several methodologies discussed by researches however, there is no best methodology, because there is no “correct” way to model a domain (Gašević et al., 2004).

In this study, one of the most comprehensive and well-established ontology construction frameworks, which is known as “methontology” was applied. Methontology provides a complete process with a series of activities, including specification, knowledge acquisition, conceptualization, formalization, integration, implementation, evaluation, documentation, and maintenance, all of which cover the entire lifecycle of the ontology.

The visual description of the methontology method adapted from Goméz-Pérez et al. (2004) by Breitman et al. (2007) is presented in Figure 5.1.

This study includes the stages of specification, conceptualization, formalization and implementation of the ontology development process. Within this process, framework given in the previous chapter will be analyzed again in terms of “ontology” concept by referring literature review and case studies.

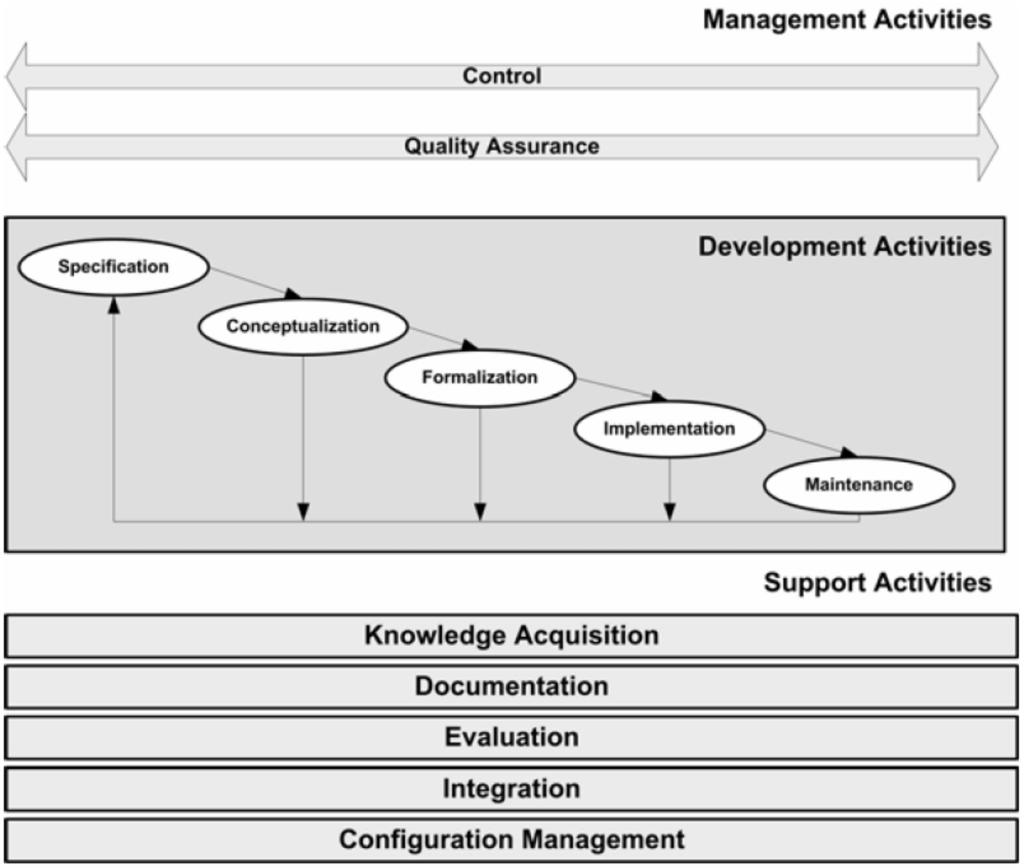

Figure 5.1: Ontology Development Procedure (Breitman et al., 2007)

5.1. Specification

According to Breitman et al. (2007), specification includes the determination of scope and goals of the ontology, which can be maintained by addressing following questions "why is this ontology being built?"

In literature, although the researches often share the same objective such as developing a system that considers influence of system on risk, they do not necessarily use the same terminology to communicate in the risk management process. This makes information sharing and re-using difficult. Development of ontology will be a practical solution for this problem. Ontology is the demonstration of organized knowledge that gives well-defined and precise semantics which can be computationally processed for more sophisticated knowledge management applications.

The main reason of ontology development in this study is to build up a knowledge based system for problem-solving and decision-making in construction management sector. In further stages of this research, a multi-agent system will be developed for risk management of construction projects. The final impact of risks on each party will be quantified through the negotiation processes between the project participants on a multi-agent platform. Designed ontology will serve for development of a knowledge base system (database) which provides the information for problem-solving and decision-making to intelligent agents. Therefore, developed ontology will be used to share the common structure and to form a database for risk and vulnerability management.

5.2. Conceptualization

Conceptualization includes the collection and organization of the relevant domain concepts to be included in the ontology (Breitman et al., 2007).

5.2.1. Knowledge Elicitation

The ontology is the representation of the developed framework in Chapter 4. As discussed, various dimensions of knowledge are elicited through a detailed literature review as well as undertaken interviews which also form the knowledge elicitation process of ontology.

5.2.2. Development of the Taxonomy

After acquiring the necessary data, the unstructured knowledge needs to be organized. Noy (1997) considers this stage one of the most difficult activities in ontology design because it involves not only a subjective representation of the world, but also the representation of how people see this world and how they categorize things in their minds.

To obtain a more structural representation of the collected data, concepts (classes) are organized into a superclass-subclass hierarchy, which is also known as a taxonomy. A taxonomy (or concept hierarchy) is a hierarchical categorization or classification of entities within a domain. It helps the identification of main categories and determination of level of specificity to be used in further stages of the ontology development process.

All of the collected terms are analyzed and grouped in two upper-level categories: risk and vulnerability source. The main concepts are decided considering their vital roles in the framework.. In Figure 5.2, taxonomy of the main classes is presented. Because of huge sizes of the taxonomy only a small part of the sub-concepts can be displayed in figure. However, all he concepts with their subclasses can be observed from Table 5.1.

As can be clearly observed form the taxonomy, main classes of the ontology are risk and vulnerability source. Risk is composed of three main parts: risk source, risk event and risk consequence. Risk source is divided into two main groups: adverse change and unexpected events. Vulnerability source is investigated under three main heading: robustness source, resilience source and sensitivity source. Robustness source is grouped into four: country condition, company conditions, parties' conditions and project conditions; all of which has several sub-categories (Table 4.9). Resilience source includes only company conditions which cover the experience, resources and managerial capability that the company has. Sensitivity source is characterized by project size, project delivery system, etc.

