IDENTIFICATION OF RISK PATHS IN INTERNATIONAL CONSTRUCTION PROJECTS

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ABSTRACT

IDENTIFICATION OF RISK PATHS IN INTERNATIONAL CONSTRUCTION PROJECTS

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Within the context of construction projects, *risk* is generally defined as an uncertain happening which is the function of its occurrence probability and the severity of its possible impacts on pre-defined objectives. According to this definition, international construction projects are high-risk endeavors, since they are known with their complex natures, large sizes, multidisciplinary frameworks, and unfamiliar and uncertain environments. International construction projects have more complex risk emergence patterns as they are affected from multiple global and foreign country conditions as well as project-related factors. Huge and complicated interrelationships and dynamic interactions among these influencing factors necessitate more systematic, comprehensive, and multi-attribute risk management process for overseas projects. In order to satisfy the requirements of such a risk management system, a realistic, inclusive, and accurate picture of the real case, reflecting all the aforementioned aspects of the international projects, is necessary.

The major aim of this study is to demonstrate that there are causal relationships between various risk factors which necessitate identification of *risk paths* rather than *individual risk factors* during risk identification and assessment phases. Identification of a network of *interactive risk paths*, each of which initiated from diverse vulnerabilities of the project system, is considered to be a better reflection of the real conditions of construction projects rather than using generic risk checklists. In this study, using the data of 166 projects carried out by Turkish contractors in international markets, and utilizing Structural Equation Modeling (SEM) technique, 36 interrelated risk paths were identified and the total effects of each vulnerability factor and risk path on cost overrun were assessed. SEM findings prove the main hypotheses of the study. The results demonstrate that every risk path is generated from specific vulnerabilities of inherent in project environment. Risk identification using SEM helps decision-makers in answering "what-if" questions in early stages of a project, in tracing the effects of interdependent risks throughout the life of the project, and in evaluating the influence of alternative mitigation strategies, not only on specific risks, but also on the whole network of interrelated risk factors.

Keywords: Risk Paths, Risk Identification, International Construction, Structural Equation Modeling.

ÖZ

ULUSLARARASI İNŞAAT PROJELERİNDEKİ RİSK ROTALARININ TANIMLANMASI

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Yüksek Lisans, İnşaat Mühendisliği Bölümü
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İnşaat projeleri kapsamında *risk*, gerçekleşme olasığına ve önceden tanımlanmış proje amaçları üzerindeki olası etkilerin ağırlığına bağlı olan belirsiz olaylar olarak tanımlanır. Bu tanıma göre; uluslararası projeler karmaşık nitelikleri, büyük boyutları, disiplinler arası ve belirsiz yapılarından dolayı, yüksek riskli deneyimler olarak tanınırlar. Bir çok küresel, bölgesel ve projeye özel faktörler tarafından etkilenmekte olduklarından, uluslararası projeler daha karmaşık risk gerçekleşme modeline sahiptirler. Bu faktörlerin kendi aralarındaki büyük, karmaşık ilişkiler ve dinamik etkileşimler, uluslararası projeler için daha sistematik, kapsamlı ve çok nitelikli risk yönetim sürecini gerektirmektedir. Böyle bir risk yönetim sistemi için uluslararası projelerin söz konusu yönlerini yansıtan, olayların gerçekçi, kapsamlı ve doğru tasvirinin yapılması gereklidir.

Bu çalışmanın asıl amacı, değişik risk faktörleri arasında nedensel ilişkiler olduğunu göstermektir. Bu ilişkiler, risk tanımlama ve risk değerlendirme aşamalarında *bireysel risk faktörleri* yerine *risk rotaları* tanımlamalarını gerektirmektedir. İnşaat projelerinin gerçek şartlarını yansıtmak için genel risk katalogları yerine projenin değişik kırılganlıklarından kaynaklanmış olan risk rotalarının oluşturduğu bir risk şebekesinin, daha iyi bir yöntem olduğu belirlenmiştir. Bu çalışma kapsamında, Türk müteahhitleri tarafından, yabancı ülkelerde gerçekleştirilmiş 166 inşaat projesinin verileri kullanılmıştır. Bu veriler ve Yapısal Denklem Modelleme (YDM) tekniği aracılığıyla 36 risk rotası tanımlanmış olup, proje kırılganlıkları ve tanımlanan risk rotalarının projedeki bütçe artışı üzerindeki toplam etkileri değerlendirilmiştir. YDM sonuçları, çalışmanın genel varsayımlarını ispat etmekte olup, belirlenen her risk rotasının projenin kırılganlıklardan kaynaklandığını göstermektedir. YDM aracılığı ile yapılan risk tanımlama süreci, projenin erken aşamalarında karar merciilerine "eğer" sorularının cevaplanmasına yardımcı olmaktadır. Bunun yanında, proje süresince etkileşimli risklerin etkilerini takip etme ve her bir stratejinin etkisini sadece özel risklerin üzerinde değil, bütün risk şebekesinde değerlendirme imkanı sağlamaktadır.

Anahtar Kelimeler: Risk Rota, Risk Tanımlama, Uluslararası İnşaat Projeleri, Yapısal Denklem Modelleme.

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To My Beloved Family….

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LIST OF ABBREVIATIONS

AC	Adverse Change
ADF	Asymptotically Distribution-Free
CBR	Case Based Reasoning
CFA	Confirmatory Factor Analysis
CFI	Bentler Comparative Fit Index
CIA	Cross Impact Analysis
CRMS	Construction Risk Management System
DF	Degrees of Freedom
DV	Dependent Variable
EFA	Exploratory Factor Analysis
FIDIC	International Federation of Consulting Engineers
FST	Fuzzy Set Theory
GFI	Goodness of Fit Index
GLS	Generalized Least Squares
ICRAM	International Construction Risk Assessment Model
IF	Independent Factor
IV	Independent Variable

MAS	Multi-Agent System
ML	Maximum Likelihood
NFI	Bentler-Bonett Normed Fit Index
NNFI or TLI	Bentler-Bonett Non-Normed Fit Index
PRM	Project Risk Management
PUMA	Project Uncertainty Management
R1	Risk Source Type 1(Adverse Changes)
R2	Risk Source Type 1(Unexpected Events)
RC	Risk Consequence
RE	Risk Event
RMSEA	Root Mean Error of Approximation
SD	Standard Deviation
SEM	Structural Equation Modeling
V1	Vulnerability Type 1
V2	Vulnerability Type 2
V3	Vulnerability Type 3

CHAPTER 1

INTRODUCTION

International construction projects have high level of risks and complex natures which result in higher possibility of overrun and conflict when compared with domestic projects (Zhi, 1995; Han and Diekmann, 2001; Gunhan and Arditi, 2005, and Han et al., 2008). Complexities derived from dynamic interactions between various global, country and project specific factors necessitate a systematic, comprehensive and proactive risk management process for international construction projects. Risk management process is generally defined as an iterative process that starts with identification of risk factors, followed by qualitative and/or quantitative assessment of risk impacts on the project, and finally, development of risk mitigation strategies to maintain an optimum risk-return structure between the project participants (Zhi, 1995; Wang et al., 2004; Han et al., 2008, and Edwards et al., 2009).

Several authors (e.g. Al-Bahar and Crandall, 1990; Bajaj et al., 1997; Ward, 1999; Zoysa and Russell, 2003; Wang et al., 2004; Baston, 2009, and Edwards et al., 2009) have emphasized the importance of identification phase of risk management process, as subsequent phases (assessment, analysis and responding) are carried out based on the pre-identified risk factors. Therefore, as Chapman (1998) and Bajaj et al. (1997) also stated, benefits of the risk management process are mostly affected by the reliability and inclusiveness of identification and further assessment phases. Comprehensive consideration of all probable risks and accurate modeling of them would lead to better understanding of the project and wider view of the future, and hence, less uncertainty. Unidentified important risks or wrongly identified ones may lead to reactive responses to occurred problems rather than proactive management of possible risks and may even affect the success of the project.

During the risk identification phase, risk checklists are widely used in the construction industry. A project-specific risk checklist is constructed by decision-makers or a generic risk checklist is adapted to the project. The probability of occurrence of risk factors within the risk checklist is tried to be estimated along with their possible impacts on project outcomes mainly by brainstorming, interviews, surveys or using expert judgments (Zoysa and Russell, 2003, and Maytorena et al., 2007). After the magnitude of each risk factor is assessed, the critical risk factors are identified for further analysis and development of response strategies (Ward, 1999).

However, risk checklisting approach has serious flaws. First, listing of individual risks as if they are independent factors ignores the interdependencies between them. For example, “productivity lower than expected” is usually considered as an independent risk factor and factors leading to low productivity such as adverse weather conditions, inexperienced site manager, delay in logistics etc. are listed within the checklist as if they are independent from productivity. Second, risk checklisting approach ignores the multiple risk occurrence scenarios and assumes as if risk factors occur individually. Assessment of magnitude of individual risk factors regardless of probability of occurrence of a chain of risk events and probability of co-occurrence of several risk factors that emerge from the same source may result in underestimation of overall risk level of the project.

Although there are vast amounts of literature emphasizing on the existence of causalities among risk factors and their sources and consequences, limited causality-integrated risk-based approaches are introduced. Even methods that have taken the source-event relationships among risk factors into account, have failed to incorporate the possible interactions among diverse risk scenarios. However, in today’s complex construction projects, not only risks occur through a chain of cause-effect events, but the occurrence of different risk scenarios and their effects on project objectives are not independent from other possible scenarios and the existed counter-effects.

The main objective of this study is to demonstrate that there are interrelations between various risk factors and propose that decision-makers should identify “**interactive risk paths**” rather than “**independent individual risks**” for better simulation of project conditions. This study is an effort to mitigate negligence of previous studies that depend on separate risk categories, generic checklists and one-way risk hierarchies and propose an alternative Risk-Path Model. In this model, risk factors, their sources, and their consequences are assumed to be causally dependent. Moreover, within the context of this study, the vulnerability factors inherent in the project environment are assumed to act as the initiatives of the possible risk paths. It is believed that incorporating system’s vulnerabilities into the risk-path identification process will lead to more realistic and more accurate estimations about the future since these factors are known with higher level of certainties at early stages of the projects. All the possible interactions among diverse identified vulnerability-generated risk paths are tested and the cross-impacts are estimated employing Structural Equation Modeling (SEM) technique.

This study is a part of an ongoing larger research project supported by “The Scientific and Technological Research Council of Turkey (TUBITAK)”. The ultimate aim of the project is development of a Multi-Agent System (MAS) for simulation of the argumentation-based negotiations between project parties for achievement of an acceptable cost sharing between them. The Risk-Path Model consisting of significant risk scenarios identified by SEM, and the estimated cross-impacts will act as an independent agent for identification of possible chain of risk events and will provide agents with the necessary justifications supporting their arguments.

Within the context of this thesis, chapter 2 introduces the background of the research through summarizing previous risk-based approaches, reasons, justifications and motivations for conduction of this study, and the main objectives. Chapter 3 describes general structure and the conceptual framework based on which the Risk-Path Model will be developed. Within the context of chapter 4, various aspects of the research methodology are represented. In chapter 5, the processes for identification of causal relationships among risk attributes are summarized. The hypothesized interactions are analyzed employing SEM technique, and reliability and significance of the estimated risk paths are tested. In chapter 6, identified paths, interactions, structures, results and effects are discussed and compared with previous research findings. In chapter 7, the prediction capability of the SEM-based models is introduced as a supplementary aspect of the identified Risk-Path Model. Five case studies are applied to demonstrate the implication of the Risk-Path Model as a prediction tool for estimation of possible values for project risks and their likely consequences. Chapter 8 summarizes the main motives and objectives of the study. Major findings, advantages and contributions of the conducted study, and of the introduced approach, are also overviewed in this chapter. Finally, recommendations for further studies, works conducted as initial steps of the upcoming works, and suggestions for improvement of the developed Risk-Path Model are given.

In addition to the main text, this thesis also contains two appendixes, namely Appendix A, and Appendix B. Appendix A includes an example illustrating the step by step estimation process of the developed SEM-based Risk-Path Model. Within the context of Appendix B, estimation of the contribution rates of each risk factor on the magnitudes of its possible consequences are illustrated for a sample case.

CHAPTER 2

RESEARCH BACKGROUND

This chapter presents the background of the present research via six main sections. In the first section, the concept of the project risk management (PRM) is defined and the main challenges of its effective application in international construction projects are introduced. Second section emphasizes on the identification phase of the PRM and its importance in construction projects. In third section, a literature review on present risk-based studies is conducted in order to clarify the approaches of various researchers toward different risk concepts. In the forth section, common shortcomings of these approaches are discussed and the research problem is defined. Within the context of the fifth section, the research objectives are introduced with the aim of structuring the problems. Finally, in the last section, literature surveys on the previous risk-based approaches which have considered possible causalities among various risk factors are summarized.

2.1 Risk and Project Risk Management Concept

2.1.1 Project Risk Definition

Risk is the function of the probability and outcomes of an uncertain happening. Although the concept of “risk” is defined and approached differently by different points of views, within the context of construction projects, it is generally defined as the probability of occurrence of events that may positively or negatively affect the project’s predefined objectives (Al-Bahar and Crandall, 1990; PMBoK, 2000; Baston, 2009, and Edwards et al., 2009). Even if risk may have both adverse and favorable consequences according to this definition, risk-based approaches are mostly concentrated on its negative outcomes.

Project risks are uncertain phenomena, but their likelihoods and outcomes can be estimated, and hence managed (Olsson, 2007).

2.1.2 Project Risk Management Definition

According to PMI PMBok (2000), “Project Risk Management (PRM) is the systematic process of identifying, analyzing, and responding to project risks”.

In spite of different definitions and processes adopted for risk management of construction projects, most of the introduced approaches cover these aforementioned three phases. Supporting the integration of PRM processes with companies’ routines and with project environments, Sanchez (2005) claims that the main objectives of risk management are oriented toward these three tasks. Wang et al. (2004) defines PRM as a systematic and formal process which should be conducted throughout the life of the construction project and comprises of three phases, namely identifying, analyzing and responding to the project risks. Going further than the three-step PRM, authors such as Berkely et al. (1991) and Zhi (1995) considered PRM process as a four-step systematic approach including 1) Risk Classification, 2) Risk Identification, 3) Risk Assessment, and 4) Risk Responses phases. Han et al. (2008) claim that the most effective approach toward the PRM of construction projects is the process consisting of the following five steps: 1) Risk Identification, 2) Risk Analysis, 3) Risk Evaluation, 4) Risk Response, and 5) Risk Monitoring. Edwards et al. (2009) modify such definitions through emphasizing on the importance of the risk-related knowledge after the accomplishment of each PRM cycle. They introduced six subsequent phases as the necessary steps for PRM of construction projects, namely 1) Establishment of the Context, 2) Risk Identification, 3) Risk Analysis, 4) Risk Response, 5) Risk Monitoring and Controlling, and 6) Capturing Risk Knowledge. Numerous other PRM approaches similar to, or differing in some details from, these mentioned approaches are also offered within the construction management literature (see for example, Hampton, 1993, and Caňo and Cruz, 2002).

Reviewing the formal PRM processes developed by researchers, it is found that proposed systems are typically common in the following major phases;

1) Risk Identification
2) Risk Assessment
3) Risk Response

2.1.3 Project Risk Management Objectives

According to authors such as Al-Bahar and Crandall (1990), and Wang et al. (2004), the aim of the risk management is to optimize the level of the risk mitigation, risk elimination, and risk control through a whole-life practice. A realistic and comprehensive approach toward PRM and effective implementation of it will have substantial effects on improvement of the project management success (Flanagan and Norman, 1993). According to CIRIA (2002), risk management practices should lead to time/cost savings and reductions in rate of accidents. Skorupka (2008) defines PRM as a systematic process the major aim of which is to guarantee the accomplishment of all the steps necessary for achievement of project objectives. According to Sanchez (2005), the main issue of the PRM in construction industry is evaluation of risk impacts on various objectives and estimation of the costs of potential risks.

2.1.4 Project Risk Management Challenges in International Construction Projects

Project risk management is a crucial success factor for effective project management practices and for overall success of the project (Baloi and Price, 2003, and Han et al., 2008). In the case of international construction projects, PRM is even more critical task being characterized by high complexities and difficulties.

Internationalization of the construction industry and effects of the globalization have made conduction of an effective PRM a difficult course of action. Generation of more complex projects, establishment of multi-cultural and global teams usually collaborating remotely, intensification of the competition, increase in diversity of the factors influencing project objectives such as global, domestic, project, and company-specific factors, increase in the possible interactions among these factors, and all in all, complication of the project environments are some of the outcomes of the internationalization in construction industry. Zhi (1995) classifies risk factors affecting international projects as *external* and *internal* ones, modeling, identification, and understanding of the huge and complex relationships among which are highly difficult and tedious endeavors.

All these effects call for more accurate understanding about the nature and environment of the projects, and for more comprehensive PRM approaches in overseas projects. However, as Han et al. (2008) state, traditional risk management methods are not adequate for modeling and management of diverse risks and complex and dynamic interactions among them in international construction projects. According to authors such as Perry and Hayes (1985), and Flanagan and Norman (1993), the formulated PRM techniques lack adequate applicability in real construction projects, mostly because of shortcomings of the developed methods for different phases of PRM in addressing such aforementioned issues. Generally, construction risks are dealt based on personal experiences, rules of thumbs and subjective judgments of the practitioners (Al-Bahar and Crandall, 1990). Therefore, there is a need for exploring new approaches in different stages of PRM for development of more realistic, accurate, and applicable models and techniques.

2.2 Risk Identification Concept: Definition and Importance

Al-Bahar and Crandall (1990) define risk identification as “the process of systematically and continuously identifying, categorizing, and assessing the initial significance of risks associated with a construction projects”. Risk identification is one of the initial steps of the most of the offered PRM systems through which potential risk factors that may have adverse impacts on project objectives, and their sources and possible consequences are recognized in a systematic manner.

Within the literature, there is a common consensus that the risk identification is the most important phase of the PRM process, and at the same time, the most difficult one. Smith (1999) considers “unknown” projects (those the risks of which are not identified) naturally more risky than “known” ones. Bajaj et al. (1997) relates the success of the PRM process and the total advantages gained from its application, and also achievement of the project objectives, to the effective conduction of the risk identification phase. Based on an overview on the related literature (e.g. Al-Bahar and Crandall, 1990; Bajaj et al., 1997; Ward, 1999; Zoysa and Russell, 2003; Wang et al., 2004; Baston, 2009, and Edwards et al., 2009), the main justifications for this emphasize on risk identification phase can be summarized as follows;

- Unrealistic, inaccurate, and incomprehensive list of risks will lead to reactive responses to the occurred problems rather than proactive strategies for mitigation of their impacts and controlling their occurrence patterns. In other words, the accuracy of the risk identification phase will directly affect the rationale of applying PRM which is proactive dealing with probable risks and threats before they become surprising problems.

- Effectiveness and advantages of further stages of the risk management process depend on accuracy and reliability of the identified risks, since these phases are conducted based on the initially identified risk factors.

- An adequate risk identification at initial stages of a candidate project will lead to a more realistic simulation of the unknown future, better understanding of the project environment, less uncertainty, and hence, more reliable and effective decisions.

However, as Maytorena et al. (2007) also mentioned, limited researches have been conducted on risk identification, and the currently developed methods lack adequate applicability; this phase is mostly done through brainstorming, interviews, surveys or expert judgments. Therefore, new approaches are needed to be developed for the improvement of the existing risk identification methods through introduction of more realistic, applicable and comprehensive methods.

2.3 Literature Review on Previous Risk-Based Approaches

Various approaches have been offered within the context of risk identification and assessment. Utilization of diverse risk breakdown structures, databases, taxonomies is recommended to develop some computer-based methods for facilitation of risk management process, or risk assessment using multi-attribute ratings.

Zhi (1995) suggested a structured risk management process for international construction projects. Individual risk factors are classified according to their initial sources, namely external and internal risks, and are assessed considering their likelihood and impact degrees. In their paper, Al-Bahar and Crandall (1990) have presented a risk model entitled as “Construction Risk Management System” (CRMS) comprising of four main phases of risk management process. For the identification purposes, they classified risks in accord with their natures and potential outcomes. They also offered utilization of influence diagrams and Monte Carlo simulation methods as appropriate approaches for analysis and evaluation phases. Caño and Cruz (2002) support the development of project and organization-specific risk management process. They proposed a “project uncertainty management” (PUMA) including a generic PRM process from the view point of project owner and consultant. This presented process is accomplished through four sequential stages, namely initiation, balancing, maintenance, and learning for complex projects undertaken by organizations with high level of risk management maturity. Supporting the application of a systematic risk management process, Zou et al. (2007) identified different project stakeholders’ risk factors throughout the life cycle of the project using questionnaire survey. They claim that risk factors of construction projects are not one-time happening events and should be studied through whole phases. Wang et al. (2004) identified critical risk factors affecting construction projects in developing countries, classified them under three main levels, ranked them, and proposed some response strategies to cope with these identified risks. Batson (2009) have developed taxonomy of possible risk factors for infrastructure projects with the aim of facilitating risk identification at the planning phase of the project. Batson introduced 15 risk headings which may cause 96 potential problems in terms of quality, quantity, schedule and cost. Sanchez (2005) has identified a list of most critical risk factors affecting cost performance of infrastructure projects in Germany, and developed a Neural-Risk Assessment System to quantify the money value of the identified risks' impacts. The work of Choi et al. (2004) is one of the most recent approaches proposed for risk assessment of underground construction projects. Their presented assessment process starts with identification of most critical risk events based on collected risk-related data and information. A probabilistic fuzzy-based approach is recommended for evaluation and assessment of these identified events. Kaming et al. (1997) have identified the most important risk factors leading to cost and time overruns in Indonesian construction industry through expert interviews. They propose the identified list of risk groups comprising of most important individual risks to be considered during risk management process in construction projects conducted in Indonesia. ICRAM-1 model (International Construction Risk Assessment Model), developed by Hastak and Shaked (2000), is another systematic approach toward the assessment of potential risk factors in international projects. They categorized 73 tangible and intangible risk indicators under three interrelated levels, namely "macro environment", "construction market" and "project" levels. Tah and Carr (2000) have proposed a hierarchical risk breakdown structure in order to classify diverse risks (categorized as external and internal) that may affect construction projects. Three attributes of each risk, called "risk factors", "risks" and "consequences" are assumed to be causally dependent, and are assessed using a structured fuzzy risk rating approach. In their research, Dikmen et al. (2007a) utilized a fuzzy risk rating approach to qualitatively assess the risk of cost overrun in the bidding stage of international projects by taking into account of interrelations between various risk factors and impact of project-related factors as well as contract conditions on the risk level of projects. In order for development of a fuzzy decision making framework, Baloi and Price (2003) have identified several global risk factors affecting cost performance of construction projects through detailed literature review. Assessment and management issues of such identified risks were examined for further modeling purposes. Claiming global risk factors to be the most critical ones in international projects, they classified potential risks under the headings of "organization-specific" (internal environment), "global", and "acts of God" (external environments).

Some researchers have mentioned knowledge-based techniques to be more suitable for risk identification because of limited information available at the early stages of the projects. For example, Zoysa and Russell (2003) have developed a knowledge-based approach for identification of possible risks associated with a new large infrastructure project by means of two types of knowledge structures, namely a reusable document comprising of stored past experiences, and rule sets defined for reasoning and similarities used in determination of project attributes and characteristics of the environment. As an outcome, a project-specific updatable risk register is developed comprising of a list of probable risks under diverse categories. They have mentioned “process”, “physical”, “socio-economic” and “organizational” factors to be the most dominant risk areas in infrastructure projects. Leung et al. (1998) have formulated a risk identification model explaining the causality among each risk factor and its possible consequences. A knowledge-based risk identification system is then established employing some If-Then rules acquired from expert knowledge. The other learning-based approach is the proposed tool developed by Dikmen et al. (2008a). Early learning from past risk-related information and life-time risk management process, and hence early actions, are recommended to be more appropriate philosophy for risk management of real construction projects rather than managing effects of occurred risks. Lessons learned related to project risks, vulnerabilities, consequences and responses are documented in an organization memory database. Choi and Mahadevan (2008) have proposed an updating approach for identification of a limited number of most critical project-specific risks which are obtained referring to large amount of data available. These project-specific identified risks will be used as the inputs for their developed risk assessment methodology. The work of Tah and Carr (2001) is another attempt in development of software tools facilitating the learning-based risk management of construction projects. In their formulated system, risks, classified in a hierarchical risk breakdown structure which comprises project and work package risks, and the corresponding actions are stored in a catalog which is customizable for every project and forms the risk database of the developed system. A risk management framework supporting all stages of risk management process in an updatable and flexible manner is developed and tested through a software prototype. Tserng et al. (2009) developed an ontology-based process-oriented risk management framework. It is claimed that reuse of risk-related knowledge and past experiences of the experts through this validated knowledge extraction model can enhance the performance of various risk management processes.

Moreover, there are several risk-based approaches having been employed to facilitate risk identification and assessment in different stages of the construction project lifecycle. For example, Han et al. (2008) developed an integrated risk management system for international construction projects comprising of a model for risk-based bidding decision, profitability estimations at preconstruction stage, and risk management of construction phase. In their scenario-based checklist, they proposed identification of risk-paths showing the cause-effect relations among diverse risks. Han and Diekmann (2001) have developed a risk-based decision support system to assist the companies' go-no-go decisions for overseas construction projects. A hierarchical risk breakdown structure including five risk categories is developed to provide critical variables which form a network leading to two project outcomes, namely "project profitability" and "other benefits". The values of these two outcomes obtained through cross impact analysis (CIA) are recommended criteria affecting go-no-go decision. Claiming that bidding decision process is highly unstructured, Chua et al. (2001) developed a model supporting the risk-based bidding decision of contractors using data related to similar cases. A limited number of possible risks along with competition factors are considered as influencing parameters in this stage.

2.4 Problem Determination

Risk identification and assessment phases are considered as most important phases of systematic risk management process by several researchers (e.g. Al-Bahar and Crandall, 1990; Bajaj et al., 1997; Ward, 1999; Zoysa and Russell, 2003; Wang et al., 2004; Maytorena et al., 2007; Baston, 2009; Edwards et al., 2009).

Identification of the most probable risks at pre-construction stage of the candidate project is of high importance for feasibility assessment purposes, and therefore, for decision on right projects or further strategies. Also, as mentioned in previous sections, exhaustive identification of potential risks that may significantly affect project and corporate objectives will lead to proactive management decisions rather than corrective responses to raised problems. On the other hand, subsequent phases of risk management process (assessment, analysis and responding) are carried out based on the identified risk factors (Al-Bahar and Crandall, 1990; Akinci and Fischer, 1998; Wang et al., 2004). Therefore, risk management practices will be beneficial for the companies only if the products of its initial stages (identification and assessment) are reliable and inclusive (Bajaj et al., 1997; Chapman, 1998).

However, although there are various efforts to support the risk identification and assessment process for construction projects, they possess some common shortcomings that prevent them to simulate real project conditions:

1) Risk factors are mostly considered individually and under the same level, neglecting the sequences of their occurrence and the causal relationships among their various attributes. Even methods having taken into account the source-event relations; have failed to reflect the possible interactions among separate risk scenarios. However, construction risks occur in the form of complex network of interactive events. Authors such as Ashley and Bonner (1987), Tah and Carr (2000), Zou et al. (2007), Dikmen et al. (2007b), Han et al. (2007), and Han et al. (2008), have discussed the importance of studying combination of diverse risks in the form of possible cause-effect scenarios, and have made some encouraging efforts for demonstration of possible causalities and associations among different attributes of construction project risks.

Identifying single risks, without examining their origins, and the effects they may have on the subsequent risks will not draw a realistic picture of what is actually experienced in construction projects. On the other hand, project outcomes are affected by the combination of various interdependent risk factors and making decisions based on the sole impacts of independent risks may lead to biased conclusions resulted from neglecting the existing cross-impacts.

Therefore, risk identification systems and subsequent assessment models, aiming to simulate real construction projects, should be based on **“interactive risk paths”** rather than **“independent individual risks”**.

2) In construction projects, identification and assessment endeavors are usually made at pre-construction or pre-contract stages in which very limited data and information are available about the upcoming project condition (Choi and Mahadevan, 2008). Therefore, predictions and further decisions are to be made with high degrees of uncertainties. Such limitations make these processes be difficult tasks mostly based on subjective judgments of managers and various rules of thumb.

Dealing with the extreme uncertainties associated with early estimates has been the main focus of several researches, and various probabilistic, statistical or qualitative methods have been developed in this regard. However, as Han and Diekmann (2004) also emphasized, these methods do not adequately reflect the complex relationships among risk variables, and therefore, are incompetent in assessing the real level of uncertainties.

However, the system's vulnerabilities, inherent in its capacities and capabilities, and known with more certainty, are the factors providing potential for occurrence of future risks (Ezell, 2007, and Sarewitz et al., 2003). The sources of vulnerability and their influence on the probability of occurrence of future events are usually neglected.

Since the knowledge about the characteristics of any system is more acquirable at early phases of the project, identification of likely risk paths, and their further assessment, based on known vulnerabilities from which risks are initiated may result in more realistic estimates.

2.5 Research Objectives

Recent trends show that the developed risk management systems are moving from being packages of quantitative calculations and predictions toward approaches which facilitate the true understanding of the processes and under-examined cases (Maytorena et al., 2007). In such a condition, experts' judgment and their perceptions about the phenomena are significant factors affecting accuracy of the predictions, and hence, made decisions (Chapman, 1990). Therefore, true understanding and realistic image of the future are of essential requirements for today's risk management processes.

In this research, it is claimed that **"interactive risk paths"** which are driven from inborn vulnerabilities of the project system, rather than individual and independent risk sources, should be identified and assessed in order to draw more precise and accurate picture of what may happen in the future.

The main objectives of this study can be summarized as follows;

1) Introduction of a methodology for the identification of critical ***risk paths***, as scenarios that most probably may affect cost performance of international construction projects.

2) Analyzing the cross-impact of the combination of such risk-path scenarios on the project cost overrun.

3) Incorporating the effects of system vulnerabilities into the identification processes by estimating the relationships between the initially known conditions of the projects and the potential risks.

This study is a part of an ongoing larger research project with ultimate aim of developing a Multi-Agent System (MAS) to simulate the argumentation-based negotiations among project parties for achievement of an acceptable cost sharing between them. The Risk-Path Model identified by SEM and consisting of significant risk scenarios, and the estimated effects will act as an independent agent for identification of possible chain of risk events and will be used for development of arguments of negotiator agents.

Risk concepts, which were determined, documented, and validated in previous stages of this research (i.e. Fidan et al., 2010) constitute the foundation of the Risk-Path Model.

2.6 Overview of Previous Causality-Integrated Risk-Based Approaches

Although the causality-based approaches are not applied systematically enough (may be because of the complexities associated with causality considerations), there are several attempts within the literature of construction risk management supporting the incorporation of causalities and interrelationships among various risk attributes into risk management processes.

With emphasizing on political risks of international construction projects, the work of Ashley and Bonner (1987) is one of the most primary studies examining the direct and indirect interrelationships among risk related concepts. Claiming that political risks have effects on cash flow elements of the project, they structured influence diagrams each of which forming “a joint cause-effect and time-sequence mapping of risks”. They claim that studying the interrelationships deriving from political risks via influence diagrams will be an adequate start point for their assessment since it provides good pictures of the project and its risks. As an example, the influence diagram showing factors that influence labor cost is given in figure 2.1.

Influence diagrams have been widely used in the risk management literature to show possible interactions among risk concepts. Dikmen et al. (2007b) utilized influence diagrams for demonstration of relationships among project and country-level risk factors, and the influencing factors mentioned as “controllability”. The developed risk identification models comprising of such interrelationships are considered to be better templates for assessment purposes of risk of cost overrun in international projects. They utilized Fuzzy Set Theory (FST) for quantifying the cost overrun risk rate resulted from such interactions.

Tah and Carr (2000) argued that the cause-effect relations among *risk factors*, their effects on project activities (named as *risks* in their study), and *risk centers*, or also among distinct *risks*, should be studied in order for assessment and analysis purposes. They claimed that risks are generated from risk factors which are less vague concepts, therefore, for estimating the likelihood of occurrence of any risk, the probability of corresponding risk factors should be considered. FST is proposed for analysis of risk concepts which are identified based on the proposed causalities.

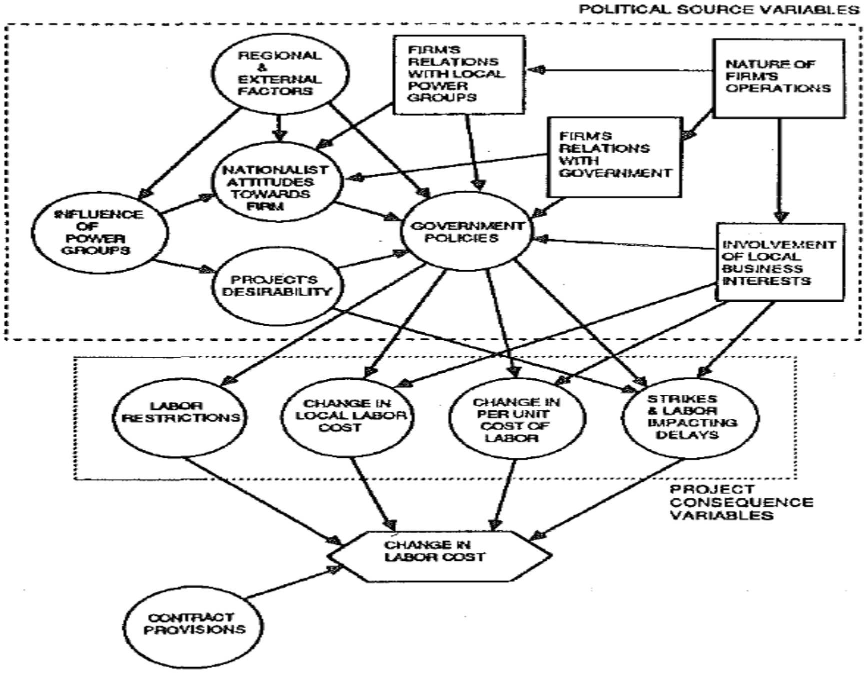


Figure 2.1: Influence Diagram of factors resulting in Change in Labor Cost (Ashley and Bonner, 1987)

Zou et al. (2007) studied the interdependencies among risks of different project parties throughout the various stages of project life cycle for China’s construction industry. Risk chains through feasibility, design, construction, and operation stages are identified, and effects of individual risks on various project objectives (cost, time, quality, safety, and environment) are examined using feedbacks obtained from experts through questionnaire surveys. Figure 2.2 shows the interactions among key risks that they identified through the project life.

The cause-effect diagram developed by Han et al. (2007) is another effort for incorporating causalities in risk management processes. Possible causal relationships among profit influencing factors (Host Country, Project Owner, Organization and Participant Characteristics, Bidding Process, Project and Contractual Conditions, and Contractor’s Ability to Perform) are depicted with the aim of examining the key causes of bad profit, identifying the most critical ones, introducing some kind of checklists for contractors’ risk management, and assisting them in reducing risks.

Figure 2.3 summarizes the causalities and strengths of the effects that they have proposed in their study.

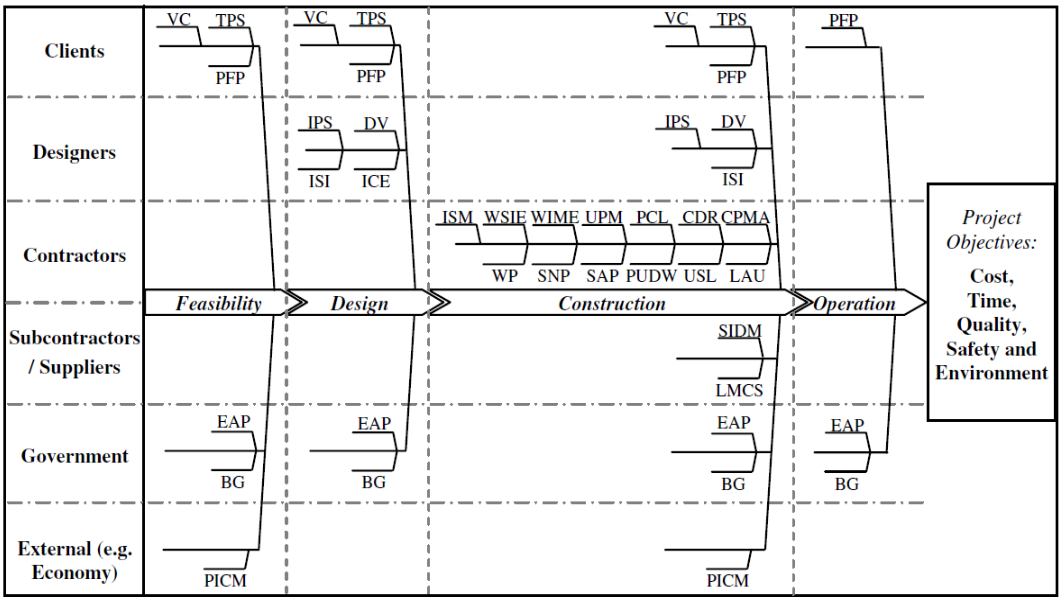


Figure 2.2: Connection of Key Risks, Stakeholders, and Project Life Cycle suggested by Zou et al. (2007).

Note: Please refer to the aforementioned paper for a list of risk factors corresponding to the acronyms.

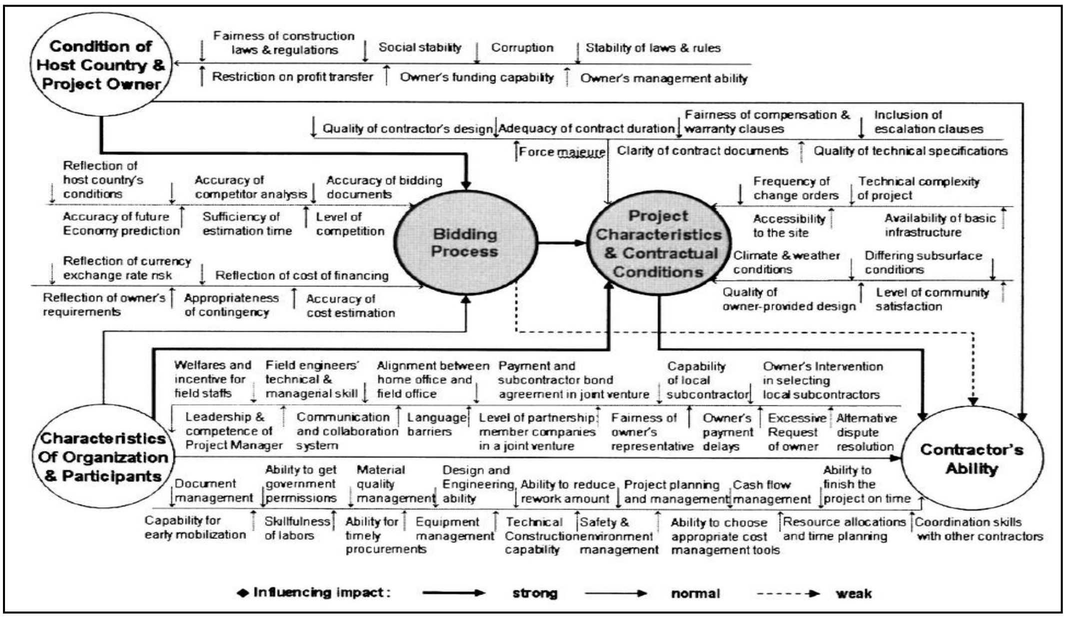
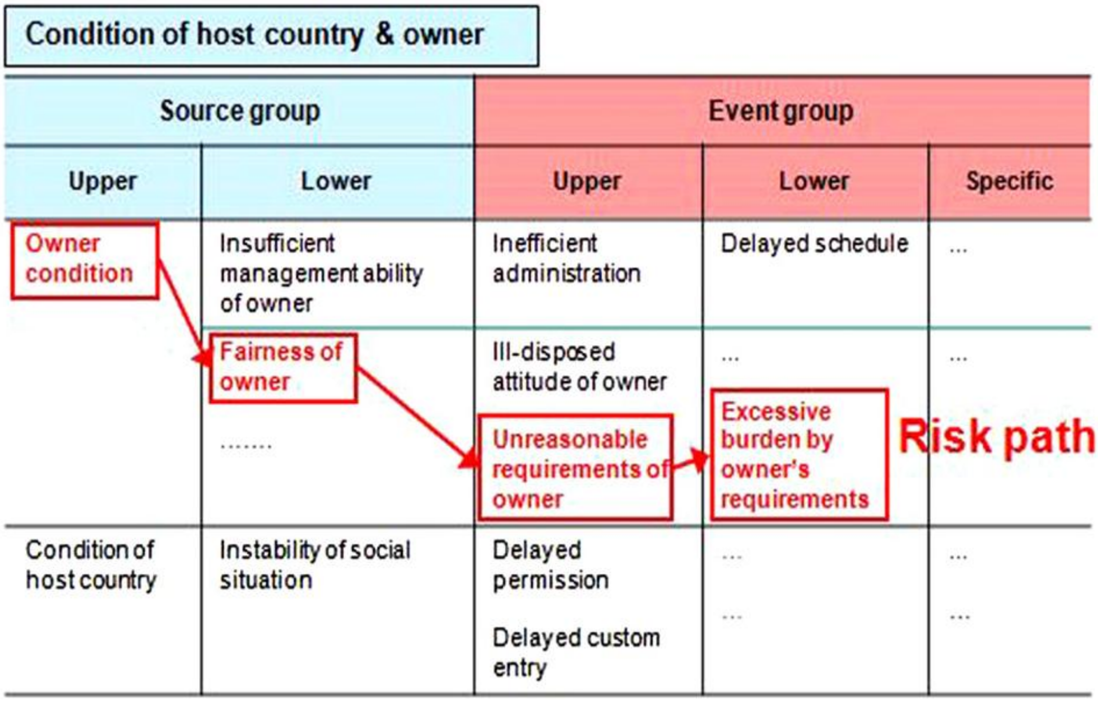


Figure 2.3: Causal relationships of Profit Influencing Factors determined by Han et al. (2007).

The integrated risk management system developed by Han et al. (2008) is one of the most noticeable efforts in this regard. Their proposed system consists of a risk-based bidding decision support tool, a model for profitability estimation at preconstruction stage, and a risk management system comprising methods for risk identification and risk assessment. The notion of *risk path* is highly supported in this research through development of a scenario-based checklist including various causalities among different possible risks throughout different stages of the project. An example of risk paths identified in this study is given in figure 2.4.



Condition of host country & owner

Source group		Event group		
Upper	Lower	Upper	Lower	Specific
Owner condition	Insufficient management ability of owner	Inefficient administration	Delayed schedule	...
	Fairness of owner	Ill-disposed attitude of owner	...	...
	....	Unreasonable requirements of owner	Excessive burden by owner's requirements	
Condition of host country	Instability of social situation	Delayed permission	...	...
		Delayed custom entry	...	...

Figure 2.4: An example of Risk Paths identified by Han et al. (2008).

In their paper, Han and Diekmann (2004) argued that the available risk analysis methods are inadequate since they are not realistic reflections of complex nature of existing risks in international construction projects. They propose the utilization of Cross Impact Analysis (CIA) method as an appropriate technique for analyzing the conditional probabilities of occurrence of various interrelated risk variables affecting project cost. Figure 2.5 shows the causal relationships among factors and the strengths of the assumed cross impacts.