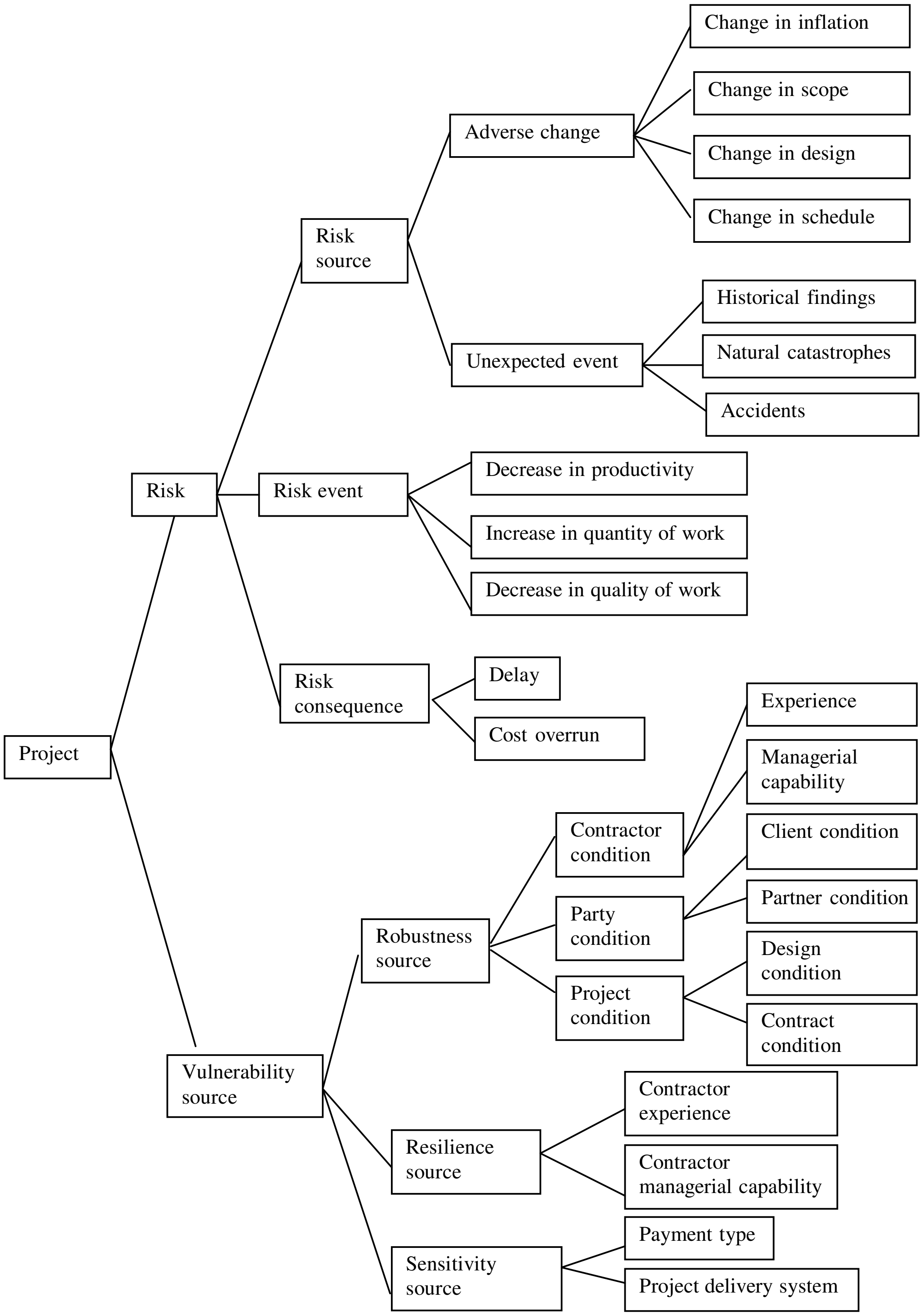

Figure 5.2: Taxonomy of Main Concepts

Table 5.1: List of the Concepts in Framework

Category	Sub-categories		
Robustness source	Country condition	Economic Condition	Instability of economic conditions
		Political Condition	Instability of government
			Instability of international relations
			Level of bureaucracy
		Social Condition	Level of bribery
			Level of mafia power
			Instability of social conditions
		Legal Condition	Immaturity of legal system
			Restrictions for foreign companies
		Market Condition	Unavailability of local material
			Unavailability of equipment
			Unavailability of labor
			Unavailability of subcontractor
			Unavailability of infrastructure
	Project condition	Design Condition	Complexity of design
			Incomplete design
			Low constructability
			Design errors
		Construction Condition	Complexity of construction method
			Poor accessibility of site
			Inadequate geotechnical investigation
			Inadequate climate conditions
		Management Condition	Strict quality management requirements
			Strict environmental management requirements
			Strict Health&Safety management requirements
			Strict Project management requirements
		Contract Condition	Vagueness of contract clauses
			Contract errors
	Company condition	Lack of experience	Lack of experience in similar projects
			Lack of experience in country
			Lack of experience in PDS
			Lack of experience with client
			Lack of experience with partner
		Lack of managerial capability	Lack of Project scope management
			Lack of Project time management
			Lack of Project cost management
			Lack of Project human resource management
			Lack of Project communications management
			Lack of Project risk management
			Lack of Project procurement management

Table 5.1: List of the Concepts in Framework (continued)

<table>
<tr><th>Category</th><th colspan="3">Sub-categories</th></tr>
<tr><td rowspan="22">Robustness source</td><td rowspan="3">Company condition</td><td rowspan="3">Lack of resources</td><td>Lack of financial resources</td></tr>
<tr><td>Lack of technical resources</td></tr>
<tr><td>Lack of staff</td></tr>
<tr><td rowspan="19">Parties condition</td><td rowspan="4">Partner Condition</td><td>Technical incompetency</td></tr>
<tr><td>Managerial incompetency</td></tr>
<tr><td>Lack of financial resources</td></tr>
<tr><td>Cultural differences with the contractor</td></tr>
<tr><td rowspan="4">Designer Condition</td><td>Technical incompetency</td></tr>
<tr><td>Managerial incompetency</td></tr>
<tr><td>Lack of financial resources</td></tr>
<tr><td>Cultural differences with the contractor</td></tr>
<tr><td rowspan="4">Consultant Condition</td><td>Technical incompetency</td></tr>
<tr><td>Managerial incompetency</td></tr>
<tr><td>Lack of financial resources</td></tr>
<tr><td>Cultural differences with the contractor</td></tr>
<tr><td rowspan="7">Client Condition</td><td>Unclarity of objectives</td></tr>
<tr><td>Level of bureaucracy</td></tr>
<tr><td>Negative attitude</td></tr>
<tr><td>Poor staff profile</td></tr>
<tr><td>Unavailability of financial resources</td></tr>
<tr><td>Technical incompetency</td></tr>
<tr><td>Poor managerial/organizational ability</td></tr>
<tr><td rowspan="15">Resilience Source</td><td rowspan="15">Company condition</td><td rowspan="5">Sufficiency of experience</td><td>Lack of experience in similar projects</td></tr>
<tr><td>Lack of experience in country</td></tr>
<tr><td>Lack of experience in PDS</td></tr>
<tr><td>Lack of experience with client</td></tr>
<tr><td>Lack of experience with partner</td></tr>
<tr><td rowspan="3">Sufficiency of resources</td><td>Lack of financial resources</td></tr>
<tr><td>Lack of technical resources</td></tr>
<tr><td>Lack of staff</td></tr>
<tr><td rowspan="7">Sufficiency of managerial capability</td><td>Lack of Project scope management</td></tr>
<tr><td>Lack of Project time management</td></tr>
<tr><td>Lack of Project cost management</td></tr>
<tr><td>Lack of Project human resource management</td></tr>
<tr><td>Lack of Project communications management</td></tr>
<tr><td>Lack of Project risk management</td></tr>
<tr><td>Lack of Project procurement management</td></tr>
<tr><td rowspan="4">Sensitivity Source</td><td colspan="3">Project size</td></tr>
<tr><td colspan="3">Project payment type</td></tr>
<tr><td colspan="3">Project deliery system</td></tr>
<tr><td colspan="3">Partnership type</td></tr>
</table>

5.1: List of the Concepts in Framework (continued)

Category	Sub-categories	
Risk Source	Adverse Change	Adverse change in currency rates
		Adverse change in inflation
		Adverse change in tax rates
		Adverse change in laws and regulations
		Adverse change in relations with the government
		Adverse change in relations with the partner
		Adverse change in relations with the engineer
		Adverse change in relations with the designer
		Adverse change in relations with the client
		Adverse change in communication between parties
		Adverse change in performance of the partner
		Adverse change in performance of the designer
		Adverse change in performance of the engineer
		Adverse change in scope
		Adverse change in design
		Adverse change in technology/method
		Adverse change in client's staff
		Adverse change in original schedule/sequence
		Adverse change in site organization
		Adverse change in project team
		Adverse change in top management
		Adverse change in availability of labor
		Adverse change in availability of material
		Adverse change in availability of equipment
		Adverse change in availability of subcontractor
		Adverse change in public reaction
		Adverse change in attitude of client
		Adverse change in weather conditions
		Adverse change in geological conditions
		Adverse change in site conditions
		Adverse change in work quality/rework
		Adverse change in financial situation of the client
		Adverse change in financial situation of contractor
		Adverse change in financial situation of the partner
		Adverse change in performance of contractor
	Unexpected Event	War/hostilities
		Rebellion/terrorism
		Natural catastrophes
		Historical findings
		Accidents
		Social unrest/disorder
		Strikes/labor problems

Table 5.1: List of the Concepts in Framework (continued)

Category	Sub-categories
Risk Events	Decrease in productivity
	Increase in quantity of work
	Decrease in quality of work
	Increase in unit cost of resources
	Delay in bureaucracy
	Delay in site hand-over
	Delay in logistics
	Delay in progress payments
Risk Consequence	Impact on cost
	Impact on duration

5.2.3 Determination of Class Attributes

In the ontology development stage, case studies are analyzed again to figure out the attributes of main concepts. Attributes provide additional information about the elements. Attributes are one of the significant elements of the ontologies since they define the characteristics of items.