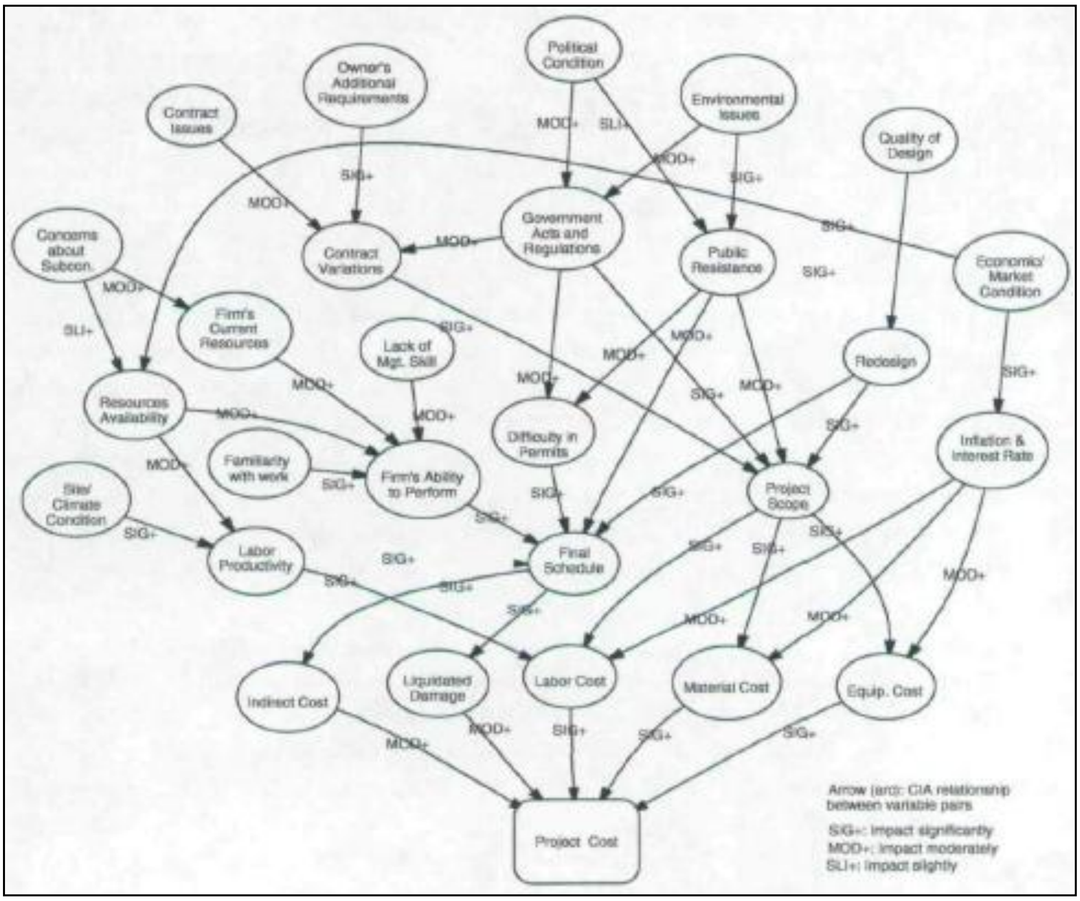


Figure 2.5: The developed CIA Model showing the interactions and cross impacts among Risk Variables assumed by Han and Diekmann (2004).

CHAPTER 3

STRUCTURE OF THE RISK-PATH MODEL

In this chapter, overall rationale of the research project and the general framework based on which the Risk-Path Model is developed are described through four main sections. In the first section, general risk-path structure which is developed in previous stages of this research project, and forms the foundation of further studies, is briefly introduced. Second section is allocated to a brief explanation of risk related concepts which are going to be included in identified risk paths and in developed Risk-Path Model. In section three, the conceptual framework of Risk-Path Model, which shows the rationale traced for development of the model, is described. Finally, in fourth section of this chapter, utilized vulnerability and risk variables, developed questionnaire, and data collected for analyze purposes are explained.

3.1 Generic Risk-Vulnerability Structure of the Research

Various case studies conducted, and causal maps drawn in previous stages of this research (i.e. Dikmen et al., 2009) proved the existence of various cause-effect relations among different vulnerabilities, risk factors, risk events, and consequences in real construction projects. Therefore, within the context of this research, risk paths are assumed to be identified instead of hierarchical checklists of independent risks. Moreover, it is considered that different internal fragilities of any system (vulnerabilities) affect different stages of the risk realization process. Some kinds of vulnerabilities affect the probability of occurrence of subsequent risk sources. For example complexity of the project design enhances the likelihood of adverse change in performance of the contractor. Some of the vulnerabilities have influences on manageability level of the occurred risk events. For instance, adverse change in market availability may have less impact on project schedule if the contractor has necessary managerial capabilities. Other kinds of vulnerabilities influence the magnitude of the impacts of risk factors on project objectives. These are vulnerabilities arise from factors such as project type, and delivery or payment method. The generic structure of this research project (Figure 3.1), comprising of assumed causalities among risk and vulnerability factors, has been formed based on this explained rationale (for more detailed explanations please refer to Dikmen et al. (2009)).

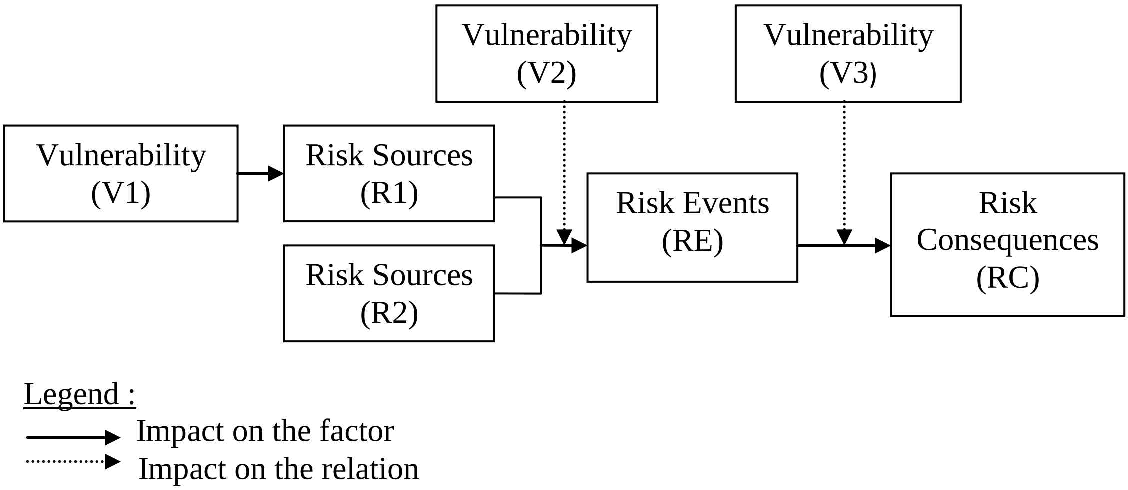


Figure 3.1: Generic Vulnerability-Risk Path Structure suggested by Dikmen et al. (2009)

3.2 Risk-Related Concepts Used in Risk-Path Model

In order to elucidate the rationale for development of the Risk-Path Model, a brief description of utilized risk concepts is necessary.

3.2.1 Definition of Vulnerability Sources

The concept of vulnerability has been highly considered within the economic, sociology, and management literature. Chambers (2006) defines vulnerability as “defenselessness, insecurity and exposure to risk, shocks and stress”. Agarwal and Blocky (2007) consider vulnerabilities as hazards which are internal to the system. Vulnerabilities of a system represent its innate characteristics and capacities, the existence of which creates possibilities for future harms and their subsequent consequences (Zhang, 2007; Barber, 2005, and Sarewitz et al., 2003). Unfavorable rules, structures, routines, cultures, actions, or conditions surrounding a system will increase its risk exposure. The extent to which a system is vulnerable to potential risks, determines the type and magnitude of this future consequences. In other words, vulnerability factors are the influence of the environment on the potential risk events.

Although occurrence of risks in construction industry is a matter of fact rather than exception, some firm and project-specific features will influence the impact of risk events in the case of their occurrence (Khattab et al., 2007). Zhang (2007) stated that project system, or its innate vulnerabilities, have mediating effects on the relationships among risk events and their consequences. Vulnerabilities of a system determine the degree to which it is susceptible to unfavorable impacts of occurred changes (Brook, 2003).

In this study, it is hypothesized that the vulnerabilities inherent in the project environment will provide occasions for the initiation of possible risk paths. Therefore, the first level of possible risk sources, and probably their magnitudes, will be predicted according to the types and sizes of related vulnerabilities.

3.2.2 Definition of Risk Sources

The notion of “risk” is an abstract concept having various connotations for different people (Al-Bahar and Crandall, 1990; Baloi and Price, 2003; Skorupka, 2008; Edwards et al., 2009). One of the widely referred definitions is the one recommended by Australian Standard AS 4360 (2004) which explains risk as “*the chance of* *something happening that will have an impact upon objectives*". In the case of construction industry, risk can be defined as likelihood of occurrence of unfavorable and uncertain events or combination of them throughout the life cycle of the project which will affect project objectives (Faber, 1979; PMBoK, 2000; Wang et al., 2004).

Within the context of this research, risk sources are studied under two main categories with the aim of covering all possible risks that may affect cost performance of international projects: "unexpected situations" and "adverse changes".

Unexpected situations are unforeseen events that will either occur or not. Since they are unpredictable (Smith et al., 2006), risk paths comprising such unexpected risks won't derive from any vulnerability or risk sources. That is, no factor will influence the possibility of their occurrence, but if they occur, they will affect cost performance of the project. An example of such risk sources is "natural catastrophe".

Adverse changes imply unfavorable alterations from the initially predicted conditions, such as "adverse changes in country economic condition". Since the existence of susceptibilities in some phases of the system increases the possibility of such unfavorable variations, the risk paths passing through these types of risk sources are assumed to initiate from some related vulnerability sources.

3.2.3 Definition of Risk Events

Al-Bahar and Crandall (1990) defines risk event as "what might happen to the detriment or in favor of the project". However, generally, risk event is considered as the occurrence of a negative happening (Australian Standard AS 4360, 2004). The ultimate aim of the risk management process is to minimize the consequences of probable risk events.

Different risk sources will impact the project objectives via occurrence of some risk events. Risk events in this research are described as variations (increase or decrease) in performance indicators such as quality, quantity, productivity, time, etc, and in the identified risk paths, act as mediators between risk sources and project cost overrun.

3.2.4 Definition of Risk Consequences

"Project risks tend to be consequence-based concepts" (Zhang, 2007). According to the international standard "Project risk management-Application guidelines" (IEC, 2001), risk is a combination of probability of occurrence of an event and its consequences on predetermined objectives. Within the literature, risk consequences are generally defined as undesired impacts (variations) of risk factors on project's preferred objectives such as cost, time, quality, client satisfaction, and safety (Al-Bahar and Crandall, 1990; Ward, 1999; Tah and Carr, 2000, etc.). Risk consequences are the outcomes of the risk events happening (Al-Bahar and Crandall, 1990).

Within the context of this study, the effects of various risk path scenarios on only cost performance of the project are examined since the negotiation process which will be simulated in forthcoming stages of this research project will be only based on cost sharing among project parties.

3.3 Conceptual Framework of Risk-Path Model

As mentioned in previous sections, major hypothesizes of this study can be summarized as;

1) Existence of interactive risk-path scenarios rather than individual risk sources
2) Generation of these risk paths from vulnerability sources inherent in project environment

Therefore, the Risk-Path Model which is going to be developed in this study will be in the form of a risk network consisting of various interactive risk-path scenarios each of which deriving from one or more system vulnerability sources. Existence of vulnerability factors will lead to occurrence of possible adverse changes in initial preferred conditions. These kinds of unfavorable variations may result in occurrence of risk events which are alterations of performance indicators. All risk events will affect different project objectives (project cost performance in this study).

According to the binding contract among client and the contractor, the raised risk sources are either under the responsibility of contractor, client, or shared among parties due to the derivation. Examining project risks in the form of risk-path scenarios facilitates tracking of their occurrence pattern, and hence, provides project parties with necessary argumentations for determination of risk sharing.

Some of the occurred scenarios can be controlled by responsible party, but some are not controllable and their impacts should be compensated via appropriate strategies. Having accurate perception about the way risks happen will result in proactive and effective responses for controlling them, and for management of their impacts.

Figure 3.2 illustrates the conceptual framework based on these considerations, which encompasses the identification of possible risk paths and structure of Risk-Path Model.

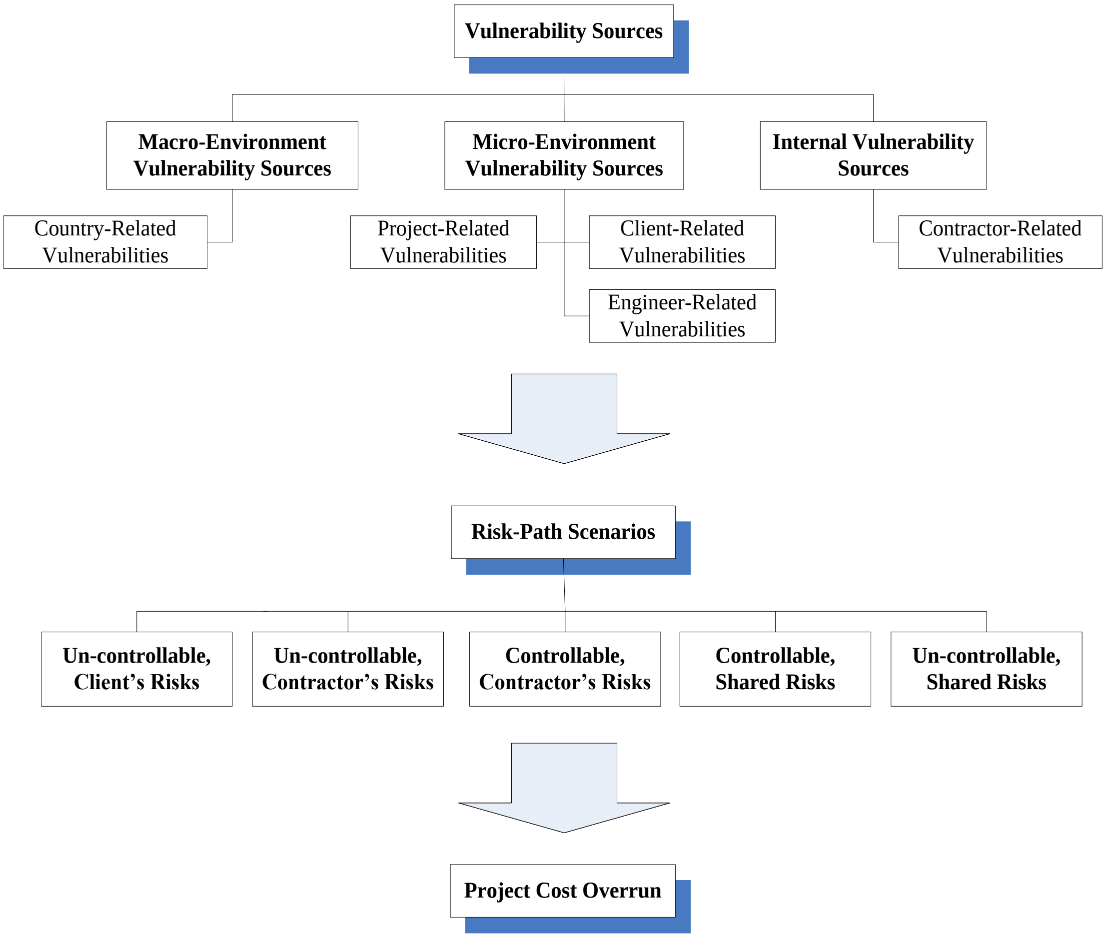


Figure 3.2: Conceptual Framework of Risk-Path Model

3.4 Review of Variables and Data Collection

3.4.1 Research Variables

The vulnerability and risk variables documented in an ontology-based database, the generality and completeness of which are validated in previous phases of this research project (i.e. Fidan et al., 2010), are used for development of the Risk-Path Model. Figure 3.3 summarizes the previous steps of the research project through which the Risk-Path Model's variables and data utilized for path analysis are acquired.

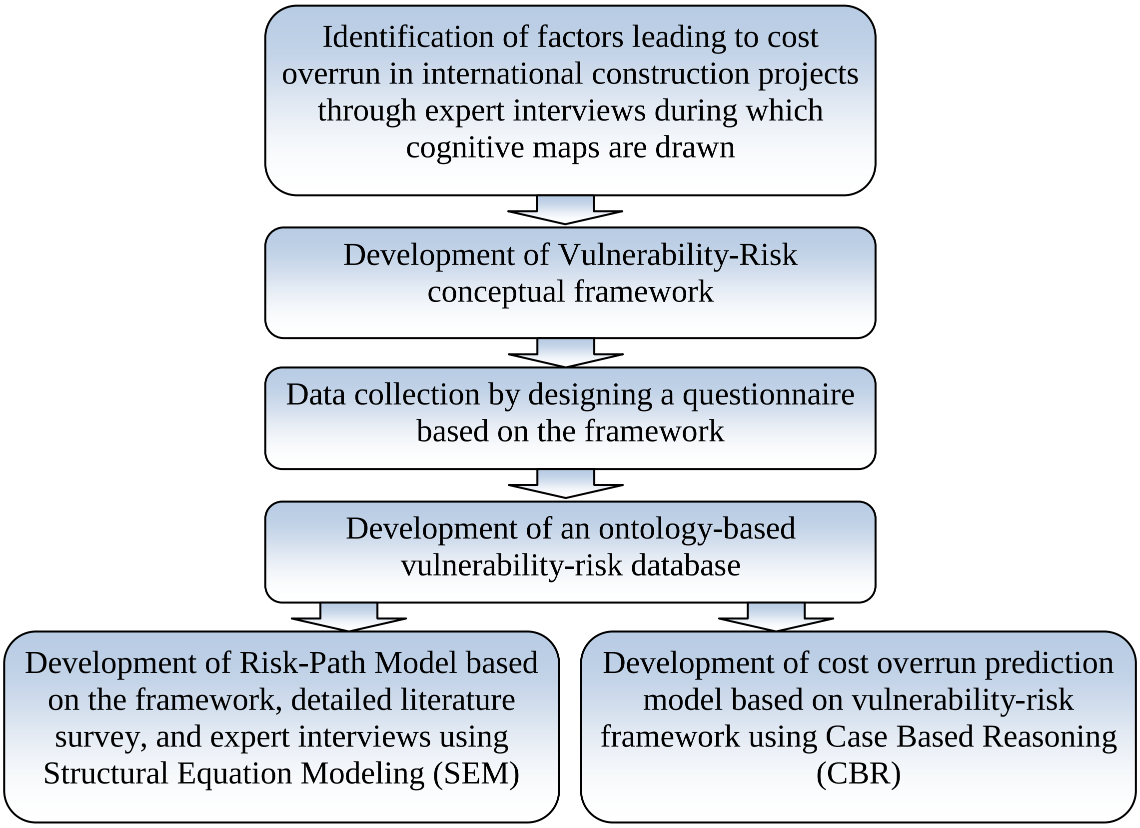


Figure 3.3: Previous steps of the research project

In this study, as also illustrated in figure 3.2, vulnerability variables are grouped under four categories in order to cover the influence of project environment on risk realization process of international construction projects:

1) Host Country-related vulnerabilities,

2) Project-related vulnerabilities,

3) Contractor-related vulnerabilities,

4) Project Participants-related vulnerabilities.

Risk related variables are also selected accordingly so as to cover possible risks related to the same categories. Table 3.1 summarizes the list of 82 variables, comprising of 51 vulnerabilities, 21 adverse changes, 3 unexpected events, 6 risk events, and one risk consequence used as observed variables for development of SEM-based Risk-Path Model.

Table 3.1: Risk and Vulnerability variables used for Risk-Path Model development

Type	No	Observed Variables
Vulnerability (1)	1	Instability of Economic Condition
	2	Instability of Government
	3	Instability of International Relations
	4	Social unrest
	5	High Level of Bureaucracy
	6	Immaturity of Legal System
	7	Restrictions for Foreign Companies
	8	Unavailability of Local Material
	9	Unavailability of Equipment
	10	Unavailability of Local Labor
	11	Unavailability of Local Subcontractors
	12	Unavailability of Infrastructure
	13	Poor/Incomplete Design
	14	Design Errors
	15	Complexity of Design
	16	Low Constructability
	17	Complexity of Construction Method
	18	Uncertainty of Geotechnical Condition
	19	Strict Quality Requirements
	20	Strict Environmental Regulations
	21	Strict Health & Safety Regulations
	22	Strict Project Management Requirements
	23	Vagueness of Contract Clauses
	24	Contractual Errors
	25	Technical Incompetency of Engineer
	26	Managerial Incompetency of Engineer
	27	Engineer’s Lack of Financial Resources
	28	Client’s Unclarity of Objectives
	29	Client’s High Level of Bureaucracy
	30	Client’s Negative Attitude
	31	Client’s Poor Staff Profile
	32	Client’s Lack of Financial Resources
	33	Client’s Technical Incompetency
	34	Client’s Poor Managerial/ Organizational Abilities

Table 3.1: Risk and Vulnerability variables used for Risk-Path Model development (Continued)

Type	No	Observed Variables
V (1)	35	Poor Site Supervision
	36	Lack of Site Facilities
Vulnerability (2)	37	Contractor's Lack of Experience in Similar Projects
	38	Contractor's Lack of Experience in the Country
	39	Contractor's Lack of Experience about the project delivery System
	40	Contractor's Lack of Experience with Client
	41	Contractor's Lack of Financial Resources
	42	Contractor's Lack of Technical Resources
	43	Contractor's Lack of Staff
	44	Poor Project Scope Management
	45	Poor Project Time Management
	46	Poor Project Cost Management
	47	Poor Project Quality Management
	48	Poor Human Resources Management
	49	Poor Communication Management
	50	Poor Project Risk Management
	51	Poor Procurement Management
Risk Sources (R1) (Adverse Changes)	52	Changes in Currency Rate
	53	Change in Economic Indicators
	54	Change in Taxation Policies
	55	Change in Laws & Regulations
	56	Conflicts with Government
	57	Conflicts with Engineer
	58	Conflicts with Client
	59	Poor Public Relations
	60	Change in Performance of Client Representative
	61	Change in Client's Staff/Organization
	62	Change in Financial Situation of Client
	63	Scope Changes
	64	Design Changes
	65	Change in Site/Project Organization
	66	Change in Functional Performance of Contractor
	67	Change in Availability of Labor
	68	Change in Availability of Material
	69	Change in Availability of Equipment
	70	Change in Availability of Subcontractors
	71	Change in Geological Conditions
	72	Change in Site Conditions

Table 3.1: Risk and Vulnerability variables used for Risk-Path Model development (Continued)

Type	No	Observed Variables
Risk Sources (R2) (Unexpected Events)	73	War/ Hostilities
	74	Rebellion/ Terrorism
	75	Natural Catastrophes
Risk Events	76	Delays/Interruptions
	77	Decrease in Productivity
	78	Increase in Amount of Work
	79	Decrease in Quality of Work
	80	Increase in Unit Cost of Work
	81	Lags in Cash Flow
Risk Consequence	82	Cost Overrun

3.4.2 Research Data

A questionnaire form was developed, consisting of five main sections including firm and project specific information, importance weights of various vulnerability sources in terms of their effects on cost performance of any project, and the sizes of various vulnerability and risk related concepts for a previously realized construction project. A 5 scale rating system is used for this purpose: Very High (5), High (4), Medium (3), Low (2), and Very Low (1).