To give an example for the determination of the attributes, a part of the verbal analysis of the interviews is presented below. The statements directly taken from the interviews are given in quotation mark. The key words selected from the statements are underlined and their analysis is presented in Table 5.2, Table 5.3 and Table 5.4.

Statement 1 (from Project A): "Due to the serious experience lack, partner couldn't perform the job as expected. When the partner couldn't perform the construction, client decided terminate the project because there were a delay more than two months. However, company took over the responsibilities of partner and performed the job on his own. Since they are very experienced, the company can successfully continue the job."

Table 5.2: Verbal Analysis of Statement 1

Actual Wording	**Interpretation**
"experience lack"	It is the internal characteristics of the partner; therefore it should be a vulnerability source.
"due to"	Lack of experience causes change that means there is a causal relation between vulnerability and risk source.
"couldn't perform the job as expected"	"Performance change" is defined as an adverse change.
"serious"	Vulnerability source is defined as "serious", which indicates that vulnerability should have a magnitude to better define it.
"the company can successfully continue the job."	Adverse change may lead termination of contract but this prevented by the company as they have required experience. This means that company experience is a resilience source and influences the link between source and event.
"very experienced"	Company is described as very experienced which means that experience, as a resilience source, will be characterized by a magnitude.

Statement 2 (from Project C): "The project was a villa type residence construction project which <u>necessitates a well-established project schedule</u> because of the fact that the movement of tower cranes causes idle time. The design was under the responsibility of Partner. Although the schedule is clearly stated in the contract, <u>Partner didn't develop a proper schedule</u> considering the dates given in contract. <u>As a result</u> <u>contractor couldn't perform construction in expected rapidity</u>. <u>Thus</u>, <u>the motivation of the site team got worse</u>."

Table 5.3: Verbal Analysis of Statement 2

Actual Wording	**Interpretation**
"necessitates a well-established project schedule"	It is an internal feature of the project such since scheduling is one of the essential project management activities. It indicates the high managerial requirements of the project and should be accepted as a vulnerability parameter.
"Partner didn't develop a proper schedule"	This is a characteristic of the Partner related with its managerial incapability, which is a weakness (vulnerability) of project as it causes problems.

Table 5.3: Verbal Analysis of Statement 2 (continued)

Actual Wording	Interpretation
"Contractor couldn't perform construction in expected rapidity."	There is a deviation in performance of contractor, which should be considered as an adverse change in the framework.
"as a result"	Partner's inability causes change in contractor performance that means there is a causal relation between vulnerability and adverse change.
"the motivation of the site team got worse"	Variation in motivation is a negative happening resulting from an adverse change. It should be considered as a risk event parameter in the framework.
"thus"	There is a causal relationship between parameters, such that an adverse change causes the generation of a risk event.

Statement 3 (from Project D): "The Company faced <u>difficulties in customs procedures</u> and <u>couldn't maintain the coordination with suppliers.</u> <u>Therefore</u>; <u>material couldn't be obtained</u> and <u>as a result</u> <u>couldn't be delivered to site on time</u>. Thus, the <u>project couldn't be completed within pre-defined schedule</u>."

Table 5.4: Verbal Analysis of Statement 3

Actual Wording	Interpretation
"difficulties in customs procedures"	High custom procedures (high bureaucracy level) is a characteristics of the country, therefore should be considered as a vulnerability parameter.
"couldn't maintain the coordination with suppliers"	It is an inherent characteristic of the company such that it is related with procurement management capability of the company. Therefore it should be accepted as a vulnerability.
"material couldn't be obtained."	There is a variation in expected conditions; therefore it should be accepted as an adverse change.
"therefore"	Determined vulnerabilities influence the occurrence of an adverse change in material availability, there is a causal relationship between vulnerability and risk source.
"couldn't be delivered to site on time"	It indicates there is a delay in logistics, which is a negative event. Therefore, it should be considered a risk event.
"as a result"	It reveals that adverse change may cause a negative event.
"project couldn't be completed within pre-defined schedule"	It means there is a delay in project completion date. It is the result of the negative happening, therefore should be considered as a risk consequence.

All the attributes of the classes are determined with the same logic, through verbal analysis of the interviewees. To demonstrate the attribute of each class, a brief overview of the classes of the ontology will be given. Detailed information about the identification of each concept in the risk and vulnerability domain and the role of each element is given in previous chapter. Therefore, they will not be repeated in this section, instead brief descriptions (meaning of the class), attributes (characteristics of class), usages in terms of knowledge creation (importance of class) and their role in the framework will be discussed.

5.2.3.1. Project Class

The first concept of the risk and vulnerability ontology is "project", which is represented in Table 5.5. Project refers to only the construction projects. In the fields of civil engineering, construction is a process that is a multitasking process including design, procurement, construction, etc. Before performing risk and vulnerability management process, it is necessary to identify the main characteristics of the project. It presents the duration and budget which make it possible to measure risk consequences. In addition, project delivery system, payment type or location are defined which shape the project vulnerabilities. Project class also presents the objectives that are aimed to be achieved.

Table 5.5: RV Ontology Concept: Project

Notion	Project Class
Description	A project is a series of related activities with a well-defined set of desired end results, objectives.
Attributes	ID, name, description, type, duration, budget, payment type, project delivery system, partnership type, payment type, impacted from, objective, location
Knowledge creation point of view	Risk and vulnerability management is a project-based process. Existence of different characteristics and objectives makes the implementations of the risks and vulnerabilities different for each project. Therefore, required information will be collected through the investigation of various projects.
Role	Project class defines the main objectives that are tried to be achieved. Risk consequences cause deviation in objectives.

5.2.3.2. Risk Class

As the nature of the construction projects each project has several risks that affect the project outcomes. Risk is composed of three main parts: risk source, risk event and risk consequence.

5.2.3.2.1. Risk Source Class

Risk source indicates the situations that have potential to cause harm to the project. The risk sources are investigated under two groups, considering their origin. Risk source will be either an adverse change or unexpected event. Adverse change is a negative variation from the initial conditions of the project (Table 5.6). Changes occur due to the existing vulnerabilities. They have a magnitude to indicate the level of change. The strength of a causal relation between risk source and risk event depends on manageability of the occurred risk.

Table 5.6: RV Ontology Concept: Adverse Change

Notion	Adverse Change Class
Description	A negative variation from the initial conditions of the project
Attributes	ID, name, description, magnitude of change, manageability level, manageability cost, impact level, impacted from, impact on
Knowledge creation point of view	Possible risk paths will be defined by collecting information on changes that includes why the change occurs and what it causes.
Role	Changes are generated due to the high level of vagueness and/or weakness in projects (robustness source) and causes the generation of risk events.

Unexpected event is something that happens suddenly and causes problems in a project as presented in Table 5.7. Unexpected events differ from adverse changes, such that an unexpected event will either occur or not, it does not have a level of occurrence. Therefore, in the developed ontology unexpected events are characterized with their states in addition to their impact level on the generation of negative events.