A total number of 166 distinct international construction projects conducted by Turkish contractors in foreign countries were accrued to form the required data for SEM analysis. Industry practitioners with minimum of ten years experience in managerial and executive positions in international projects were interviewed, either through face-to-face meetings with the researchers, or via e-mail. Before answering questions, respondents were given a few minutes presentation about the vulnerability and risk concepts, and about the ultimate purpose of the research, in order to make sure that all of them possess the same perceptions about the concepts and to reduce the misunderstandings.

Project characteristics such as types, regions, sizes and range of cost overrun are presented in Table 3.2. For analysis purposes, cost overrun percentages were converted to a 5 scale system. The ranges selected for this purpose are shown in Table 3.3. (For more detailed information about the questionnaires' structure and data collection process, please refer to Çelenligil (2010)).

Table 3.2: Characteristics of projects identified via interviews

Feature	**Category**	**Number of Projects**
Project Type	Building (shopping malls, hospitals, etc.)	28
	Coastal structure (harbor, breakwater etc.)	7
	Dam	16
	Energy (nuclear, hydroelectric plants, etc.)	9
	Housing	8
	Industrial plant (chemical, refinery, factories, etc.)	26
	Infrastructure	20
	Pipeline (petroleum, natural gas)	7
	Transportation	30
	Other	15
Region	Asia	75
	Africa	47
	Europe	44
Project Size	Smaller than 100 million USD	92
	Greater than 100 million USD	74
Actual Cost Overrun	Smaller than 50%	125
	Between 50 to 100%	26
	Greater than 100%	15
Contract Type	FIDIC	90
	Local contract	76
Project Delivery System	Turnkey	101
	Traditional(Design Bid Build)	47
	Engineering, Procurement, Construction (EPC)	6
	Build Operate Transfer (BOT)	12
Payment Type	Cost plus fee	9
	Lump sum	80
	Unit price	71
	Combination of lump-sum and unit price	6
Company Role in the Project	Member of a consortium	24
	Member of a joint venture	32
	Sole contractor	92
	Subcontractor	18

Table 3.3: Equivalent scales of Cost Overrun Percentages

Scale	**Range of Cost Overrun Percentage**
Very Low (1)	Actual Overrun ≤ 20%
Low (2)	20% < Actual Overrun ≤ 40%
Medium (3)	40% < Actual Overrun ≤ 60%
High (4)	60% < Actual Overrun ≤ 80%
Very High (5)	80% < Actual Overrun

CHAPTER 4

RESEARCH METHODOLOGY

One of the substantial “*non-technical evaluative issues*” recommended by Schreiber et al. (2006) to be addressed in SEM-based studies is a brief explanation and rationale of the SEM to be addressed in the method section of the manuscript.

In this chapter, with the aim of satisfying such issues, brief descriptions of Structural Equation Modeling technique and its specific features are introduced through six sections. In these sections, a general introduction of SEM and the underlying theory is given, its advantages over other comparable statistical techniques used for identification purposes are summarized, necessary terminologies and model components are defined, the sequential steps for development of a SEM model are described, previous applications of SEM in construction literature are overviewed, and finally some features of the software package utilized in this study are listed.

4.1 Basic Theory

Structural Equation Modeling (SEM) is one of the most suitable techniques for analyzing the complex interactions among meaningful factors. Bentler (2006) considers SEM as an important methodology which can be utilized for description of the possible interrelationships among variables, for testing the hypothesis, and for estimation purposes. SEM is a collection of statistical techniques, such as confirmatory factor analysis, path analysis, and multiple regression analysis, used to estimate the direct and indirect interrelations among variables, and at the same time, to confirm the underlying structure among observed and latent factors (Hair et al., 1998; Byrne, 2006, and Ullman, 2006). SEM is mostly considered as a confirmatory technique although it can be used for exploratory purposes (Schreiber et al., 2006, and Garson, 2008).

Moreover, SEM is usually used for testing the hypotheses about possible causalities (Bentler, 2006). Biddle and Marlin (1987) mentioned SEM as a "*technique that is suggested for improving our ability to make causal inferences from field-study data*".

Therefore, SEM is selected as the most appropriate methodology fitting to the main objective of this study being the identification and analysis of the causalities among diverse system vulnerabilities and risk factors.

Within the literature, SEM is also referred to as Causal Modeling, Causal Analysis, Simultaneous Equation Modeling, Analysis of Covariance Structures, Path Analysis, and Confirmatory Factor Analysis (CFA).

4.2 Superiority of SEM over Other Comparable Methods

Although the building block of SEM is ordinary multiple regression equations (Bentler, 2006), it has obvious superiorities over simple regression techniques or other alternative methods.

1) SEM encourages confirmatory rather than exploratory or descriptive approach for data analysis. This enables the evaluation of hypotheses. Various fit indexes and validity/reliability tests are available for examining the compatibility of the developed models and assumed relationships with the sample data. (Schreiber et al., 2006; Ullman, 2006; Byrne, 2006, and Garson, 2008)

2) In contrast to ordinary regression methods, SEM takes into consideration the possible errors in measurement of observed variables. The assumption of perfect measurement of variables is not a realistic approach and as Byrne (2006) and Ullman (2006) emphasize may affect the reliability of analysis and lead to serious inaccuracies, especially when errors are fairly large.

Measurement errors can increase model error variance, and lead to biased estimates (Myers, 1990, and Greene, 1990). This shortcoming of alternative methods is eliminated in SEM to take the effects of poorly measured data into account (Bentler, 2006).

3) SEM provides the researchers with the possibility of studying problems which are neither observable nor quantifiable through the concept of *latent factors*. SEM allows testing of hypothesis at the construct level with adequate accuracy. That is, while other methods deal only with measured observed variables, SEM enables creation and estimation of latent factors underlying the indicator observed variables, and also examination of their interrelationships (Jackson et al., 2005; Ullman, 2006; Bentler, 2006; Byrne, 2006, and Garson, 2008).

4) SEM enables the analysis of highly complex models containing diverse types of relations and high number of variables. Direct and indirect causal effects and covariances among variables can be investigated instead of studying all variables under the same unique level. That is, dependent variables can also act as the predictors of other variables. Other comparable statistic methods allow for more limited number of hypothesis to be evaluated. (Biddle and Marlin, 1987; Byrne, 2006, and Bentler, 2006).

5) "Testing of model adequacy, parameter estimation, and comparison of nested models are questions that are adequately addressed in SEM" (Kaplan, 2009).

4.3 Conceptual Features

4.3.1 Terminology

Path Diagrams **:** Path diagrams are visual representation of assumed and analyzed Structural Equation Models. Although they are not necessary for SEM analysis, authors such as Ullman (2006) consider them essential for clarification of the research theory and the hypothesized relationships. Drawn paths should exactly correspond to the equations included in analysis.

***Observed Variables* :** Observed variables are also referred as; *measured variables, manifest variables,* and *indicators*. They are tangible variables for which data can be acquired. Conventionally, observed variables are shown via rectangles in drawn path diagrams.

***Latent Factors* :** One of the advantages of SEM over other techniques is the concept of latent factors used to indicate intangible concepts which cannot be measured directly. The magnitudes of such factors are measured through the hypothesized effects of observed variables indicating them. Latent factors are also mentioned as *factors,* or *constructs,* and in path diagrams, are conventionally depicted with circles or ovals.

***Exogenous Variables* :** Are also referred as *Independent Variables*. These variables are not structurally regressed on other variables. That is, they have effects on other variables (are causes of other variables) but are not affected by other constructs (Schreiber et al., 2006, and Kline, 2005). The exogenous constructs are not indicated by any causal (one-way) arrow though they can be correlated with other independent variables depicted with two-way arrows. The exogenous variables are the elements of the vector variable which is conventionally indicated by ξ (“ksi”) (Garson, 2008, and Bentler, 2006).

***Endogenous Variables*:** Are also referred as *Dependent Variables* and *Mediating Variables*. These variables can be defined through the regression of other variables. They are influenced by either independent variables or other dependent variables and can have effects on other endogenous variables in the model (Schreiber et al., 2006, and Kline, 2005). The magnitude of these variables can be estimated via the sizes of their influencing variables; however, these dependent variables can’t be correlated with each other through two-headed arrows. The endogenous variables are the elements of the column vector variable which is conventionally indicated by η (“eta”) (Garson, 2008, and Bentler, 2006).

***Standardized Path Coefficients*:** Standardized estimates are used when not all variables have interpretable metrics, or when the measurement units of model variables differ from each other; for example, when the cause factor is measured by “day” units and the effect factor is measured by “dollars”. Some SEM-based software packages provide the standardized solutions in which all variables are standardized to have unit variances with mean of zero. Estimated standardized path coefficient among two factors (also noted as *“Standardized Structural Coefficients”*) shows the number of standard units that dependent factor will increases due to each unit increase in its influencing factor (Garson, 2008, and Bentler, 2006).

Figure 4.1 shows the general representation (suggested by Byrne (2006)) of a SEM model in EQS, the software which is used in this study for analysis purposes.

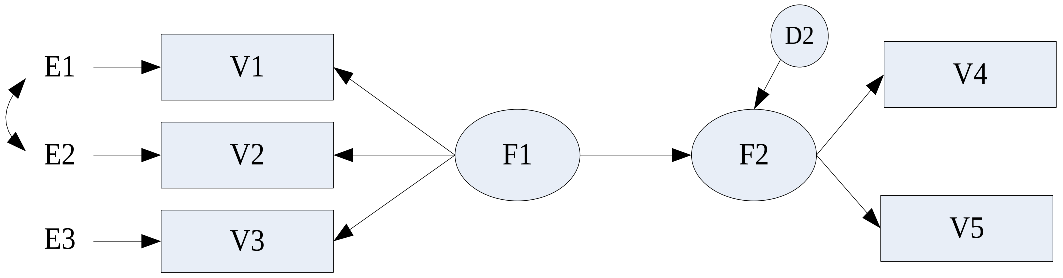


Figure 4.1: A general EQS Structural Equation Model suggested by Byrne (2006)

<u>**Figure Legend**</u>**:**

Vi: Observed (measured) Variables

Fi: Latent Factors

Ei: Random Measurement Errors of Observed Variables

D2: Errors in Prediction of F2

⟶ : Causality

↕ : Correlation or Covariance among Pairs of Independent Variables

4.3.2 Components of SEM Models

The analysis process of Structural Equation Models starts with the development of a hypothesized conceptual model based on the underlying theory. This model will illustrate all hypothesized relationships between observed variables and latent factors. The conceptual model will consist of two main parts, namely ***measurement model*** and ***construct model***.

The measurement model (also called "*Factor Analytic Measurement Model"* and *"Confirmatory Factor Analysis Model"*) shows the hypothesized relations between the observed measured variables and the latent factors to which they indicate, and will be tested through Confirmatory Factor Analysis (CFA). In CFA, in contrast to Exploratory Factor Analysis (EFA), researcher has a strong knowledge about the structure of the variables and the hypotheses about these structures are tested statistically. The fit degree of a measurement model indicates the extent to which it's exogenous observed indicators measure the latent factor.

The construct model (also called "*Simultaneous Equation Model"* and *Structural Model"*) shows the assumed causal relations among latent factors (or possibly measured variables). The hypothesized construct models are also tested statistically and the path coefficients, which indicate the strength of the assumed relations, are estimated. It is the structural component of the SEM model which allows for representation of the research theory about the relationships between different concepts.

In order to test the extent to which the entire model describes the actual data, both hypothesized measurement and construct models are tested simultaneously via various fit indexes and validation tests. However, it is noteworthy that the reported indexes are only representatives of statistical fits, and the theoretical appropriateness of the model should be verified by researcher. A highly fitted model is accepted only if it is theoretically logical (Molenaar et al., 2000; Byrne, 2006; Bentler, 2006, and Schreiber et al., 2006).

4.4 Development Process of a Structural Equation Model

Authors such as Jackson (2005) and Ullman (2006) have defined the processes of modeling as five subsequent steps which are briefly described in this section:

1) **Specification of the model:** It is the first step of the model development process which can be studied under three sub-steps.

   Firstly, the conceptual model consisting of hypothesized relationships should be specified based on the underlying theory, and the corresponding equations and diagrams should be drawn. This step may be the fundamental part of the research, since the research's theory is developed in this step. As Bentler (2006) also mentioned, it is up to researcher to ensure that the research questions are adequately answered by SEM, that the hypotheses are theoretically reasonable, that all major theoretically possible relations are addressed, and that the data are reliable and collected for this specific purpose. A highly fitted model which is not adequately supported by theory is by no mean meaningful.

   If diagrams are going to be drawn, it must exactly correspond to the hypothesized relations and developed equations.

   Secondly, the developed model should be statistically identified. According to the method that is used for model specification, the equations representing the assumed relations are generated and utilized for model estimation. In Bentler-Weeks method (Bentler and Weeks, 1980) which is applied in EQS 6.1 (the SEM-based software package that is used in this study), all the variables are considered either Independent (IV) or Dependent (DV). Every DV is defined by one regression-like equation comprising of all variables indicating it along with a residual variable (Bentler, 2006). Residuals are one of the indicators of any DV, therefore, they are also considered as IV. One of the general representations of such regression-like equations is as follows where Y stands for the DV, X_i for indicator IVs, *e* for the residual, and β_i for the predicted coefficients which are also named as *parameters* of the model.

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots.. + \beta_n X_n + e$$

The Bentler-Weeks model consists of various such equations relating IVs to DVs resulting in series of matrices as illustrated following equation:

$$\eta = \beta \,.\, \eta + \gamma \,.\, \xi$$

Where, q being the number of DVs and r being the number of IVs in the model, η is a qx1 vector of DVs, β is a qxq matrix of estimated regression parameters (path coefficients) between DVs, γ is a qxr matrix of estimated regression parameters (path coefficients) between DVs and IVs, and ξ is the rx1 vector of IVs. In the Bentler-Weeks models, the variances and covariances of the IVs (reported in a rxr matrix named $\boldsymbol{\phi}$) are estimated through analysis; therefore, the parameter matrices estimated by packages such as EQS 6.1 employing the Bentler-Weeks method are β, γ, and $\boldsymbol{\phi}$.

Third, the specified model's identification is tested in order to make sure that it can be estimated. After development of the theory and selection of the appropriate data fitting to the research rationale, deciding on whether the model is identified or not is one of the main difficulties in practices (Bentler, 2006). When there is unique numerical solution for the specified model, it is considered as identified. The number of model parameters and available data points are obtained as summarized below:

- *Number of Model Parameters to be Estimated* = Number of Regression Coefficients + Number of Variances (Number of error terms and IVs) + Number of Variable Covariances (Number of covariation among IVs)

- *Data Points* = Number of Variances and Covariances of Observed Variables
  = $P.\ (P+1)/2$
  (P: Number of Observed Variables)

- *Degrees of Freedom* = Data Point - Parameters

Generally, if the number of the parameters of the model is more than the available data points, the specified model is *under-identified*. In this case the model parameters can't be estimated since the number of unknowns exceeds the number of equations. A model with parameters equal to data points is *just-*

identified one. The degrees of freedom in a *just-identified* model are zero, and hence, the entire model can't be tested. The preferred case is the one that possesses positive degrees of freedom, that is, when number of unknown parameters is less than the known data points and the model is *over-identified*. In order to increase the chance of model identification, it is effective to increase the number of observed variables, or decrease the number of parameters through fixing more certain parameters to some specific values, or deletion of some of the less important ones, of course only if this is consistent with the research theory and face validity (Garson, 2008). It is notable that increasing the sample size has no effect on degrees of freedom (Jackson et al., 2005).

For more detailed explanation of this step please refer to Bollen (1989), Bentler (2006), and Ullman (2006).

2) **Estimation of the model:** As the model is specified, the parameters should be estimated using appropriate estimation method. SEM-based software packages offer a number of estimation methods each of which addressing specific features. Some of the most popular ones are briefly described below:

   Maximum Likelihood (ML): is the default method for lots of programs such as EQS. ML estimates the parameters based on maximizing the probability that the observed covariances are the same as the estimated ones in the hypothesized model. The estimated parameters with highest probability of reproducing observed data are selected by ML. This method is suitable for multivariate normally distributed data. It predicts parameters with smaller standard errors, especially in large sample models. According to Garson (2008), this method should be used for SEM model estimation unless acceptable reasons exist.

   Generalized Least Squares (GLS): This method is the second most-common method of normal theory after ML. It has similar features like ML and in Large samples may show better results for even non-normal data; however, there are cases that GLS does not reproduce variables adequately where ML shows perfect results. The Least Square criterion forms the basis for estimation process of this method; however, unlike multiple regressions, all parameters are estimated simultaneously. Multivariate normality and zero kurtosis are major assumptions of this method (Bentler, 2006; Garson, 2008; Kline, 2005). Kline (2005) considers less computation time and less computer memory as some of advantages of GLS over ML.

Asymptotically Distribution-Free (ADF): Also named as *Optimal Minimum Distance* by some authors. Brown (1982) and Chamberlain (1982) were the first developers of this method. It is a large-sample and small-variable method, but it has no distribution assumption, and therefore, is more general than other methods. In other words, this method can be utilized for estimation purposes if the sample data violates the multivariate normality criterion (Brown, 1982; Bentler, 2006; Ullman, 2006, and Garson, 2008).

Other Methods: The *Residual-Based Tests* methodologies developed by Yuan and Bentler (1998) and the *Satorra-Bentler* methodology developed by Satorra and Bentler (1994 and 2001) are two other estimation methods which are adequately adjusted for non-normality and result in accurate predictions in non-normal distributed data. Offered by EQS program, these methods can be applied to other methods such as ML and GLS.

3) **Evaluation of the model:** After the model is estimated and the hypothesized relations are analyzed, the fit of the model to the sample data should be evaluated. This process is conducted through various fit indexes offered by SEM-based programs. Fit indexes demonstrate overall fit of the model, not a specific path’s significance. Interpretations about the path coefficients and their meanings should be done after accepting the whole model as an adequate match to data. Different fit indexes address different characteristics of the models fit (Sivo et al., 2006); therefore, in order for a comprehensive evaluation of the model, an adequate list of fit indexes should be selected to cover important aspects of the model. Jaccard and Wan (1996) recommended consideration of at least three fit indexes for adequate fit tests, whereas Kline (1998) suggested at least four tests to be required. Vast numbers of fit indexes are reported by different SEM-based software some of most well known and mostly used ones are briefly introduced here;

Discrepancy Function or Model Chi-Square ($\chi 2$): Chi-Square is the most commonly reported fit index. It is one of the badness-of-fit measures whose insignificant value indicates higher fit of the model. It compares the hypothesized model's covariance structure with the observed covariance matrix to check the extent to which they are different. Chi-square checks whether the over-identified model with positive degrees of freedom fits worse than if it was just identified with zero degrees of freedom. This index is highly sensitive to sample size since in large samples even small deviations may be statistically significant. It is generally agreed that P value for the reported $\chi 2$ which are smaller than 0.05 are indicators of adequate model fits. (Jackson et al., 2005, and Garson, 2008)

Relative Chi-Square: One common approach for mitigating the dependency of the $\chi 2$ to the size of the sample data is to divide it by model's degrees of freedom (DF). Various thresholds have been suggested most of which are based on experiences and rules of thumb. The values less than 2 are considered as good fit indicators by Ullman (2001). Authors like Jashapara (2003), and Kline (1998), consider ratios equal or less than 3 as acceptable fit values. Authors such as Schumacker and Lomax (2004) take the range as wide as 5 to address adequate model fit. Jackson et al. (2005) stated that ratios less than 2 are indicators of well-fitted models, values less than 3 belong to acceptable fitted models, and values greater than 5 indicate that the model is definitely not acceptable.

Jöreskog-Sörbom Goodness of Fit Index (GFI): This index determines the proportion of the observed covariance which is explained by the hypothesized model's covariance. GFI is estimated through the following equation;

GFI = 1 - (chi-square for the default model / chi square for the null model)

This index is sensitive to sample size as for large samples it is usually overestimated. GFI values vary from 0 to 1with 1 indicating perfect fit of the model. Meaningless negative values can also be estimated in some cases. (Jackson et al., 2005, and Garson, 2008)

Root Mean Error of Approximation (RMSEA): This index checks the average discrepancy between observed and predicted covariances. That is, it gives the absolute value for the covariance residuals. This index checks the lack of the model fit when compared to saturated or perfect model. Therefore, RMSEA is also a *badness-of-fit* index whose lower bound is zero. The lower the value of RMSEA, the lower differences among observed and hypothesized covariances, and hence, the better the model fit. Although RMSEA has no upper bound, there are various rules of thumb for its preferred values. For example, Jackson et al. (2005) considers values less than 0.05 as indicators of adequate fits. Authors such as Chou and Bentler (1990), Bollen and Long (1992), and Brown and Cudeck (1993) have mentioned that models with RMSEA values equal or less than 0.1 are good fitted models. Since there exist no upper bound for RMSEA, values slightly greater than these thresholds do not necessarily indicate poor fits. RMSEA is less affected by sample size, so is an adequate measure for small samples. (Jackson et al., 2005, and Garson, 2008)

Bentler Comparative Fit Index (CFI): This index compares the hypothesized model with independence model in which no relationships exist among variables (model variables are uncorrelated), and checks the extent that the model fits the sample data better than the independent model. Its reported values also range from 0 to 1, with values closer to 1 indicating better fit. CFI is adequate index for estimation of model fits even in small samples (Hu and Bentler, 1999).