Table 5.7: RV Ontology Concept: Unexpected Event

Notion	Unexpected Event Class
Description	Something that happen suddenly and will cause problems in a project
Attributes	ID, name, description, state, impact level, impact on
Knowledge creation point of view	Possible risk paths will be defined by collecting information related with unexpected events.
Role	Unexpected events occur suddenly therefore, no factor influences the occurrence of it. However, unexpected situations will influence the occurrence of a negative event (risk event).

5.2.3.2.2. Risk Event Class

The definition and attributes of the risk event class is given in Table 5.8. Risk event represents the occurrence of a negative happening. Risk event is occurred as a result of the occurrence of a risk source either an adverse or unexpected event and it will cause the generation of a risk consequence. To represent these causal relations in a more structural manner, information about the magnitude of events and their impact level on the risk consequences should be collected.

Table 5.8: RV Ontology Concept: Risk Event

Notion	Risk Event Class
Description	A negative happening
Attributes	ID, name, description, magnitude, impact level, impacted from, Impact on
Knowledge creation point of view	Most probable risk paths will be figured out by collecting information related with risk events.
Role	Risk event is in between risk source and consequence. It is generated by risk sources and lead to cost overrun or delay.

5.2.3.2.3. Risk Consequence Class

Risk consequence implies the outcome of the occurred event which causes deviation in the project objectives (Table 5.9). Risk consequence can be characterized by determining the percent change of project cost and duration. Risk consequence is generated through the occurrence of risk event and will directly influence the project objectives.

Table 5.9: RV Ontology Concept: Risk Consequence

Notion	Risk Consequence Class
Description	The outcome of the occurred event.
Attributes	ID, name, description, percentage of increase, impacted from, impact on
Knowledge creation point of view	Possible risk paths will be defined through collecting the information related with risk consequences, such that how occurred risks affect project can be described.
Role	Risk events lead to risk consequences and risk consequences cause deviation in project objectives.

5.2.3.3. Vulnerability Source Class

The term "vulnerability" is used to characterize the influence of project system in risk processes. Vulnerability factors are categorized considering their influence on risk paths into three groups: robustness, resilience and sensitivity.

5.2.3.3.1. Robustness Source Class

As soon as the project is set, the characteristics that make the system more open to the risk sources should be identified as a first stage of risk and vulnerability management process. Robustness source is the collection of country, company, project and project participants characteristics that affect the probability of occurrence of an adverse change (Table 5.10).

Investigation of robustness sources is important, since it leads the identification of vagueness and weaknesses in the project that influences the occurrence of changes. Potential robustness sources of the system can be characterized by project, contractor, involved parties and country characteristics conditions. The attributes of these subclasses will not be given separately as they have the same attributes with their parent class.

Table 5.10: RV Ontology Concept: Robustness Source

Notion	Robustness Source Class
Description	Robustness source indicates the factors that affect the probability of occurrence of adverse change.
Attributes	ID, name, description, priority, magnitude, impact on, impacted from
Knowledge creation point of view	Robustness source determines the potential weaknesses of the project by identifying priority and magnitude of each item.
Role	The robustness sources having high vulnerability influences the occurrence of adverse changes.

5.2.3.3.2. Resilience Source Class

Resilience sources refer to the factors that affect manageability of changes (Table 5.11). Resilience is mainly related with the manageability of risk, and it directly influences the manageability level of the adverse change. Similar to the robustness source, resilience source also has a magnitude but this time magnitude indicates the capacity of the company in terms of experience, resources and managerial abilities to cope with the changes.

Table 5.11: RV Ontology Concept: Resilience Source

Notion	Resilience Source Class
Description	Resilience sources are the factors that affect manageability of changes.
Attributes	ID, name, description, magnitude, impact on
Knowledge creation point of view	Resilience source determines the rules of defining the capacity of the system to cope with changes.
Role	Resilience source influences the manageability level of the adverse changes.

5.2.3.3.3. Sensitivity Source Class

Sensitivity refers to the factors that influence the impact of risk events on project success. Those are the factors which affect the magnitude of risk consequences. Similar to other vulnerability sources, it has also a magnitude showing its influence level on the impact of risk event. The brief information related with sensitivity source concept is given in Table 5.12.

Table 5.12: RV Ontology Concept: Sensitivity Source

Notion	Sensitivity Source Class
Description	Sensitivity sources are the factors that influence the impact of risk events on project success. Those are the factors which affect the magnitude of risk consequences
Attributes	ID, name, description, magnitude, impact on
Knowledge creation point of view	Sensitivity source determines the main parameters used to precisely define the impact of risk event on risk consequence.
Role	Sensitivity source influences the impact level of the risk event on the consequence.

5.3 Formalization

Formalization indicates the formal representation of the developed conceptual model (Breitman et al., 2007). Formalization is concerned with the description of concepts and their relationships in some representation form.

Ontology provides taxonomy in a machine readable form. However, an ontology is more than a taxonomy; it is a full specification of a domain. Therefore, in addition to a detailed taxonomy, relations between concepts should be determined. The ontology representation is formalized within an iterative development process in order to produce a mature ontology that is suitable for real world implementation. Skuce (1995) suggests the concepts should be represented in an intermediate format more formal than natural language, but not completely formalized. This intermediate representation is achieved through graphical notations. The common meanings of the arrows used in graphs are shown in Figure 5.3. Figure 5.4 presents a visual representation of the relationships within the concepts and Figure 5.5 shows the relationships between the concepts. Finally Figure 5.6 demonstrates the class diagram which is designed through the utilization of software Poseidon for UML. Class diagram provides a clear representation of concepts by demonstrating class attributes in addition to interrelations between concepts.

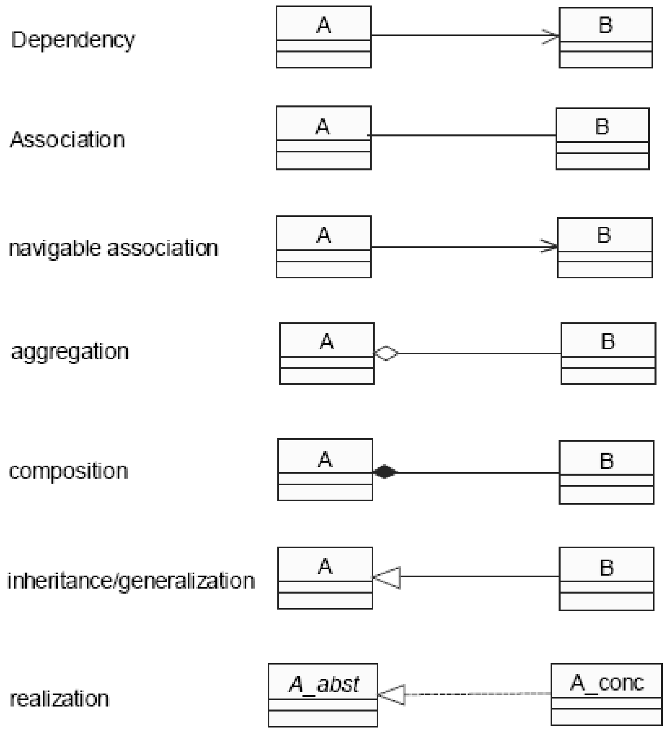

Figure 5.3: Relations Used in the Diagrams

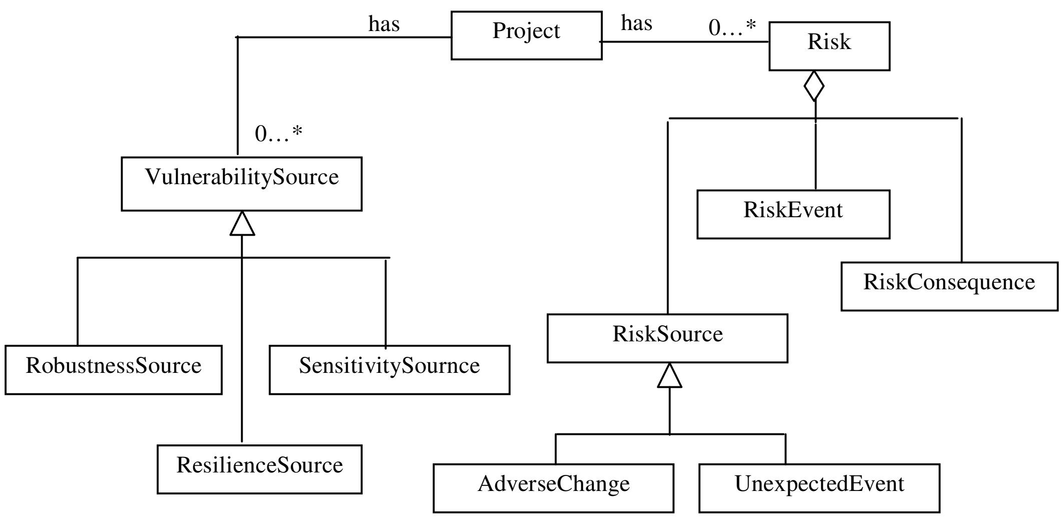

Figure 5.4: RV Ontology-Relationships within the Concepts

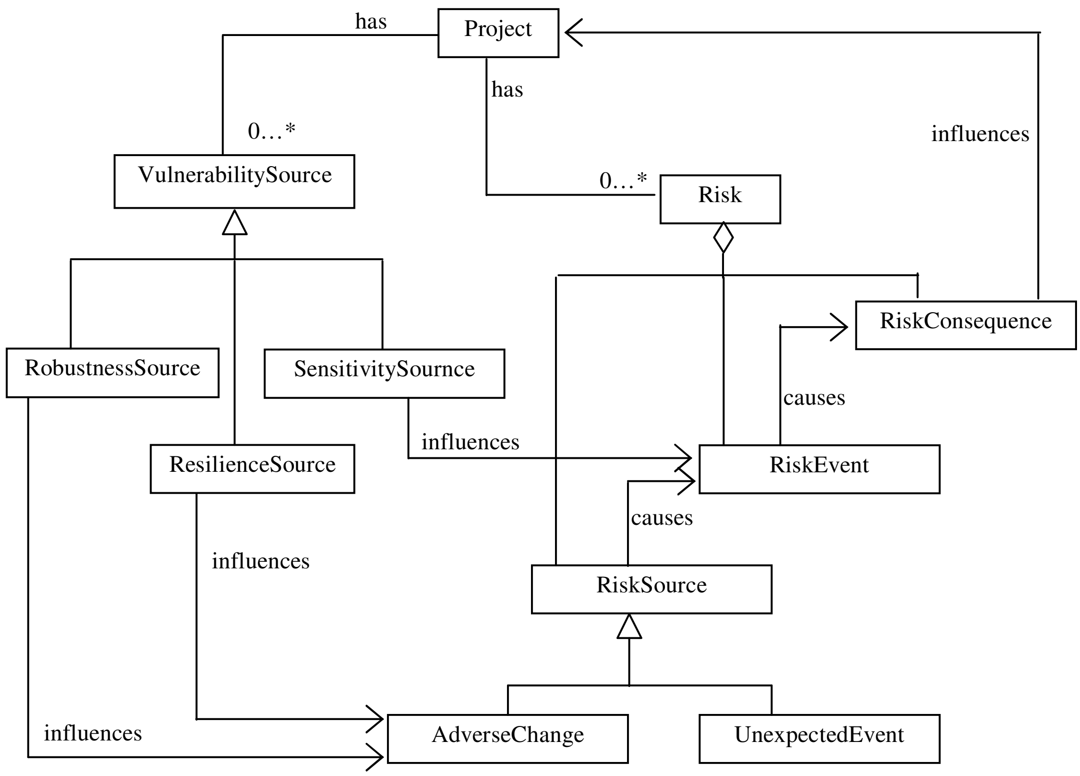

Figure 5.5: RV Ontology-Relationships between the Concepts

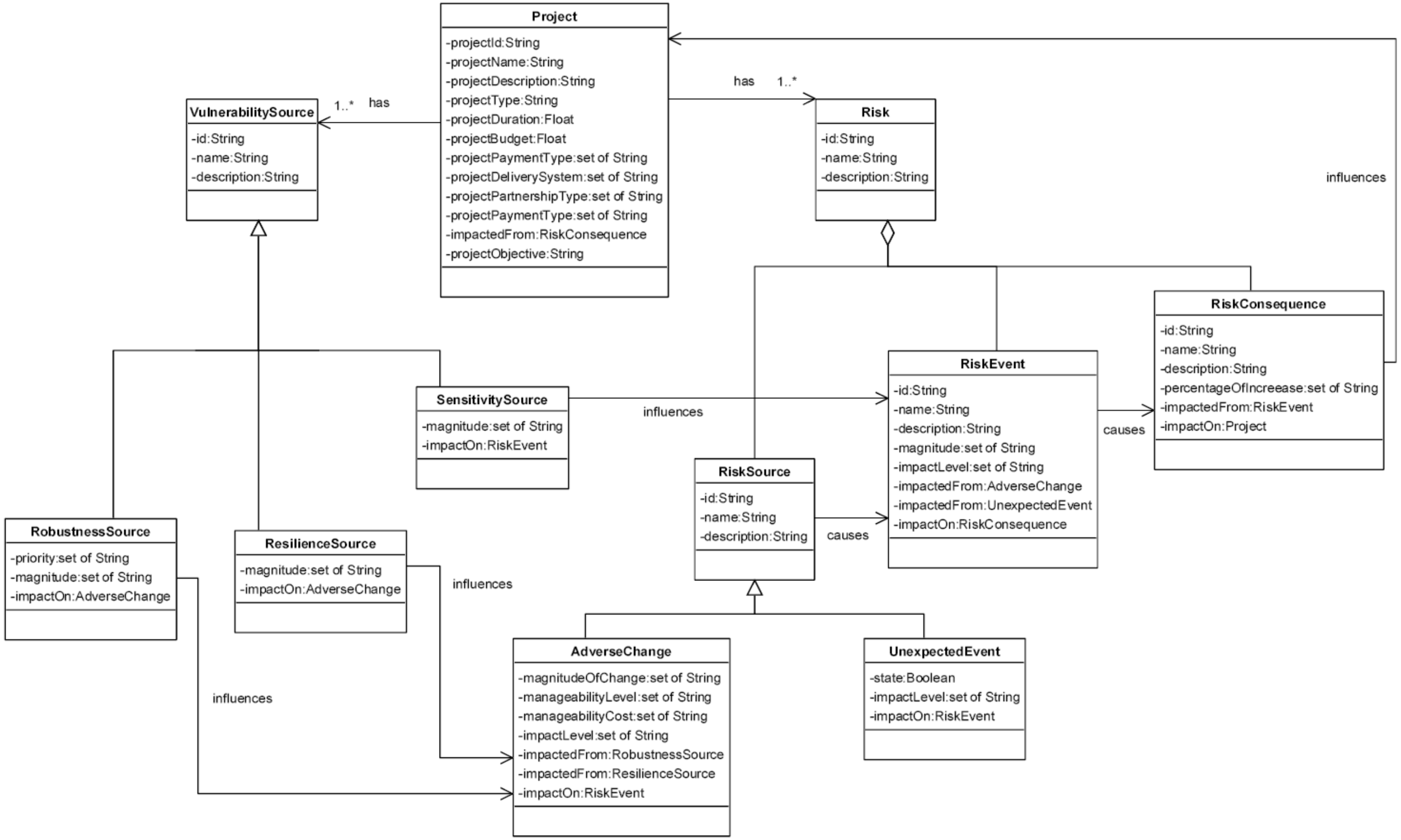

Figure 5.6: RV Ontology-Class Diagram

5.4. Integration

Integration indicates the reuse of concepts from other ontologies. However, due to the limited number of ontology development studies in risk management literature, re-using of exiting ontologies is not possible.