Bentler-Bonett Normed Fit Index (NFI): it is an alternative to CFI but it is more sensitive to sample size, so that, in small samples, it tends to under-estimate the model fit Ullman (2001). Moreover, this index is not adequately capable to reflect model's parsimony since it may be over-estimated in complex models with higher number of parameters (Garson, 2008). NFI is estimated through the following equation;

$$\text{NFI} = (\chi 2 \text{ for null model} - \chi 2 \text{ for hypothesized model}) \,/\, \chi 2 \text{ for null model}$$

Bentler-Bonett Non-Normed Fit Index (NNFI or TLI): NNFI is the adjusted form of NFI for model complexity. It is also less sensitive to, or even independent of (Marsh et al., 1988, and Marsh et al., 1996), sample size. Although its values may not range from 0 to 1, any reported value outside this range will be reset to 0 or 1 so as to values close to 1 reflect the perfect fit and 0 no fit. NNFI is estimated through the following equation;

$$\text{NNFI} = (\chi 2 \text{ for null model}/DF_n - \chi 2 \text{for hypothesized model}/DF_h) / (\chi 2 \text{ for null model}/DF_n - 1)$$

4) **Modification of the model:** Usually, the initially hypothesized model is not adequately fit to the collected data. The common practice is to explore a model which better matches the data through modifying the assumed relations, variables, or parameters. Although SEM is a confirmatory technique, the analysis becomes more exploratory throughout the modification step (Ullman, 2006, and Kline, 2005). Insignificant paths, poor fit indexes, and some reported modification indexes are all indicators for revision of the developed model. However, it is noteworthy that the conducted modifications should correspond to the underlying theory. It is up to the researcher to stick to the study's theory or empirical background when revising the relationships and variables. A highly fit model with meaningless relationships and variables is of no value. As Byrne (2006) also stated, researchers should not solely rely on fit indexes for assessment of the SEM models, but consider multiple criteria taking into account theoretical, statistical, and practical issues. Ullman (2006) have introduced three methods for model modification; 1) Chi-Square Difference, 2) Lagrange Multiplier, and 3) Wald Tests. One of the advantages of EQS over other available SEM-based software packages is that it offers both Lagrange and Wald tests for modification purposes. Through Lagrange Multiplier test, a list of possible parameters whose adding to the model will significantly improve the model fit is reported, along with the amounts of this improvement for each addition. The results of the Wald test, however, report the list of parameters, currently estimated in the model, which can be deleted without significantly reducing the fit of the model (Byrne, 2006, and Ullman, 2006).

5) **Reporting the results:** After achieving to a model which best fits the data and corresponds to research's theory and available related empirical knowledge, the results of all mentioned steps should be reported. Such reports should include both *nontechnical evaluative issues* such as research questions answered through

SEM analysis, and measurement and construct models' conceptual features, and *technical issues* like sample size, factors loadings, path diagrams, estimated path coefficients, significance level and other estimated statistics, results of various validity and reliability tests, direct and indirect effect decompositions of the factors on each other, etc. (Schreiber et al., 2006).

4.5 Application of SEM in Construction

Structural Equation Modeling is a widely applied technique in non-experimental research areas in which theory testing techniques are not well developed (Kline, 2005). Superiorities of SEM over other statistical techniques and the applicability of its assumptions have caused it to be widely used in IT, Psychology, Sociology, Medical, and Behavioral sciences.

However, lots of construction management issues are related with measurement of latent factors or observations with significant error ratios; therefore, SEM seems an appropriate technique can be applied in construction management context for development of *decision support systems*, *expert systems*, *risk analysis*, and *predictive models* (Molenaar et al., 2000). These factors may be the reasons for the rapidly increased popularity of the application of SEM in this context over the last decade.

For example, Molenaar et al. (2000) developed a SEM model for identification and quantification of factors that affect the dispute potential between project parties. They claim SEM to be a suitable approach for clarifying the relationships among unobservable factors such as management ability of project parties and dispute potential. Mohamed (2003), Ozorhan et al. (2007), and Ozorhan et al. (2008) utilized SEM for testing and analyzing the hypothesized relationships between various factors that may affect performance of international joint venture. Cheung et al. (2009) have utilized SEM to confirm three construct models explored for three dimensions of negotiation, namely “Dispute Sources”, “Negotiator Tactics”, and “Negotiation Outcomes”. The ultimate aim of their research is to examine the conditional application of negotiation tactics with respect to negotiation outcomes and sources of the disputes. The work conducted by Kim et al. (2009) is one of the most recent SEM-based researches within the context of construction management. In this paper, they have compared the applicability and suitability of SEM with regression analysis and artificial neural network methods in terms of predicting the performance of any international project. They conclude that SEM is more appropriate for this purpose since it allows for more systematic and complex modeling of influencing factors.

As further examples of application of SEM in construction industry it can also be referred to the works of Lin et al. (2005), Wong and Cheung (2005), Jugdev et al. (2007), Stewart (2007), Raymond and Bergeron (2008), Wong et al. (2008), Cho et al. (2009), Prasertrungruang and Hadikusumo (2009), Panuwatwanich et al. (2009), Wong et al. (2009), etc.

4.6 Utilized Software Package

Various SEM-based software packages are commercially available to support both confirmatory factor analysis and path analysis required for testing hypothesized structural equation models. As examples of such programs, LISREL, SIIMPLIS LISREL, AMOS, EQS, and SAS CALIS can be mentioned. EQS 6.1 is selected for analysis purposes of this study. Some of the most noteworthy superiorities of the EQS over other available programs are reported here referring to the works of Bentler (2006) and Byrne (2006);

- EQS reports several robust and residual-based test statistics which are the most accurate estimation methods when data are not normally distributed.

- EQS provides its users with two state-of-the-art methods for entering the input files of the SEM model; 1) building an input file interactively through using BUILD EQS, and 2) building an input file graphically through DIAGRAMMER.

- Various customization options are available in EQS to allow user-specific features.

- Due to high complexities associated with SEM models and utilized data, identifying occurred errors and their correction is highly difficult task that EQS is able to overcome sufficiently through providing diverse clues and error messages related to their location and correction.

- The standardized solutions offered by EQS differ from those of other programs like LISREL in that EQS produces completely standardized results in which all model variables (both measured and latent), error terms, and disturbances are standardized to unit variance.

- EQS provides simple solutions in dealing with outlier cases through its graphical versions. The program also automatically prints out five extreme cases in respect to multivariate kurtosis.

- EQS program is unique in provision of WALD test results for model modification purposes. The results of the WALD test offer the list of (if any) currently estimated parameters fixing of which to zero won’t lead to substantial loss in model fit.

- EQS is flexible in setting up non-FASEM (Factor Analytic Simultaneous Equation Model) model in which various types of paths such as V→V, V→F, and E→F are allowed.

- EQS is extremely user-friendly and facilitates following of the analysis processes

CHAPTER 5

DEVELOPMENT OF RISK-PATH MODEL

This chapter summarizes the development processes of the Risk-Path Model through two main sections. In the first section, steps for specification and validation of the hypothesized measurement models are described. Different processes required for development of the Risk-Path Construct Model, namely specification, estimation, evaluation, and model modification, are summarized in the second section through corresponding subsections. The results of each step are reported in tables and figures.

5.1 Development of Measurement Models

5.1.1 Specification of Measurement Models

The first step in constructing the Risk-Path Model is the development of measurement models which demonstrate the categorization of total of 82 observed vulnerability and risk related variables under the heading of latent factors that will form the building blocks of Risk-Path Model. In this study, the subsequently identified and analyzed risk-path scenarios will be obtained from the possible interactions among 28 measurement models which specify the way that observed vulnerability, risk source and risk event variables indicate their latent factors. The adequacy of the hypothesized measurement models is tested through Confirmatory Factor Analysis (CFA) offered by SEM-based software packages such as EQS 6.1 which is utilized in this study.

All the 28 latent factors of the Risk-Path Model are assumed so as to correspond to different factors forming the “generic vulnerability-risk path structure” (figure 3.1), namely Vulnerability 1, Vulnerability 2 (Manageability), Risk Source 1 (Adverse Changes), Risk Source 2 (Unexpected Events), Risk Events, Risk Consequence;

- Under the heading of the first type of vulnerabilities, which are believed to act as initiatives for occurrence of various adverse changes, a total number of 9 latent factors are formulated measured by 36 observed variables. All of the country related vulnerabilities are grouped under the same factor named as "Adverse Country-Related Conditions" since it was found that separating these variables as economic, regulation, or market condition will lead to problems such as some insignificant factor loadings, and insignificant causal paths derived from such latent factors in subsequently developed Risk-Path Construct Model. Other latent factors for this type of vulnerabilities were developed so as to cover project, engineer, and client-specific fragilities.

- A total of 3 measurement models are developed to cover the second type of the vulnerabilities which are believed to affect the manageability of the occurred risks. These factors represent the resilience in the contractor's experience, resources, and managerial capabilities. Such resilience sources are measured by 15 observed variables.

- The first group of the risk sources in this study, namely "Adverse Changes", is categorized so as to cover areas that may be affected by mentioned vulnerability sources. Adverse changes in country, project, project parties, and site-related conditions form the headings of the 8 latent factors which are represented by a total of 21 observed risk sources.

- Since the second groups of the risk sources, namely unexpected events, are commonly less frequently seen than other risk sources, not most of the projects in the sample data contained information related to them. Hence, although various unexpected situations were initially considered, only 3 mostly observed variables, namely War/Hostilities, Rebellion/Terrorism, and Natural Catastrophe were selected to measure the only latent factor representing "Unexpected Events".

- Each of the 6 latent factors representing risk events are measured by one distinct observed risk event. One of the unique features of EQS is that it allows for one-indicator latent factors.

- Finally, the only risk consequence which is considered in this study, namely “Cost Overrun”, is demonstrated by one unique latent factor.

After specification of the measurement models, in order for confirmation of the hypothesized relationships under the concept of 28 latent factors, corresponding equations which represent these assumptions are generated. All the hypothesized relationships are analyzed through Confirmatory Factor Analysis offered by EQS.

Table 5.1 summarizes the formulated latent factors, the observed indicator variables measuring each of them, and the standardized factor loadings estimated through CFA. All the obtained factor loadings are statistically significant at 5% level.

Table 5.1: Structure of the Measurement Models and CFA Results

Type	No	Latent Factors	No	Observed Variables	Mean	SD	Factor Loading
Vulnerability (1)	F1	Adverse Country-Related Conditions (Conty-Cndtn)	V1	Instability of Economic Condition	2.94	1.27	0.486
			V2	Instability of Government	2.96	1.18	0.54
			V3	Instability of International Relations	2.96	1.12	0.544
			V4	Social unrest	2.94	1.05	0.522
			V5	High Level of Bureaucracy	3.04	1.05	0.478
			V6	Immaturity of Legal System	2.97	1.12	0.499
			V7	Restrictions for Foreign Companies	2.92	1.13	0.488
			V8	Unavailability of Local Material	3.06	1.19	0.843
			V9	Unavailability of Equipment	3.07	1.24	0.903
			V10	Unavailability of Local Labour	3.05	1.29	0.947
			V11	Unavailability of Local Subcontractors	3.05	1.29	0.943
			V12	Unavailability of Infrastructure	3.04	1.33	0.899
	F2	Design Problems (Dsgn-Prblm)	V13	Poor/Incomplete Design	2.99	1.11	0.885
			V14	Design Errors	2.95	1.13	0.792
	F3	Project Complexity (Pjt-Cmx)	V15	Complexity of Design	2.96	1.11	0.675
			V16	Low Constructability	2.96	1.35	0.77
			V17	Complexity of Construction Method	2.96	1.16	0.967
	F4	Uncertainty of Geological Conditions (Glgcl)	V18	Uncertainty of Geotechnical Condition	2.95	1.31	0.521
	F5	Strict Requirements (Strct-Rqr)	V19	Strict Quality Requirements	2.99	1.4	0.917
			V20	Strict Environmental Requlations	2.98	1.39	0.948
			V21	Strict Health & Safety Requlations	2.99	1.39	0.936
			V22	Strict Project Management Requirements	2.98	1.32	0.921
	F6	Contract-Specific Problems (Cont-Prblm)	V23	Vagueness of Contract Clauses	2.71	1.0	0.891
			V24	Contractual Errors	2.77	1.02	0.826
	F7	Engineer's Incompetency (Eng-Incpt)	V25	Technical Incompetency of Engineer	2.84	1.21	0.921
			V26	Managerial Incompetency of Engineer	2.88	1.24	0.895
			V27	Engineer's Lack of Financial Resources	2.67	1.34	0.763
	F8	Client's Incompetency (Clt-Incpt)	V28	Client's Unclarity of Objectives	2.85	1.18	0.793
			V29	Client's High Level of Bureaucracy	2.95	1.23	0.765
			V30	Client's Negative Attitude	2.85	1.25	0.86
			V31	Client's Poor Staff Profile	2.92	1.17	0.886
			V32	Client's Lack of Financial Resources	2.81	1.42	0.683
			V33	Client's Technical Incompetency	2.99	1.24	0.87
			V34	Client's Poor Managerial/ Organizational Abilities	3.01	1.22	0.934
	F9	Adverse Site Conditions (Sit-Condtn)	V35	Poor Site Supervision	2.66	1.5	0.802
			V36	Lack of Site Facilities	2.74	1.24	0.708
Vulnerability (2)	F10	Contractor's Lack of Experience (Con-Expr)	V37	Contractor's Lack of Experience in Similar Projects	2.62	1.21	0.746
			V38	Contractor's Lack of Experience in the Country	2.87	1.38	0.776
			V39	Contractor's Lack of Experience about the project delivery System	2.66	1.32	0.769
			V40	Contractor's Lack of Experience with Client	2.98	1.39	0.796

Table 5.1: Structure of the Measurement Models and CFA Results (Continued)

Type	No	Latent Factors	No	Observed Variables	Mean	SD	Factor Loadings
Vulnerability (2)	F11	Contractor's Lack of Resources (Con-Res)	V41	Contractor’s Lack of Financial Resources	2.84	1.33	0.789
			V42	Contractor’s Lack of Technical Resources	2.75	1.2	0.833
			V43	Contractor’s Lack of Staff	2.84	1.31	0.899
	F12	Contractor's Lack of Managerial Skills (Con-Mngt)	V44	Poor Project Scope Management	2.66	1.15	0.897
			V45	Poor Project Time Management	2.91	1.11	0.845
			V46	Poor Project Cost Management	2.85	1.18	0.838
			V47	Poor Project Quality Management	2.74	1.25	0.911
			V48	Poor Human Resources Management	2.8	1.22	0.869
			V49	Poor Communication Management	2.84	1.14	0.857
			V50	Poor Project Risk Management	2.85	1.25	0.91
			V51	Poor Procurement Management	2.72	1.21	0.9
Risk Source (1)	F13	Adverse Change in Country Economic Condition (Conty-Econ)	V52	Changes in Currency Rate	2.64	1.36	0.86
			V53	Change in Economic Indicators	2.66	1.31	0.897
	F14	Adverse Changes in Laws & Regulations (Law-Reg)	V54	Change in Taxation Policies	2.1	1.66	0.93
			V55	Change in Laws & Regulations	2.51	1.49	0.819
	F15	Conflicts with Project Stakeholders (Coflt)	V56	Conflicts with Government	2.52	1.03	0.764
			V57	Conflicts with Engineer	2.62	1.01	0.844
			V58	Conflicts with Client	2.68	1.1	0.846
			V59	Poor Public Relations	2.54	1.1	0.829
	F16	Adverse Change in Performance of Client (Clt-Prfc)	V60	Change in Performance of Client Representative	2.42	1.34	0.831
			V61	Change in Client’s Staff/Organization	2.32	1.39	0.875
			V62	Change in Financial Situation of Client	2.43	1.47	0.65
	F17	Changes in Project Specifications (Prjt-Sps)	V63	Scope Changes	2.63	1.33	0.918
			V64	Design Changes	2.6	1.2	0.874
	F18	Adverse Change in Performance of Contractor (Con-Prfc)	V65	Change in Site/Project Organization	2.7	1.08	0.855
			V66	Change in Functional Performance of Contractor	2.67	1.18	0.881
	F19	Adverse Change in Availability of Local Resources (Avlb-Res)	V67	Change in Availability of Labour	2.73	1.31	0.848
			V68	Change in Availability of Material	2.73	1.34	0.933
			V69	Change in Availability of Equipment	2.66	1.24	0.893
			V70	Change in Availability of Subcontractors	2.61	1.35	0.769
	F20	Adverse Change in Site Conditions (Chng-Sit)	V71	Change in Geological Conditions	2.45	1.51	0.716
			V72	Change in Site Conditions	2.54	1.50	0.879
R S (2)	F21	Unexpected Events (Unxpt-Evnt)	V73	War/ Hostilities	0.40	0.99	0.977
			V74	Rebellion/ Terrorism	0.34	0.97	0.95
			V75	Natural Catastrophes	0.38	0.95	0.916

Table 5.1: Structure of the Measurement Models and CFA Results (Continued)

Type	**No**	**Latent Factors**	**No**	**Observed Variables**	**Mean**	**SD**	**Factor Loadings**
Risk Event	F22	Delays/ Interruptions (Dely-Intrpt)	V76	Delays/Interruptions	2.76	1.09	0.952
	F23	Decrease in Productivity (Prdcty)	V77	Decrease in Productivity	2.4	1.1	0.986
	F24	Increase in Amount of Work (Wrk-Amnt)	V78	Increase in Amount of Work	2.3	1.23	1.0
	F25	Decrease in Quality of Work (Qlty)	V79	Decrease in Quality of Work	2.33	1.1	1.0
	F26	Increase in Unit Cost of Work (Unt-Cst)	V80	Increase in Unit Cost of Work	2.45	1.23	0.773
	F27	Lags in Cash Flow (Csh-Flw)	V81	Lags in Cash Flow	2.96	0.89	1.0
R C	F28	Cost Overrun (Cst-Ovrn)	V82	Cost Overrun	2.83	1.26	0.945

The path diagrams virtually representing the hypothesized measurement models for all the aforementioned risk concepts, assumed relations and correlations which are confirmed through CFA, along with the resulted standardized path coefficients, are reported in figures 5.1 through 5.6.

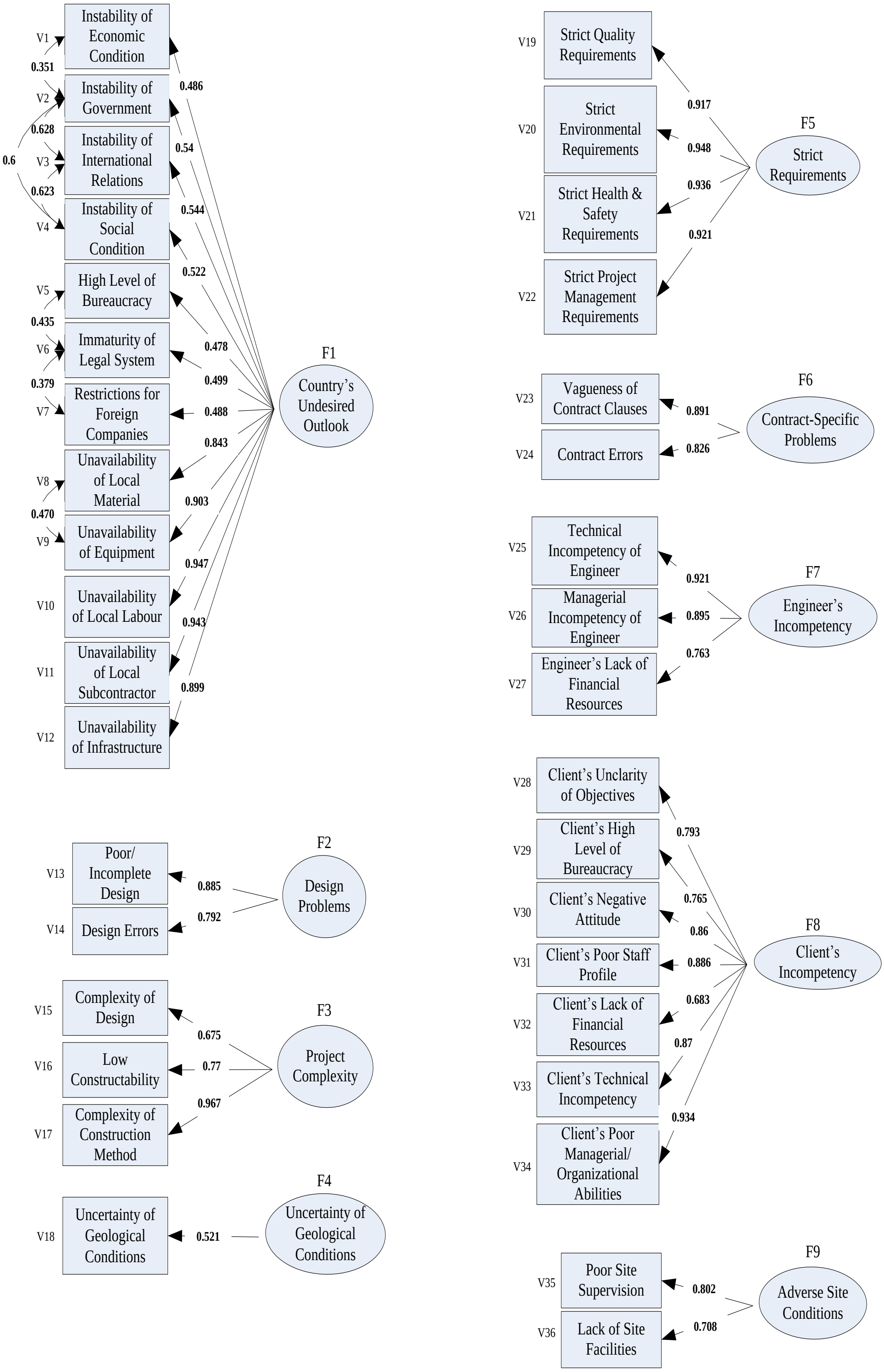


Figure 5.1: Path diagrams representing the measurement models for Vulnerability (1)