5.5. Implementation

Implementation indicates the writing of the ontology in a machine-processable ontology language (Breitman et al., 2007). The ontology is implemented through the utilization of software Protégé. The details of the software usage are out of the scope of this study; instead, the main parts of the ontology will be summarized by the demonstrated snapshots from the program in this section.

5.5.1. Class Hierarchy in Protégé

Classes in Protégé-Frames are shown in an inheritance hierarchy. Therefore, while defining the classes and sub-classes, this hierarchy is tried to be established. For example, "adverse change" and "unexpected event" classes are defined as child-class of "risk source" class. In case, there is not a direct inheritance relation (is-a relation) between the classes, those classes are defined as separate classes like "Project" class and "Risk" classes.

The taxonomy developed in Protégé is demonstrated in Figure 5.7. As can be captured, there are internal Protégé system classes "Thing" and "System-class". Protégé defines all the classes as a sub-class of "Thing" domain.

In the implementation, class names are capitalized, for example "adverse change" class is demonstrated as "AdverseChange".

Figure 5.7: Class Hierarchy in Protégé

5.5.2. Attributes in Protégé

After the implementation of class hierarchy, to give the detailed information about each class, attributes are defined as slots. The determined attributes in conceptualization stage of ontology development phase as well as the facet of these attributes described in formalization stage are implemented in Protégé. For example, as a facet, impact level attribute has "symbol" value type which indicates that impact level can take value form the set of {very low, low, medium, high, very high} as shown in Figure 5.8. After each attribute is defined with its facets, they are assigned to the relevant classes.

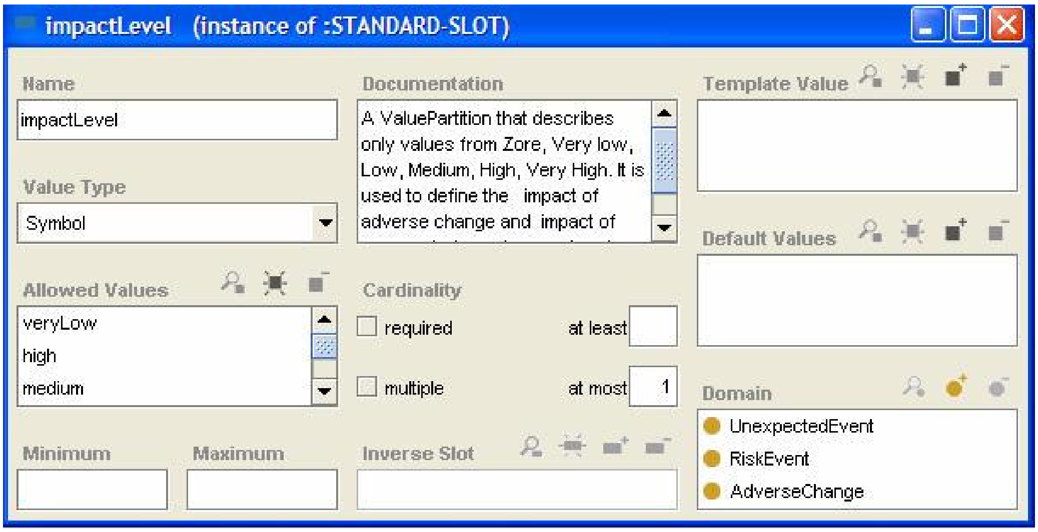

Figure 5.8: Impact Level Attribute in Protégé

Figure 5.9 demonstrates a snapshot from Protégé class window that presents the assigned slots to "adverse change" class. As discussed before, adverse change has a name, id, description, change level, manageability level, manageability cost, impact level and roles in the framework as impacted from and impact on.

In Protégé, slot names starts with low-case letters, for instance "impact level" attribute is demonstrated as "impactLevel".

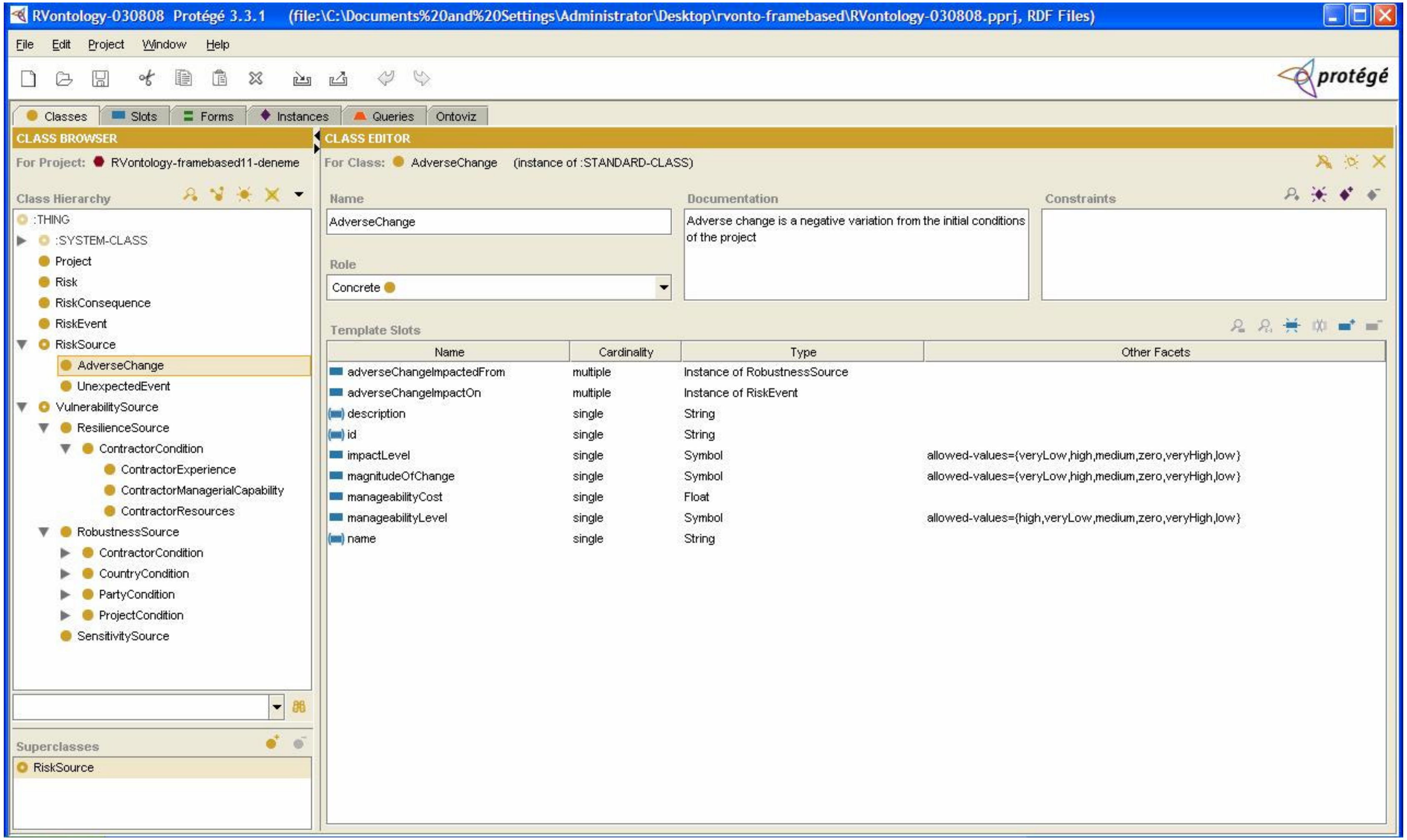

Figure 5.9: Snapshot from Protege Class Window

5.5.3. Instances in Protégé

After all the attributes are integrated to the system, instances of classes are defined. To illustrate, for "risk consequence" class "impact on duration" and "impact on cost" instances are defined which all have the same attributes with the class they belong to such as percentage of increase, impact on, impacted from, etc. (Figure 5.10). A knowledge base can be created by defining individual instances of classes, filling in specific slot value information and additional slot restrictions.

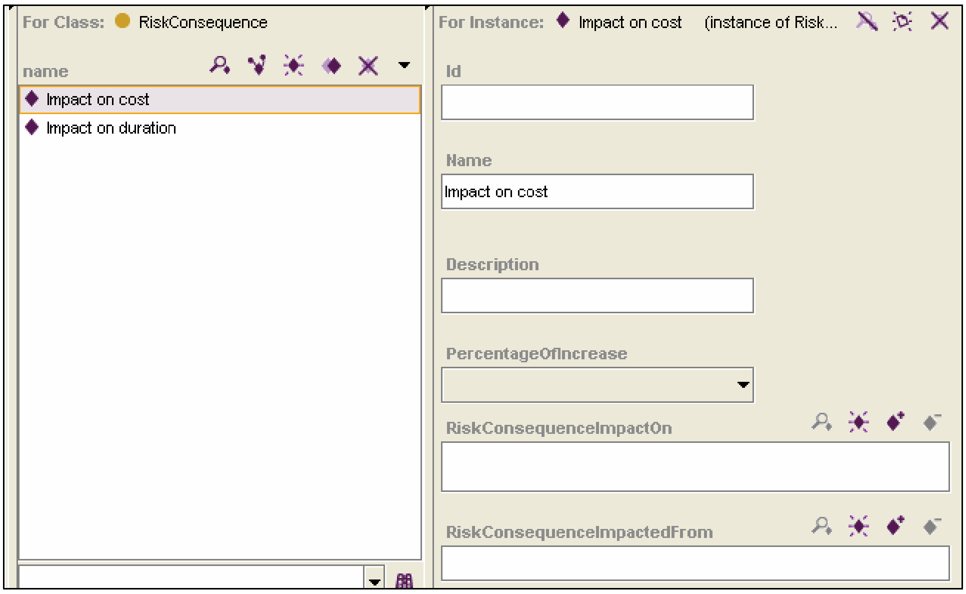

Figure 5.10: Instances in Protégé

5.5.4. Developed System in Protégé

Finally, the system that is aimed to be developed through the content of this research is achieved. The overview of risk and vulnerability concepts is shown in the form of a semantic network in Figure 5.11. Black boxes show the classes and arrows represent the slots. A relation between a class and an attribute is represented with a blue arrow and relations directly between classes are demonstrated with red arrows.

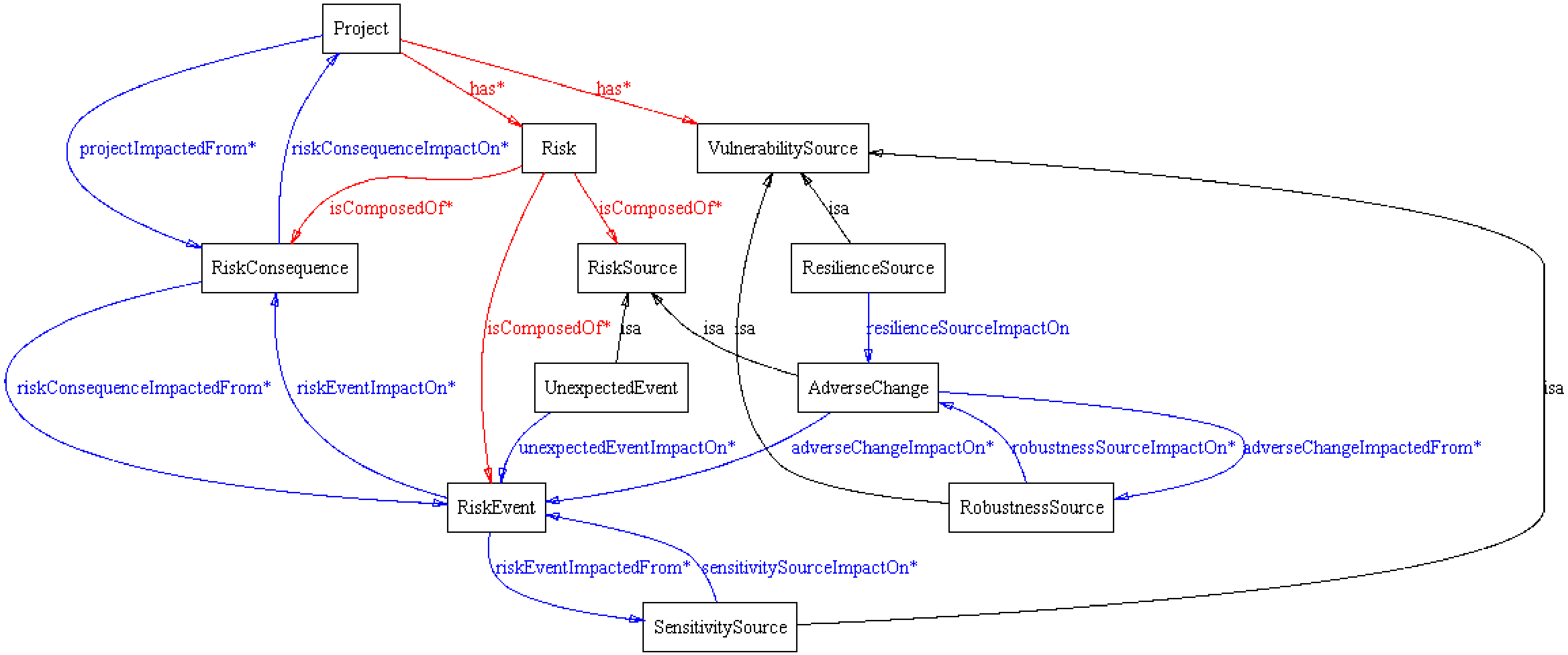

Figure 5.11: RV Ontology in Protégé

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS FOR FURTHER RESEARCH

This chapter concludes the main findings of the study by referring to the importance of risk paths and vulnerability in the realistic risk models, the stages of development of a framework that integrates risks with vulnerability, the usability of ontology and the applied ontology development methodology.

This study has two main goals:

- Identification of project vulnerabilities and structuring the relation between risk and vulnerability concepts
- Development of a risk and vulnerability ontology

To achieve these objectives, the entire study was executed through two sequential parts: development of framework and development of ontology for risk and vulnerability.

The initial aim of this study was to improve traditional risk management process and to make it more realistic by considering risk paths and influence of system on these paths, with a special emphasis on the system influence (vulnerability). In traditional risk management process, as Sarewitz et al. (2003) note, vulnerability too often lies in the shadow of risk and a narrow-minded focus on risk to the omission of vulnerability can easily increase the prospects for negative outcomes rather than reduce. Vulnerability is a very momentous concept as focusing on vulnerability management provides guidance to seek and cope with uncertainty in the project.

In the first part of the study, such a framework was intended to be developed. The concept of vulnerability as a part of risk assessment was introduced and factors that can be used for vulnerability assessment were presented after a comprehensive literature review. A hierarchical structure that comprises of factors related with the contract, company, project and parties involved in the project were developed. Risks were investigated in paths rather than individual sources of risk because of the fact that there are cause-effect relationships between the risk factors leading to a network form rather than a one-way hierarchical structure. Afterwards, the relation between identified vulnerability factors and risk paths were figured out. Validity of these factors was discussed by referring to findings of seven case studies. Case studies were conducted for four main purposes:

1) The parameters in framework were verified. While talking about the project progress, interviewees were requested to give information especially on problematic issues they faced and their results. The points mentioned by the interviewee were identified. For instance, in Project F, the interviewee mentioned that the escalation clause was not well defined such that the formulation for currency rate variations in Turkey includes both increase and decrease in rates, whereas for Austrian currency rate, the formula did not include the decline. This term corresponds the "contract error" term in framework. The tables presenting the interviewee expression and corresponding factor in the framework were given for each case study.