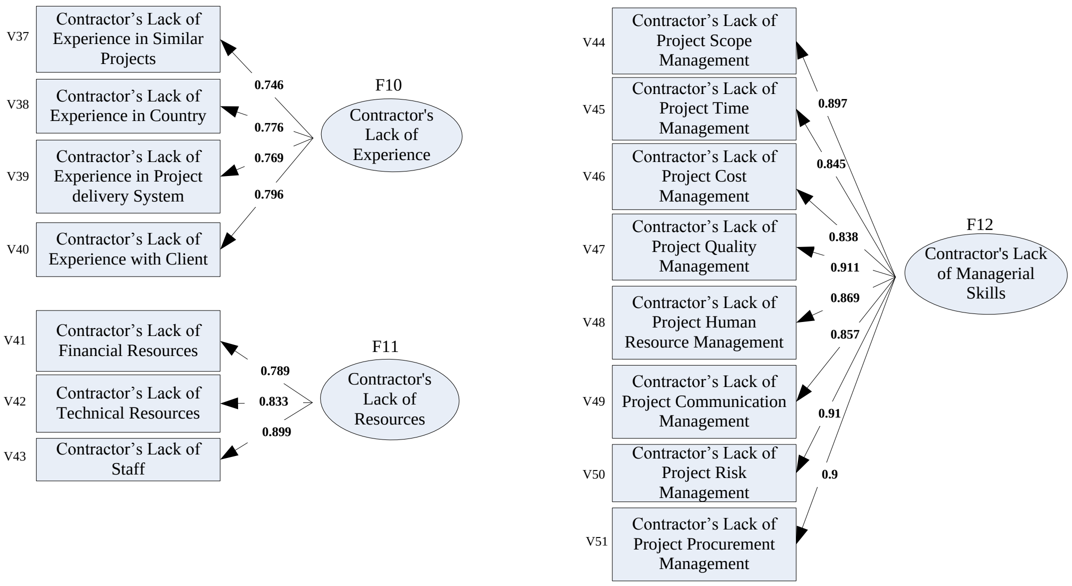


Figure 5.2: Path diagrams representing the measurement models for Vulnerability (2)

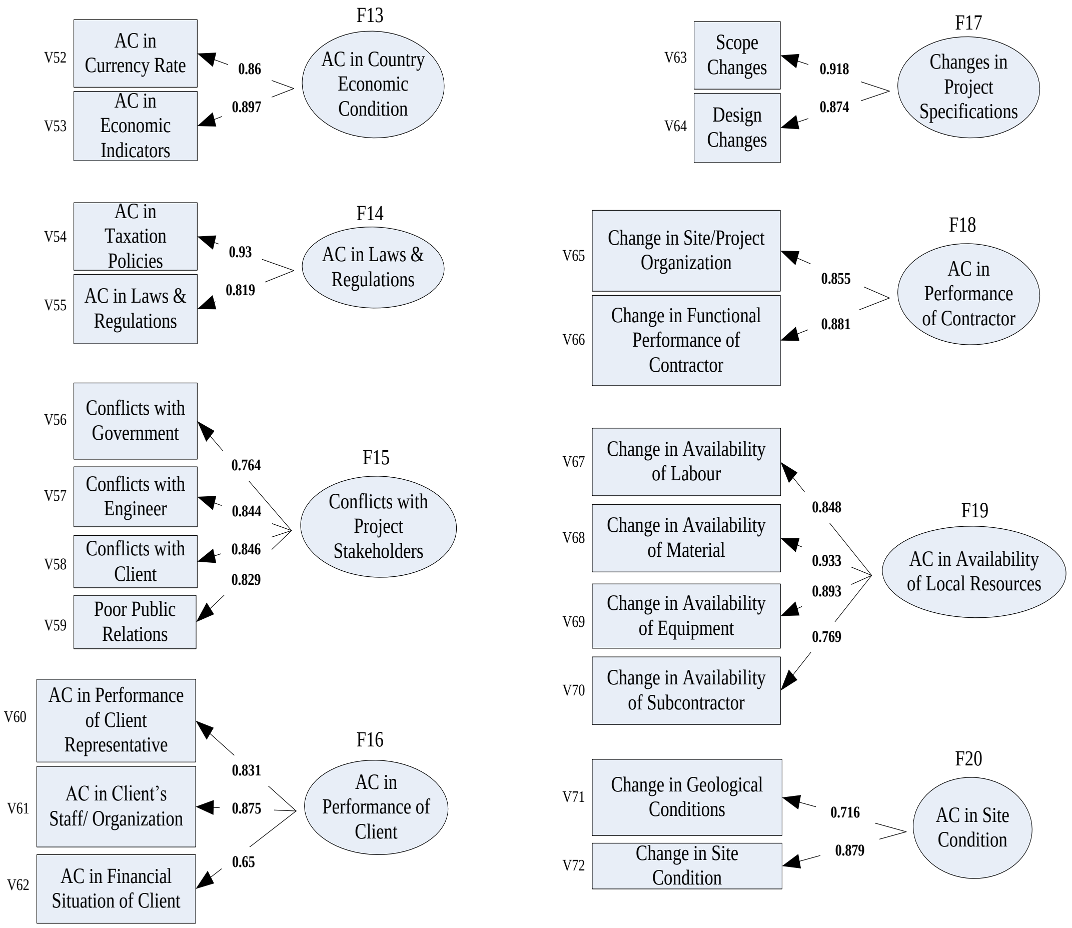


Figure 5.3: Path diagrams representing the measurement models for Adverse Changes

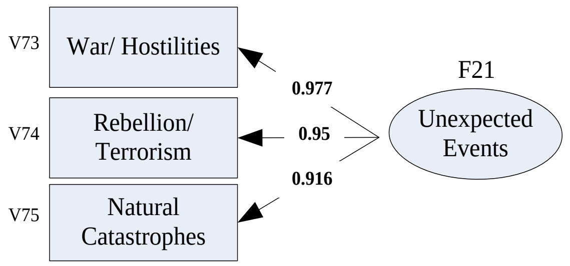


Figure 5.4: Path diagrams representing the measurement models for Unexpected Events

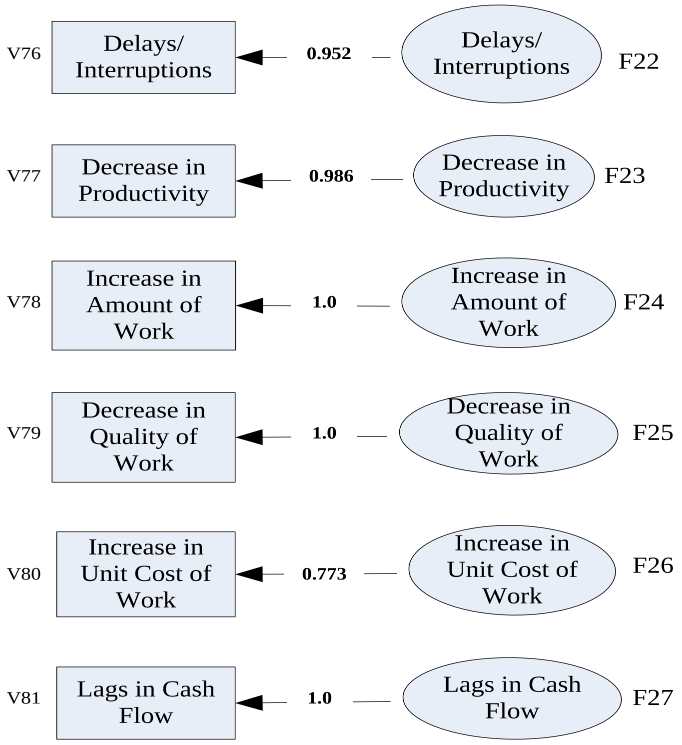


Figure 5.5: Path diagrams representing the measurement models for Risk Events

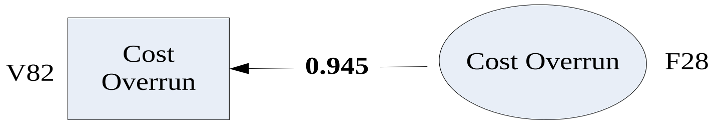


Figure 5.6: Path diagrams representing the measurement models for Risk Consequence

Figure 5.1-5.6 legends

□ Observed Variables

◯ Latent Factors

5.1.2 Testing Reliability and Validity of the Measurement Models

The fundamental requirement of conducting scientific researches in the modern paradigm is the development of theoretical structures followed by strict tests of these theorems (Garver and Mentzer, 1999). Various reliability and validity testes are proposed to verify that data is generally consistent with the hypothesized measurement constructs. Figure 5.7 summarizes the hierarchical arrangement of tests mostly recommended within the literature for examination of the reliability and validity of the hypothesized measurement models which are analyzed through CFA.

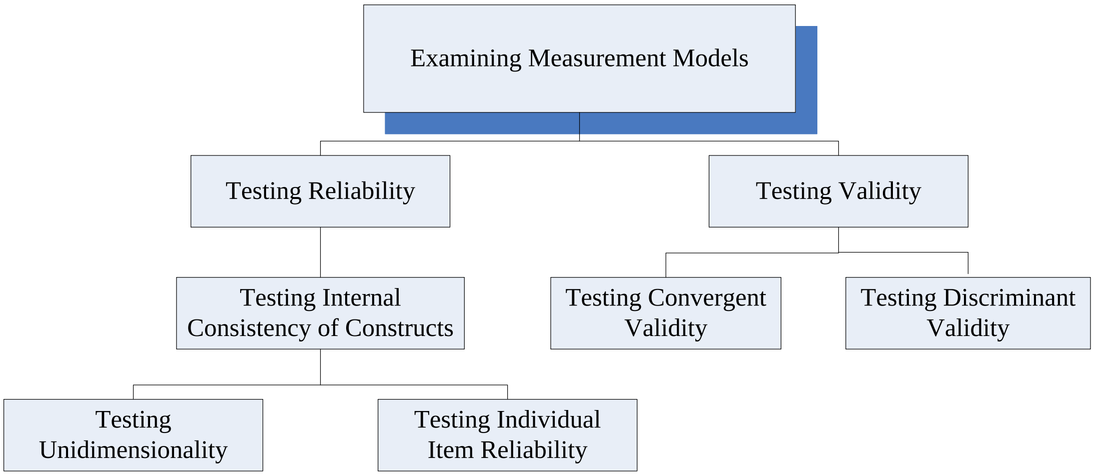


Figure 5.7: Hierarchical representation of recommended reliability and validity tests

In order to examine the *reliability* of the measurement models, the “internal consistency of constructs”, measuring the same latent factor for the collected data, is tested first. For this purpose, the “unidimensionality” and “individual item reliability” are tested for the constructs with more than two indicators.

Unidimensionality indicates the degree to which items represent *one and only one* underlying latent factor (Garver and Mentzer, 1999). Commonly, measured variables with standardized factor loadings close or greater than 0.5 are accepted to be unidimensional (Hair et al., 2006). It means that such variables explain a significant portion of the variance in their indicated latent factors. As illustrated in Table 5.2, all observed variables indicate sufficient degrees of unidimensionality.

Individual reliability of variables, which shows the extent to which distinct indicators for a latent factor belong together (Garson, 2008), is accepted to be satisfactory if the "Cronbach's Alpha" coefficients reported for each item is greater than the threshold value of 0.7 recommended by Nunally (1978) and Hair et al. (2006). Table 5.2 demonstrates that all scales are individually reliable since the Alpha coefficients reported for observed variables range from 0.73 to 0.964.

The *construct validity* of the measurement models is examined through "Convergent" and "Discriminate" validity tests.

Convergent validity explains the degree to which indicator variables of a construct correlate and share variance with each other (Hair et al., 2006, and Garson, 2008). "Average variance extracted" is the metric that is widely proposed to test convergent validity, and is recommended to be close or higher than 50 percent for all constructs. Table 5.2 illustrates that this is the case for all measurement models. Anderson and Gerbing (1988) stated that convergent validity is satisfied for measurement models whose estimated parameters (factor loadings) are significant in an appropriate level. This criterion is also met for all constructs since all factor loadings are statistically significant at 5% level.

Discriminate validity is a measure describing how different a construct is from other constructs. To satisfy this, the shared variance among distinct constructs (i.e. squared value of any path coefficient) should be less than the average variance shared among a construct and its indicators. Table 5.2 shows that all constructs comply with this criterion, and hence, are discriminately validated.

In sum, it is confirmed that all hypothesized constructs are adequately described by their indicators. Therefore, these factors can be used for development of the Risk-Path Model.

Table 5.2: Results of CFA, Reliability and Vulnerability Tests

Type	Latent Factor	No	Observed Variables	Factor Loadings	Cronbach 's Alpha	Average Variance Extracted	Biggest squared Inter-correlation Between Constructs
Vulnerability (1)	F1	V1	Instability of Economic Condition	0.486	0.917	0.494	$0.2^2=0.04<0.494$
		V2	Instability of Government	0.54			
		V3	Instability of International Relations	0.544			
		V4	Social unrest	0.522			
		V5	High Level of Bureaucracy	0.478			
		V6	Immaturity of Legal System	0.499			
		V7	Restrictions for Foreign Companies	0.488			
		V8	Unavailability of Local Material	0.843			
		V9	Unavailability of Equipment	0.903			
		V10	Unavailability of Local Labour	0.947			
		V11	Unavailability of Local Subcontractors	0.943			
		V12	Unavailability of Infrastructure	0.899			
	F2	V13	Poor/Incomplete Design	0.885	0.826	0.71	$0.182^2=0.03<0.71$
		V14	Design Errors	0.792			
	F3	V15	Complexity of Design	0.675	0.834	0.66	$0.276^2=0.08<0.66$
		V16	Low Constructability	0.77			
		V17	Complexity of Construction Method	0.967			
	F4	V18	Uncertainty of Geotechnical Condition	0.521	——	——	——
	F5	V19	Strict Quality Requirements	0.917	0.962	0.87	$0.06^2=0.004<0.87$
		V20	Strict Environmental Requlations	0.948			
		V21	Strict Health & Safety Requlations	0.936			
		V22	Strict Project Management Requirements	0.921			
	F6	V23	Vagueness of Contract Clauses	0.891	0.847	0.74	$0.577^2=0.33<0.74$
		V24	Contractual Errors	0.826			
	F7	V25	Technical Incompetency of Engineer	0.921	0.891	0.74	$0.158^2=0.02<0.74$
		V26	Managerial Incompetency of Engineer	0.895			
		V27	Engineer's Lack of Financial Resources	0.763			
	F8	V28	Client's Unclarity of Objectives	0.793	0.937	0.76	$0.388^2=0.15<0.76$
		V29	Client's High Level of Bureaucracy	0.765			
		V30	Client's Negative Attitude	0.86			
		V31	Client's Poor Staff Profile	0.886			
		V32	Client's Lack of Financial Resources	0.683			
		V33	Client's Technical Incompetency	0.87			
		V34	Client's Poor Managerial/ Organizational Abilities	0.934			
	F9	V35	Poor Site Supervision	0.802	0.73	0.57	$0.75^2=0.56<0.57$
		V36	Lack of Site Facilities	0.708			
Vulnerability (2)	F10	V37	Contractor's Lack of Experience in Similar Projects	0.746	0.874	0.6	$0.167^2=0.03<0.6$
		V38	Contractor's Lack of Experience in the Country	0.776			
		V39	Contractor's Lack of Experience about the project delivery System	0.769			
		V40	Contractor's Lack of Experience with Client	0.796			

Table 5.2: Results of CFA, Reliability and Vulnerability Tests (Continued)

Type	Latent Factor	No	Observed Variables	Factor Loadings	Cronbach's Alpha	Average Variance Extracted	Biggest squared Inter-correlation Between Constructs
Vulnerability (2)	F11	V41	Contractor's Lack of Financial Resources	0.789	0.894	0.71	$0.667^2=0.44<0.71$
		V42	Contractor's Lack of Technical Resources	0.833			
		V43	Contractor's Lack of Staff	0.899			
	F12	V44	Poor Project Scope Management	0.897	0.964	0.77	$0.504^2=0.25<0.77$
		V45	Poor Project Time Management	0.845			
		V46	Poor Project Cost Management	0.838			
		V47	Poor Project Quality Management	0.911			
		V48	Poor Human Resources Management	0.869			
		V49	Poor Communication Management	0.857			
		V50	Poor Project Risk Management	0.91			
		V51	Poor Procurement Management	0.9			
Risk Source (1)	F13	V52	Changes in Currency Rate	0.86	0.884	0.77	$0.715^2=0.51<0.77$
		V53	Change in Economic Indicators	0.897			
	F14	V54	Change in Taxation Policies	0.93	0.861	0.77	$0.1^2=0.01<0.77$
		V55	Change in Laws & Regulations	0.819			
	F15	V56	Conflicts with Government	0.764	0.94	0.67	$0.293^2=0.09<0.67$
		V57	Conflicts with Engineer	0.844			
		V58	Conflicts with Client	0.846			
		V59	Poor Public Relations	0.829			
	F16	V60	Change in Performance of Client Representative	0.831	0.831	0.63	$0.722^2=0.52<0.63$
		V61	Change in Client's Staff/Organization	0.875			
		V62	Change in Financial Situation of Client	0.65			
	F17	V63	Scope Changes	0.918	0.906	0.80	$0.39^2=0.15<0.8$
		V64	Design Changes	0.874			
	F18	V65	Change in Site/Project Organization	0.855	0.852	0.75	$0.348^2=0.12<0.75$
		V66	Change in Functional Performance of Contractor	0.881			
	F19	V67	Change in Availability of Labour	0.848	0.917	0.74	$0.1^2=0.01<0.74$
		V68	Change in Availability of Material	0.933			
		V69	Change in Availability of Equipment	0.893			
		V70	Change in Availability of Subcontractors	0.769			
	F20	V71	Change in Geological Conditions	0.716	0.77	0.64	$0.36^2=0.13<0.64$
		V72	Change in Site Conditions	0.879			
R S (2)	F21	V73	War/ Hostilities	0.977	0.963	0.90	$0.1^2=0.01<0.9$
		V74	Rebellion/ Terrorism	0.95			
		V75	Natural Catastrophes	0.916			

5.2 Development of the Risk-Path Construct Model

5.2.1 Specification of the Risk-Path Construct Model

Through Confirmatory Factor Analysis, 12 latent factors representing various system vulnerabilities constructed by 51 vulnerability variables, 8 risk source factors formed by 21 observed adverse changes, 1 factor indicating unexpected events measured by 3 widely observed factors, 6 risk event constructs, and 1 consequence factor indicating project cost overrun are validated to be used for the development of Risk-Path Construct Model.

In this step the structural relationships between these validated latent factors should be estimated. For this purpose, different hypothesis should be made about possible causalities among divers risk concepts, and about the risk-path scenarios generating from system vulnerabilities and leading to cost overruns in international construction projects. Such hypotheses form the structure of the initial Risk-Path Construct Model. In this study, the aim of which is to prove the existence of causal interrelationships among risk-related concepts, and to identify the most common interactive risk-path scenarios affecting cost performance of construction projects, two main sources are referred for making hypotheses about such scenarios:

1) Available literature about the risk-related factors affecting cost performance of construction projects.

2) Interviews with expert practitioners from the industry.

5.2.1.1 Literature Review on Possible Risk-Path Scenarios

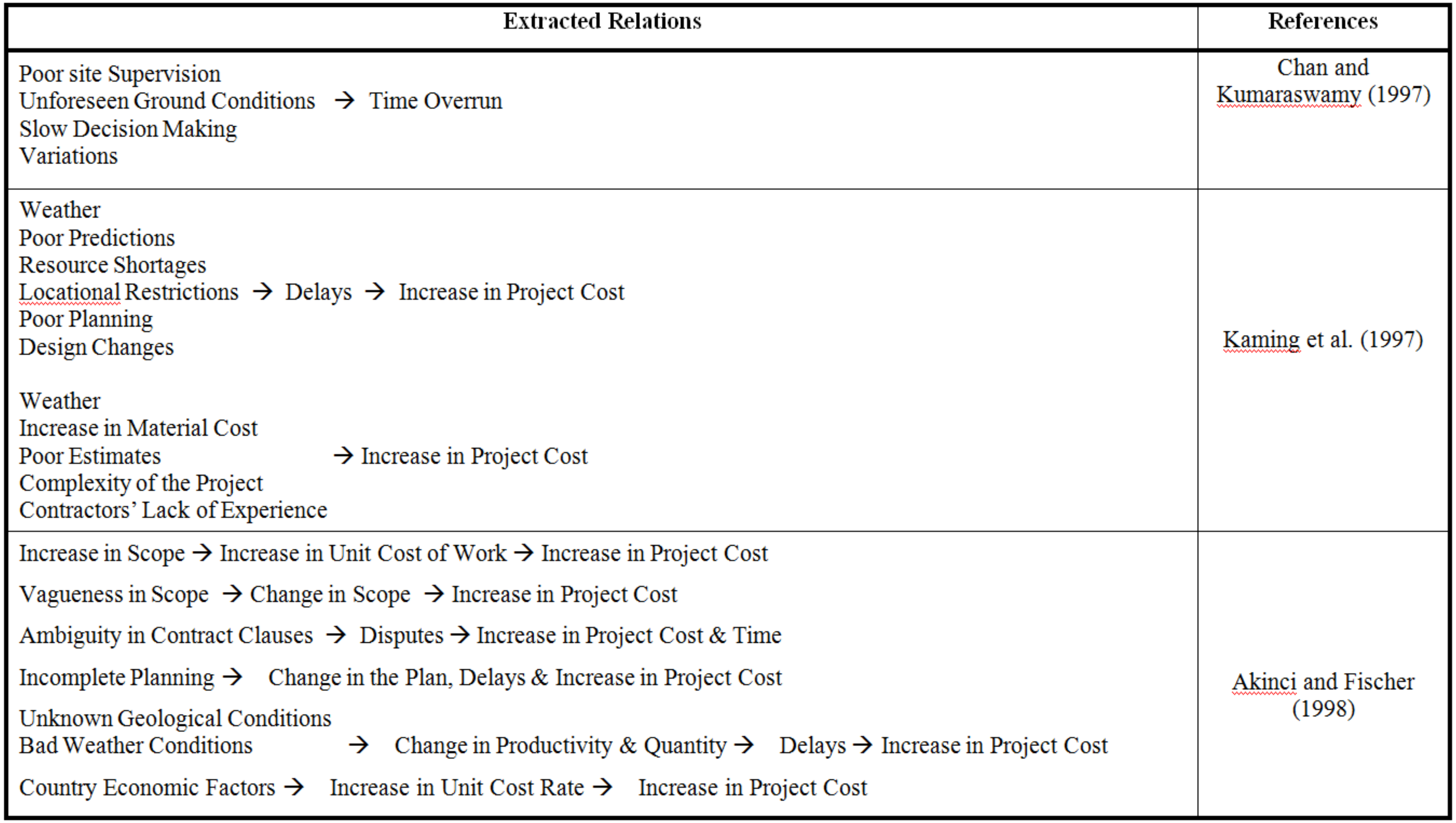
Within the literature, some individual risk sources have received more emphasis and identified as more critical than the others. Numerous researchers have examined the causes and effects of different individual risk sources, and the way that unexpected events happen in construction projects. However, as Dikmen et al. (2007a) have also mentioned, the combination of all possible interactive risks should be studied to gain a thorough perception about the consequences. In this section, an exhaustive literature review is conducted to get idea about possible causal interactions between various factors leading to cost overruns in international construction projects. Different risk scenarios and causalities being mentioned or investigated by various authors are extracted and summarized in Table 5.3. Considering possible associations among these causalities, an initial construct model comprising of several interactive risk paths was developed.