2) The relations between parameters were identified. While the interviewee talks about the progress, the causal relation between the events were tried to be analyzed. For example, in Project E, the interviewee told that the design was incomplete in tendering stage; there were only preliminary design drawings available. When the project started, they realized that design requirements were more than the expected. The designer could not

complete and submit the design on time. This situation was reflected to the framework as follows: “incomplete design” influences the “adverse change in designer performance”. To better understand these relations, cognitive maps of the interviewees were drawn with the utilization of software Cognizer and map of each project was presented in case study section.

3) Main factors within the framework were identified. It was concluded that main concepts of framework should include risk source, risk event, risk consequence and three vulnerability sources: robustness source, resilience source and sensitivity source. Robustness source influences the occurrence of adverse change, resilience source influences the manageability level of changes and sensitivity source influences the impact of risk event on risk consequence.

4) The strengths of causal relation between concepts were identified. In cognitive maps, these relations were indicated by the values on the arrows between parameters. While vulnerability parameters have vulnerability level, adverse change has a change magnitude, manageability level and impact level. An unexpected event has an impact level in addition to a state indicating whether the event is occurred or not. Risk events have a magnitude and risk consequence has a percent change value.

Face-to-face structured interviews were mostly useful because although there are several references revised to identify parameters and relations, neither of them was comprehensive enough to describe the logic, nor they do consider alternatives generated by different experts. Using case study methodology to verify the developed framework is an ideal proposal because it provides an in-depth investigation of each case. Case studies were used not only to verify the existing structure but also to revise it. Through case studies, it is realized that there are some missing points in the structure that had to be covered. Performing case studies was important for gaining insight on how the information should be collected. For example, it is decided to use a section about value (as identified as value partition) to define the strength of causal relationship which can be useful in further stages.

The major conclusions derived as a result of this part of the study are as follows:

1. The vulnerability factors affect project success by interfering with the risk events in different ways. Some vulnerability parameters affect the probability of occurrence of risk, some of them affect manageability of risk and some vulnerability factors may influence the impact of risk events on project success.

2. Vulnerability should be assessed within the context of risk scenarios. Vulnerability assessment should be done simultaneously with risk assessment. Risks should be examined through paths (risk source- risk event- risk consequence paths) and vulnerabilities should be added to those paths for estimation of risk impacts on project success. A hierarchical vulnerability structure that excludes risk factors and a multi-criteria vulnerability assessment process that does not consider risk paths may give unreliable results if used for quantification of level of vulnerability in a project. Thus, an integrated risk-vulnerability assessment procedure has to be developed.

The proposed structure may lead to the development of a common language and an ontology for formalization of risk identification process in construction projects. It can also help integration of vulnerability assessment with risk management practices.

One major shortcoming of the applied methodology is that the findings reflect mainly the Turkish contractors' experience, but it is believed that they can be applicable for all contractors, especially those working in developing countries. The level of vulnerability may be different among contractors from different parts of the world and magnitude of risk may differ from project to project. However, it is believed that the components of risk and vulnerability are similar.

In the forthcoming stages of the research related with this part of the study, hypothetical as well as some real cases were defined considering different levels of vulnerability-risk and their interrelations. Expert judgments were used to quantify the risk consequences associated with the defined paths. The collected data will be used to quantify the final impact on each party by considering their differing objective functions, risk perceptions, risk allocation schemes and negotiation processes between the project participants on a multi-agent platform.

The second foremost objective of the study was to make it possible to characterize the collected information. Ontology was indented to be designed through the scope this study, since it makes the representation of the organized knowledge in a computationally processable manner practical for more sophisticated functionalities in knowledge management applications. Building ontology was a necessity due to the fact that there is huge lack in the existing ontologies that can be used as reference models and sources of knowledge in this field. Thus, the need for common risk and vulnerability ontology is obvious in construction project management. Moreover, developed ontology is an essential part of this project, as it is used to represent and keep updated the risk and vulnerability knowledge.

Domain knowledge elicited in the first part of the study serves to specify types of concepts and the appropriate level of detail (e.g., risk, risk source, unexpected event, accident) and sets of relationships (e.g., inheritance relationships, aggregation relationship). Through the development of ontology, collected and organized knowledge was represented successfully.

Methontology framework was followed as a methodology for ontology development that involves four main stages: specification (determination of scope and purpose of the ontology), conceptualization (identification and development of the taxonomy of concepts used in the ontology), formalization (development of a more formal structure defining the relations between and within concepts) and implementation (implementing the system through the utilization of Protégé in a machine readable format). Case studies were particularly useful in this phase of ontology development for the strength and relevance of background knowledge.

The major conclusions of ontology development stage are as follows:

1) Ontology provides a better understanding of the data. Ontology makes it possible to express collected knowledge in a computer understandable language. Therefore, if it is planned to use information in a digital environment, ontology should be developed to prevent the occurrence of issues related with organizing information. In the first stage of the study, a basic framework was illustrated to define the main concepts. There were only two relations (direct and indirect) between risk and vulnerability parameters but they were not in a structured manner. This makes the comprehension of the knowledge difficult. Through the development of ontology, taxonomy was provided to illustrate the concepts in hierarchical manner. Moreover, more formal representation of the relations was achieved through the usage of notations of class diagrams. In the developed diagrams, four main relations were used: generalization (inheritance), association (calling direction), aggregation (part-of), and dependency. Moreover, attributes of each class were determined which is one of the most essential part of the ontology.

2) Ontology development is necessarily an iterative process. There is no single correct way to model a domain. The best solution should be

selected upon several alternatives by considering the future extensions of the research. In this study it was concluded that Protégé-Frames is more appropriate for this study in terms of its further usage (database development). Because as mentioned in Protégé 2000 User's Guide, "Protégé-Frames enables users to build ontologies that are frame-based, in accordance with the Open Knowledge Base Connectivity protocol (OKBC). Open Knowledge Base Connectivity (OKBC) is an application programming interface for accessing knowledge bases stored in knowledge representation systems." After the mechanism is decided, then the conceptual part was formed through a long iterative process, such that the names of the concepts and the representation of relations between concepts were revised several times to clearly represent the idea in our mind. For example, while in first stages only "vulnerability" term was used to characterize the system influence, in ontology development stage this term was revised as "vulnerability source". Revising the name of the concept provides consistency between its sub-concepts and instances.

One major shortcoming of the developed ontology is that, the last stage of the methontology framework "evaluation of the ontology" is not performed. Noy and Hafner (1997) divided ontology evaluation into two major groups: the evaluation of the formal quality of the ontology and assessing the usability of the ontology. Evaluation of the formal quality includes examining the formal features, including consistency and completeness, and is performed after the implementation stage. Assessment of usability of the ontology aims to verify the adequacy of the ontology for its intended tasks and how well it represents the domain of interest. However, in this research, since the developed ontology was conceptualized through a detailed literature review as well as several case studies and formalized through an iterative process, it is believed that implementation of an evaluation process is not essential at this stage of the project.

This study was undertaken as the initial part of an ongoing research project which aims to develop a multi-agent system for risk management of construction projects. Intelligent agents that would negotiate to quantify the final impact of risks on each party will form the basis of a multi-agent platform. Designed ontology in this study will serve for development of a knowledge base system. During negotiation intelligent agents will obtain required information for problem-solving and decision-making from the developed database. Developed ontology will serve not only for generating a database by defining the terms and relationships in a representative model of the domain, but it will be also used to check for missing terms or inconsistencies while collected information to develop required database.

To conclude, although there are some shortcomings of the study, such that case studies reflect mainly the experience of the Turkish contractors, the pre-defined objectives of the study were believed to be maintained successfully. A more realistic risk management framework, that combines identified vulnerabilities with risk paths, was developed and the framework was supported and enhanced through applied case studies. Finally ontology was designed to make collected knowledge machine processable. It is believed that the vulnerability and risk parameters will remain similar for all construction projects; therefore it can be applicable for all contractors. Moreover, ontology will eliminate the probable misunderstandings between different contractors by providing a common inclusive vocabulary.

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