Figure 5.8 demonstrates this initial Risk-Path Model which is developed based on the results of literature survey summarized in table 5.3. This model comprises of 42 risk-path scenarios each of which initiated from related system vulnerabilities, moderated by possible adverse changes and risk events, and ended with project cost overrun as the project risks' consequence. Due to limitations of sample size of the study, and for simplicity and parsimony considerations, not all possible paths but the ones being mostly emphasized within the literature were included in this model.

Table 5.3: Literature review on possible risk paths

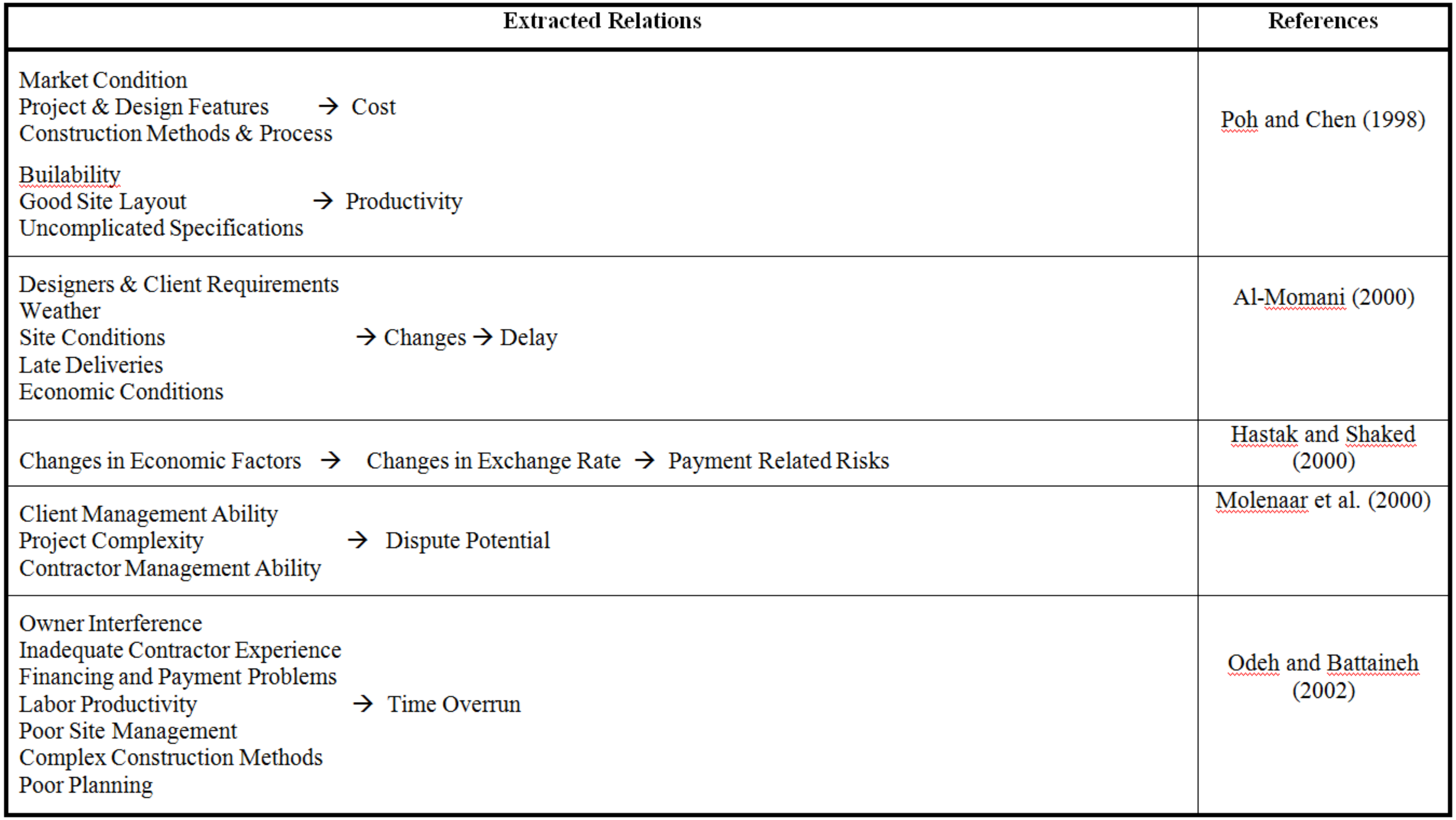
Extracted Relations	References
Lack of Statistics about Availability Fluctuation in Availability Long Waiting Time for Delivery Lack of Funds → Shortage of materials → Time & Cost Overrun Lack of Experience & Technical Skills Low Productivity Lack of Funds Lack of Specialization → poor contract management → Deficiencies in Plan, Cost & Site Management → Time & Cost Overrun Finance and Payment problems → Time & Cost Overrun Price Fluctuations Delay Fraudulent practices → Cost Overrun	Okpala and Aniekwu (1988)
Design Deviations Construction Deviations → Rework → Cost Deviations	Burati et al. (1992)
Financing & Payment Problems Poor Contract Management Changes in Site Conditions Shortage of Material Improper Planning → Time & Cost Overrun	Mansfield et al. (1994)
Increase in Scope Weather Restricted Access Acceleration Design Change Extras and Errors → Site Overhead Loss of Productivity Loss of Revenue Increase in Costs Increase in Time → Claims	Semple et al. (1994)

Table 5.3: Literature review on possible risk paths (Continued)



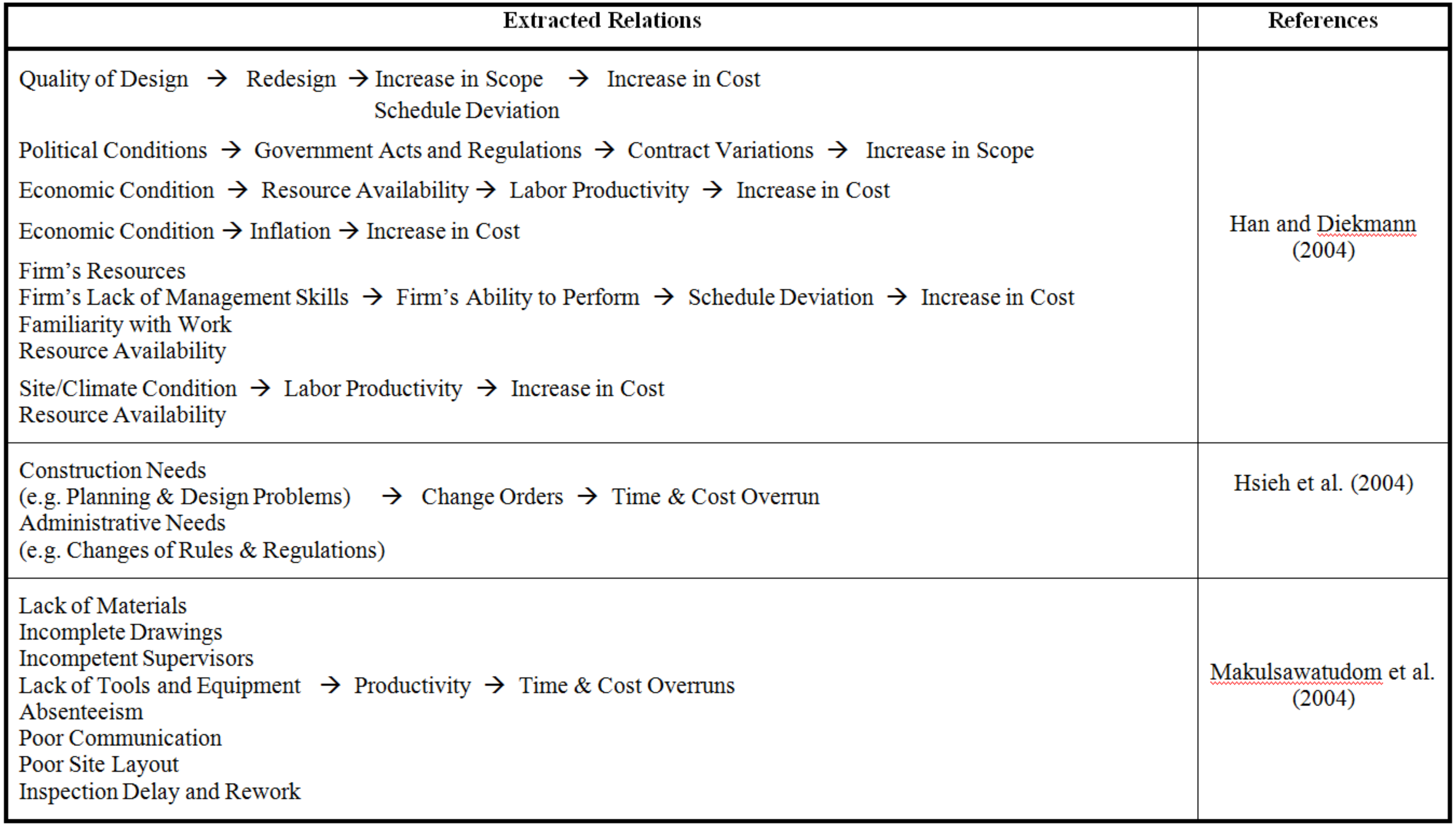
Extracted Relations	References
Poor site Supervision Unforeseen Ground Conditions → Time Overrun Slow Decision Making Variations	Chan and Kumaraswamy (1997)
Weather Poor Predictions Resource Shortages Locational Restrictions → Delays → Increase in Project Cost Poor Planning Design Changes Weather Increase in Material Cost Poor Estimates → Increase in Project Cost Complexity of the Project Contractors' Lack of Experience	Kaming et al. (1997)
Increase in Scope → Increase in Unit Cost of Work → Increase in Project Cost Vagueness in Scope → Change in Scope → Increase in Project Cost Ambiguity in Contract Clauses → Disputes → Increase in Project Cost & Time Incomplete Planning → Change in the Plan, Delays & Increase in Project Cost Unknown Geological Conditions Bad Weather Conditions → Change in Productivity & Quantity → Delays → Increase in Project Cost Country Economic Factors → Increase in Unit Cost Rate → Increase in Project Cost	Akinci and Fischer (1998)

Table 5.3: Literature review on possible risk paths (Continued)



Extracted Relations	References
Market Condition Project & Design Features → Cost Construction Methods & Process Builability Good Site Layout → Productivity Uncomplicated Specifications	Poh and Chen (1998)
Designers & Client Requirements Weather Site Conditions → Changes → Delay Late Deliveries Economic Conditions	Al-Momani (2000)
Changes in Economic Factors → Changes in Exchange Rate → Payment Related Risks	Hastak and Shaked (2000)
Client Management Ability Project Complexity → Dispute Potential Contractor Management Ability	Molenaar et al. (2000)
Owner Interference Inadequate Contractor Experience Financing and Payment Problems Labor Productivity → Time Overrun Poor Site Management Complex Construction Methods Poor Planning	Odeh and Battaineh (2002)

Table 5.3: Literature review on possible risk paths (Continued)



Extracted Relations	References
Quality of Design → Redesign → Increase in Scope → Increase in Cost Schedule Deviation Political Conditions → Government Acts and Regulations → Contract Variations → Increase in Scope Economic Condition → Resource Availability → Labor Productivity → Increase in Cost Economic Condition → Inflation → Increase in Cost Firm's Resources Firm's Lack of Management Skills → Firm's Ability to Perform → Schedule Deviation → Increase in Cost Familiarity with Work Resource Availability Site/Climate Condition → Labor Productivity → Increase in Cost Resource Availability	Han and Diekmann (2004)
Construction Needs (e.g. Planning & Design Problems) → Change Orders → Time & Cost Overrun Administrative Needs (e.g. Changes of Rules & Regulations)	Hsieh et al. (2004)
Lack of Materials Incomplete Drawings Incompetent Supervisors Lack of Tools and Equipment → Productivity → Time & Cost Overruns Absenteeism Poor Communication Poor Site Layout Inspection Delay and Rework	Makulsawatudom et al. (2004)

Table 5.3: Literature review on possible risk paths (Continued)

Extracted Relations	References
Country Level Risks → Market Level Risks (e.g. Foreign exchange and convertibility) Project Level Risks (e.g. Cost Overrun) → Project Level Risks (e.g. Cost Overrun)	Wang et al. (2004)
Lack of Skills Rework Lack of Tools/Equipment Poor Construction Methods Poor Communication → Productivity → Time & Cost Overruns Inaccurate Drawings Stoppages Political Insecurity Tools/Equipment Breakdown Harsh Weather Conditions	Alinaitwe et al. (2007)
Conditions of Host Country & Client (e.g. Stability of Laws & Rules & Owner Funding Capacity) → Project Characteristics & Contractual Conditions (e.g. Quality of → Contractor's Ability (e.g. Finish the Project On time) Characteristics of Organization & Participants (e.g. Technical & Managerial Skills)	Han et al. (2007)
Client Related Factors Contractor Related Factors Consultant Related Factors Material Related Factors → Delays → Time Overrun Labor Related Factors → Cost Overrun Contract Related Factors → Disputes Relationship Related Factors → Arbitration External Factors → Litigation	Sambasivan and Soon (2007)

Table 5.3: Literature review on possible risk paths (Continued)

Extracted Relations	References
Tight Schedule Design Variations Variations Unsuitable Planning → Cost Overrun Disputes Price Inflation of Materials Incomplete Documents Incomplete Cost Estimate	Zou et al. (2007)
Tight Schedule Design Variations Excessive Procedures & Bureaucracy → Time Overrun Incomplete Documents Unsuitable Planning High Expectations Variations	
Tight Schedule Unsuitable Planning Incomplete Cost Estimate Low management competency of subcontractors → Decrease in Quality High Quality Expectations Variations Unavailability of Skilled Labour Design Variations Lack of Coordination	
Poor Planning Change Orders → Time Overrun Lack of Technical Resources and Staff	Sweis et al. (2008)

Table 5.3: Literature review on possible risk paths (Continued)

Extracted Relations	References
Client Related Factors Lack of National Information Lack of Experience and Skills Country Related Factors → Change Orders → Plan Revision Additional Work → Time & Cost Overruns Disruption	Alnuaimi et al. (2009)
Owner Change Design Error/Omission Design Change Contractor Error/Omission → Rework → Time & Cost Overrun	Hwang et al. (2009)
Inadequate Managerial Skills Lack of Experience Poor Site Management Poor Workmanship Weather Conditions Unknown Geological Conditions Cost Fluctuations Change in Availability of Resources Change in Material Costs Legislations & Regulations → Project Change → Extra Work Rework Time Loss Design Revisions Decrease in Productivity → Increase in Project Cost	Sun and Meng (2009)

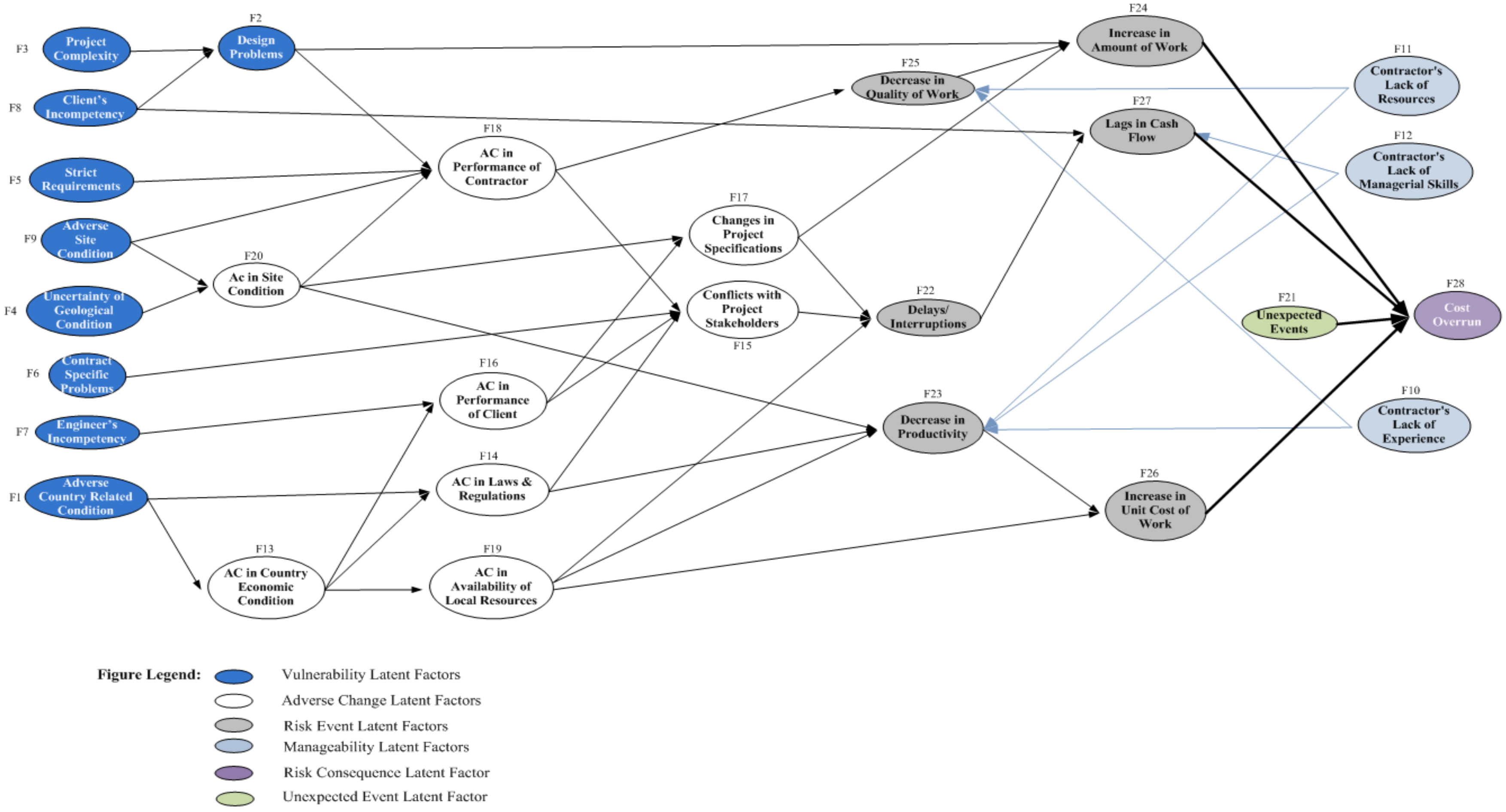


Figure 5.8: Risk-Path Construct Model developed based on conducted literature review

5.2.1.2 Expert Interviews on Possible Risk-Path Scenarios

The initially developed Risk-Path Model was consulted with six industry experts who have already participated in the validation process of the developed risk-vulnerability ontology in previous stages of this research project (see Fidan et al., 2010).

The interviews were conducted in two parts:

1) Firstly, the interviewees were provided with a list of 42 risk-path scenarios forming the initial construct model to check if the demonstrated risk paths are meaningful and possible in international construction projects. The aim of this step was validation of the recognized risk paths which form the main part of the study's hypothesis and are going to be tested through confirmatory analysis offered by SEM.

2) In the second step, in order to ensure that the Risk-Path Model addresses all possible important scenarios, experts were requested to mention any further critical paths leading to cost overruns other than those introduced in the model. The completeness and generality of the model is tested in this stage.

After the accomplishment of the interviews, the revised construct model comprising of a total of 46 interactive risk paths leading to cost overrun was considered as the initial conceptual model of the study which is going to be analyzed, tested and confirmed by means of SEM technique (see figure 5.9).

Due to limitations of sample size of the study, and for simplicity considerations, not all possible paths but the ones being mostly emphasized within the literature and mentioned as most critical ones by experts were included in the model.

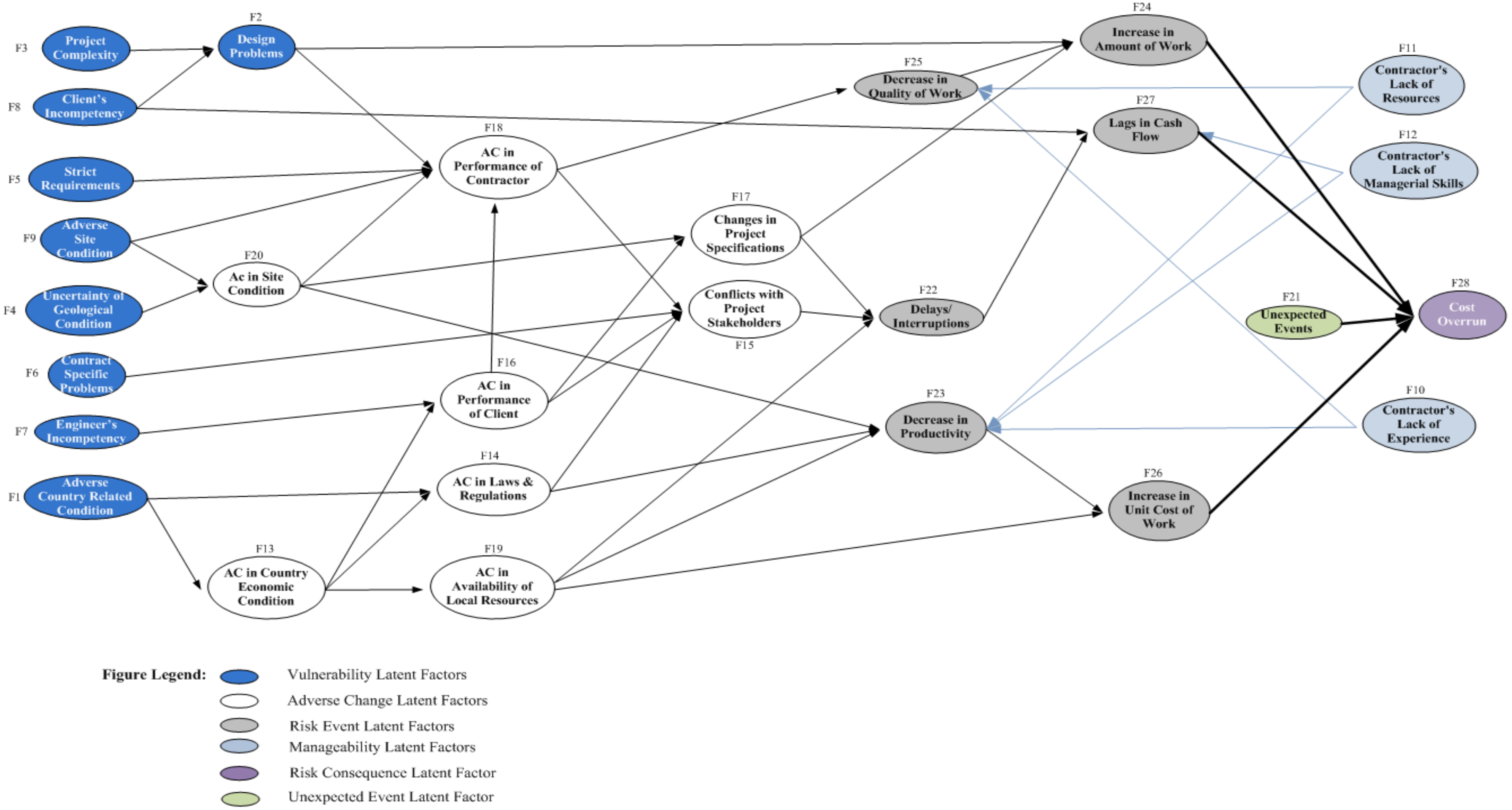


Figure 5.9: Study's Initial Risk-Path Construct Model developed based on conducted literature review and expert interviews

5.2.1.3 Identification of the Initial Risk-Path Construct Model

In previous two subsections, various hypotheses were developed based on the study's theory. Here, the specified Risk-Path Model's identification is tested in order to make sure that it can be estimated though SEM. As mentioned before, the specified model will be considered as identified when there is unique numerical solution for it.

For the initial construct model of this study (shown in figure 5.9), the number of model parameters and available data points are obtained as summarized below:

Number of Regression Coefficients = 45 (Construct Path Coefficients) + 82 (Measurement Path Coefficient) = 127

+

Number of Variances (Number of error terms and IVs) = 110

+

Number of Variable Covariances (Number of covariation among IVs) = 7

=

- ***Number of Model Parameters to be Estimated*** = 244
- ***Data Points*** = Number of Variances and Covariances of Observed Variables
  = $P.\ (P+1)/2 = 82\ .\ (82+1)/2 = 3403$

(P: Number of Observed Variables)

- ***Degrees of Freedom*** = Data Point – Parameters = 3403 – 244 = 3159

Since the number of unknown parameters in the initially specified Risk-Path Model is less than the known data points, the model is *over-identified* which is the preferred case in SEM-based construct models.

5.2.2 Estimation of the Risk-Path Construct Model

In this step, the estimation method that best fits the characteristics of the research data and the specified model should be selected. For this purpose, both *Univariate Normality* and *Multivariate Normality* of the distribution of variables should be tested.

Univariate Normality: In order for examination of the univariate normality of the observed variables, the *Kurtosis* and *Skewness* indexes reported by EQS for each manifest variable should be tested. According to Kline (1998), absolute Kurtosis index values lower than 10, and absolute Skewness index values less than 3 are considered acceptable for SEM models. In this study, these criteria are met for all observed variables since the absolute Kurtosis values range from 0.0013 for V(66) to 9.1932 for V(74), and the absolute Skewness values range from 0.002 for V(16) to 2.98 for V(74).

Multivariate Normality: *Mardia-based Kappa* is considered as the indicator for multivariate normality. As Kline (1998) stated, *Mardia-based Kappa* value around 0 indicates that data are multivariate normal distributed. The *Mardia-based Kappa* value reported for the data utilized in this study is 0.0276 which adequately satisfies the mentioned criterion.

Satisfying both univariate and multivariate normality, the data collected for a total of 82 risk/vulnerability-related variables can be considered to be normally distributed. Therefore, the Maximum Likelihood (ML) method can be selected for the analysis and estimation purposes since, as mentioned before, this method is suitable for multivariate normally distributed data. ML is the default method offered by EQS and according to Garson (2008), should be used for SEM model estimation unless acceptable reasons exist.

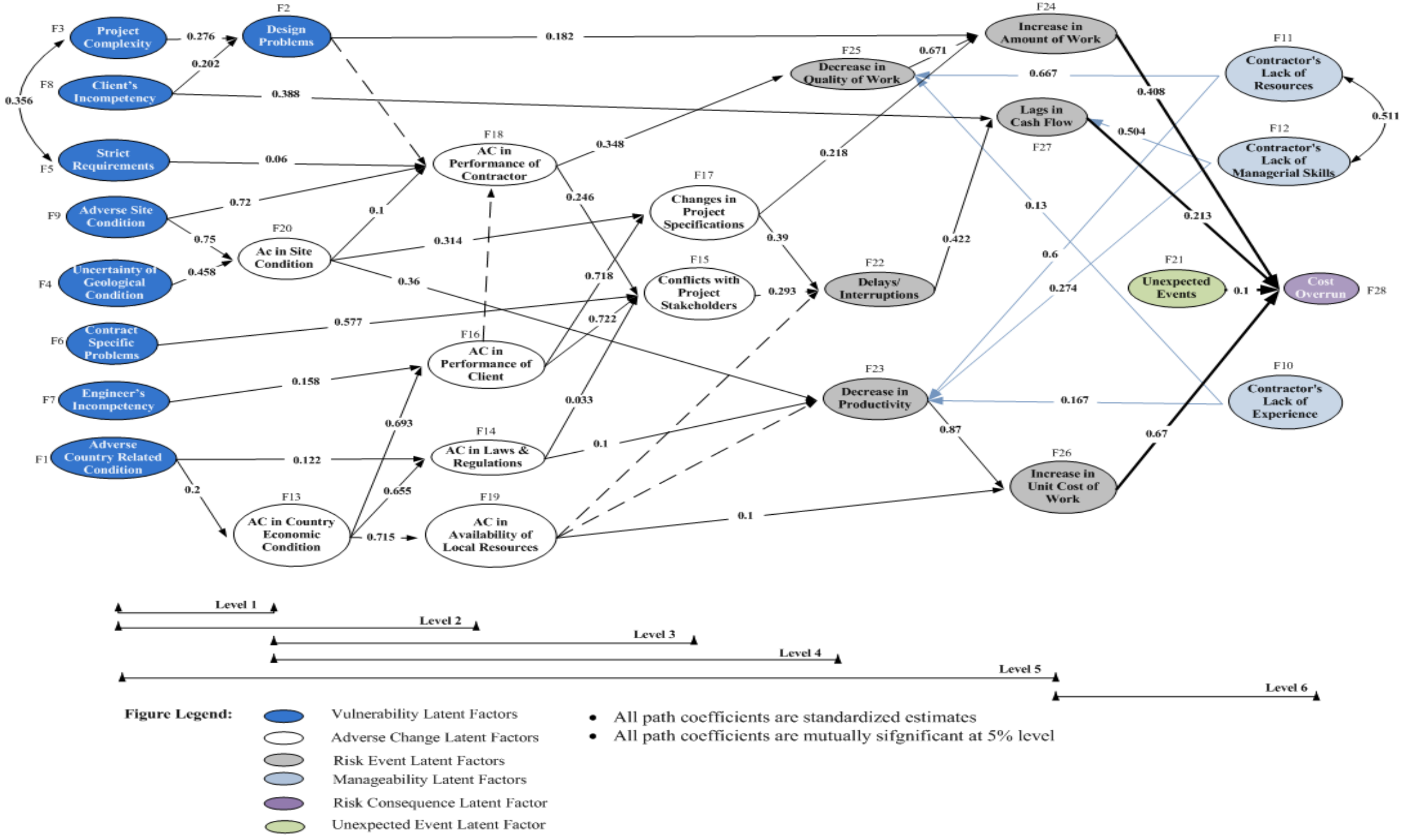
5.2.3 Evaluation and Modification of the Risk-Path Construct Model

After the development of the initial model showing possible risk paths, the properness of these hypotheses should be tested, the fit of the assumed causal relationships to the collected data should be examined, and the strengths of the existing effects should be estimated. Numerous iterative analyses were conducted and various modifications were made accordingly to achieve a model which best suits the collected data and supports the theory. In each iteration, insignificant paths, or sometimes paths elimination of which did not significantly decrease overall fit of the model (obtained through Wald Test), were removed from the construct model. Moreover, additional paths, adding of which significantly increased overall fit of the model (obtained through Lagrange Multiplier results), were supplemented to the construct model. All these trial and error processes were conducted with the aim of increasing model's fit while sticking to the study's theory, and maintaining model's parsimony and avoiding over-fit of the model.

The final Risk-Path Construct Model which best fits the data and describes the theory of this study is shown in Figure 5.10. This model demonstrates the inter-dependencies among 28 factors through 36 possible paths. The number of possible scenarios resulting from the interactions among observed variables is even higher. All demonstrated relationships and estimated path coefficients are mutually significant at the 5% level. Some of the initially hypothesized paths were found to be insignificant, and hence, were eliminated from the final model. Such paths are shown with dashed arrows in the figure 5.10.

Since "*Different fit indexes address different aspects of model appropriateness (e.g., parsimony, sample size effects, comparisons to null models)*" (Sivo et al., 2006), 4 distinct indices are selected for evaluation of the model fit and its suitability, which satisfies the minimum number of 3 indices offered by Jaccard and Wan (1996). "Comparative Fit Index" (CFI) and "Non-Normed Fit Index" (NNFI) are *goodness-of-fit* indices, and "Root Mean Square Error of Approximation" (RMSEA) and the ratio of "CHI-Square" to the "Degrees of Freedom" (χ^2/DF) are *Badness-of-fit* indexes utilized in this study. Table 5.4 reports these fit indices for the finalized Risk-Path Model along with cut-offs recommended for each.

These statistics confirm that the formulated model and the hypothesized relations are all adequately representative of the sample data.



- All path coefficients are standardized estimates
- All path coefficients are mutually sifgnificant at 5% level

Figure 5.10: Final identified Risk-Path Construct Model

Table 5.4: Reported Fit Indexes for Final Risk-Path Construct Model

Fit Index	**Covered Criteria**[a]	**Range of Indexes**	**Recommended Cut-off**	**Finalized Risk Path Model**
CFI	Less Sensitive to Sample Size	0 (no fit) - 1 (perfect fit)	0.73[1]	0.744
NNFI	Adjusted for Model Complexity	0 (no fit) - 1 (perfect fit)	0.7[2]	0.732
RMSEA	Less Sensitive to Sample Size	0 (perfect fit) - 1 (no fit)	0.1[3]	0.084
$\chi 2$/DF	Adjusted for Sample Size	Above 0	3[4]	2.17

a. Garson (2008)

1. Chou and Bentler (1990)

2. Arrindell et al. (1999)

3. Chou and Bentler (1990), Bollen and Long (1992), Brown and Cudeck (1993)

4. Kline (1998), Jashapara (2003)

CHAPTER 6

DISCUSSION ON THE IDENTIFIED RISK-PATH MODEL

Within the context of this chapter, general findings of the identified SEM-based Risk-Path Model, and their compatibility with the findings of previously conducted related researches, and also with the comments of practitioners from the industry, are discussed. In section one, general structure of the SEM model and the identified risk paths are reviewed and their compatibility with research's theory is discussed. In section two, the effects of different vulnerability factors as the main initiatives of the future risk paths, possible risk-path scenarios, along with the cross-impacts of these identified paths are examined and reported. The emphasis of the third section is on the whole risk-related factors, their counter effects, and possible risk paths passing through specific factors.

6.1 Discussion on Identified Risk Paths

Every risk path scenario in the final Risk-Path Model is initiated from a specific vulnerability factor related to project environment. Therefore, the study's hypothesis about the influence of the project environment on different stages of the risk realization process is verified being adequately supported by actual data. This also complies with various vulnerability definitions offered by researchers such as Barber (2005), Zhang (2007), Ezell (2007), and Sarewitz et al. (2003). Unfavourable rules, structures, routines, cultures, actions, or conditions surrounding a candidate project, will increase the potential for occurrence of subsequent risks and will intensify the further consequences. For example, a highly imperfect contract (vulnerability) will increase the probability of further conflicts and disagreements among project parties (risk source). The risk sources, initiated from vulnerabilities, will have direct or indirect effects on some risk events which ultimately result in cost overrun. For instance, the conflicts (risk source) may lead to delays in project schedule and project cash flow (risk events), and ultimately result in cost overruns (risk consequence). In general, the verified Risk-Path Model supports the notion of incorporating critical fragilities of the system and their possible impacts into identification and evaluation phases, which is called as “vulnerability management” by Dikmen et al. (2008b).

The other noticeable paths are those derived from contractor-specific vulnerabilities, namely “Contractor’s Lack of Resources”, “Contractor’s Lack of Experience”, and “Contractor’s Lack of Managerial Skills”. These factors are found to have significant direct or indirect effects on the five risk events, rather than any risk sources. As Dikmen et al. (2009) mentioned, these vulnerabilities affect the manageability of the risks and will influence magnitude of risk events directly. In other words, these vulnerability factors influence the size and significance of risk events which are caused by combination of different risks. The higher the level of these vulnerabilities, the less control and less manageability of the risks, and therefore, higher level of risk events. For instance, changes in project specifications (risk source) and subsequent delays (risk event 1) will have much more impact on project cash flow (risk event 2) if the contractor does not have the required management skills (contractor-specific vulnerability).

Another noteworthy point is that no significant path was estimated to be initiated from “Unexpected Events”, and this factor is found to have direct effect on project cost overrun. This means that no standard scheme, representing significant portion of cases, was found for the way these variables affect project cost overrun. In every project, these unexpected events may occur in several patterns with various types and extends. Moreover, since they are less frequently seen than other risk sources, not most of the projects in the sample data contained information related to these factors. Therefore, although the model shows that if they occur, these unexpected risks will significantly affect project cost overrun, it does not demonstrate the path through which these risks generally occur. Researchers such as Ghosh and Jintanapakanont (2004) have found similar results related to the correlation among such unexpected risks and other project risks.

Model also shows that the vulnerability factor related to design problems is affected by two other vulnerability factors, namely “Project Complexity” and “Client Incompetency”. This illustrates that apart from risk sources, vulnerabilities can also be born from other vulnerability factors.

Although all predicted paths are rationally acceptable and are supported by related literature, some logically possible paths are predicted to be insignificant. For example, the initially hypothesized paths between “Adverse Change in Resource Availability” and “Delays/Interruptions”, and also “Decrease in Productivity” were found to be statistically insignificant, and hence, were eliminated from the final model. This means that, for the cases included in the SEM database, not a significant portion of variations in “Delay/Interruption” comes from the variation of “Adverse Change in Resource Availability”. Such initially hypothesized but insignificant paths are indicated in Figure 5.10 by dashed arrows.

6.2 Discussion on Vulnerability Effects

6.2.1 Model Findings about Vulnerability Effects

The main superiority of SEM over other statistical methods previously applied in risk identification and assessment stages is that, instead of estimation of risk impacts in a single level, their interdependencies are included in the evaluation processes. Some factors affect the project cost directly; however, some influence it through indirect or both direct and indirect ways.

Table 6.1 shows all identified 36 risk-path scenarios derived from each of system vulnerability factors along with the decomposition of their standardized effects on project cost overrun. These results illustrate the way that various fragilities inherent in diverse elements of project system can affect its cost performance along with the levels of these effects.

Contractor-related vulnerabilities: As also illustrated in Figure 6.1, contractor specific vulnerabilities have the highest effect on project cost overrun, and among all, the impact of contractor's inadequate financial, technical and human resources on cost performance of the project is the largest one. This result underlines the importance of the manageability factors. That is, even though the occurrence of diverse risks in construction projects is a norm rather than exception, contractors can control the pattern of their emergence and mitigate their impacts by utilizing effective management strategies. Several authors have previously emphasized on the role of such managerial and resource specific factors on the success of the project to achieve its budget targets (e.g. Morris and Hough, 1987; Munns and Bjeirmi, 1996, and Belassi and Tukel, 1996).

Uncertain site/geological condition: The second most significant factor is found to be inadequate site and geological investigation at the primary stages of the project. This illustrates the importance of detailed site and ground surveys at the preconstruction stages since it reduces the probability and level of subsequent design/scope changes which are mostly originated from lack of enough information. Numerous researchers such as Kaming et al. (1997), Akinci and Fischer (1998), Sun and Meng (2009), and Hwang et al. (2009) have illustrated the way these changes may lead to cost overruns. On the other hand, investigating site and ground condition of the candidate projects at pre-bidding and pre-contract stages is an important requirement for realistic cost estimation since contract conditions generally do not compensate contractors for the additional costs due to such sources.

Client incompetency: The next considerable impact belongs to client specific vulnerabilities. Client is one of the main two stakeholders of the project who determines the requirements, deliverables and specifications, and provides necessary funding of the project. Besides its facilitating role throughout the lifecycle of the project, it's behavioral, managerial, financial, technical, and organizational incompetency can cause various unfavorable consequences on project objectives. Authors such as Kamara et al. (2002) have emphasized on the critical role of the project owner's characteristics and requirements in construction projects. Results of the Risk-Path Model demonstrate that client's reputation, experience in similar projects, and financial and managerial capabilities should be taken into account along with project and country conditions.

Unexpected events: The effects of unexpected events such as war, hostilities, rebellion, and natural catastrophe are also estimated to have important effects on project cost performance. Although Smith et al. (2006) consider such risks as "unknown-unknown" risks, whose neither probability nor impact can be foreseen by even highly experienced professionals, there is a general consensus that, in spite of their low probability of occurrence, if they occur, they will have significant impacts on project objectives, specially on project time and budget (Baloi and Price, 2003, and Ghosh and Jintanapakanont, 2004).

Adverse country conditions: Host country-specific factors have also considerable impacts on cost overrun. Since contractors of international projects, compared to those of domestic ones, are more unfamiliar with foreign country factors (Zhi, 1995), and due to high sensitivity of overseas projects to macro environmental issues (Gunhan and Arditi, 2005, and Han and Diekmann, 2001), possible impacts of country conditions on project success have been emphasized by several researchers (e.g. Ashley and Bonner, 1987; Zhi, 1995, and Hastak and Shaked, 2000). The results of the effect decomposition (Table 6.1 and Figure 6.1) also illustrate that country's undesired economical, political, legal, social and market conditions can result in diverse risk paths leading to significant cost overruns.

Table 6.1: Effect decomposition of identified risk paths

Risk Paths Derived from Vulnerabilities	**Effect of Each Path**	Total Effect of Vulnerability
(Conty-Cndtn) $\xrightarrow{0.2}$ (Conty-Econ) $\xrightarrow{0.715}$ (Avlb-Res) $\xrightarrow{0.1}$ (Unt-Cst) $\xrightarrow{0.67}$ (Cst-Ovrn)	0.01	**0.043**
(Conty-Cndtn) $\xrightarrow{0.2}$ (Conty-Econ) $\xrightarrow{0.655}$ (Law-Reg) $\xrightarrow{0.1}$ (Prdcty) $\xrightarrow{0.87}$ (Unt-Cst) $\xrightarrow{0.67}$ (Cst-Ovrn)	0.008	
(Conty-Cndtn) $\xrightarrow{0.2}$ (Conty-Econ) $\xrightarrow{0.655}$ (Law-Reg) $\xrightarrow{0.033}$ (Coflt) $\xrightarrow{0.293}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.0001	
(Conty-Cndtn) $\xrightarrow{0.2}$ (Conty-Econ) $\xrightarrow{0.693}$ (Clt-Prfc) $\xrightarrow{0.722}$ (Coflt) $\xrightarrow{0.293}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.003	
(Conty-Cndtn) $\xrightarrow{0.2}$ (Conty-Econ) $\xrightarrow{0.693}$ (Clt-Prfc) $\xrightarrow{0.718}$ (Prjt-Sps) $\xrightarrow{0.39}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.003	
(Conty-Cndtn) $\xrightarrow{0.2}$ (Conty-Econ) $\xrightarrow{0.693}$ (Clt-Prfc) $\xrightarrow{0.718}$ (Prjt-Sps) $\xrightarrow{0.218}$ (Wrk-Amnt) $\xrightarrow{0.408}$ (Cst-Ovrn)	0.009	
(Conty-Cndtn) $\xrightarrow{0.122}$ (Law-Reg) $\xrightarrow{0.1}$ (Prdcty) $\xrightarrow{0.87}$ (Unt-Cst) $\xrightarrow{0.67}$ (Cst-Ovrn)	0.007	
(Conty-Cndtn) $\xrightarrow{0.122}$ (Law-Reg) $\xrightarrow{0.033}$ (Coflt) $\xrightarrow{0.293}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.0001	
(Pjt-Cmx) $\xrightarrow{0.276}$ (Dsgn-Prblm) $\xrightarrow{0.182}$ (Wrk-Amnt) $\xrightarrow{0.408}$ (Cst-Ovrn)	0.02	0.02
(Glgcl) $\xrightarrow{0.458}$ (Chng-Sit) $\xrightarrow{0.36}$ (Prdcty) $\xrightarrow{0.87}$ (Unt-Cst) $\xrightarrow{0.67}$ (Cst-Ovrn)	0.096	0.122
(Glgcl) $\xrightarrow{0.458}$ (Chng-Sit) $\xrightarrow{0.314}$ (Prjt-Sps) $\xrightarrow{0.39}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.005	
(Glgcl) $\xrightarrow{0.458}$ (Chng-Sit) $\xrightarrow{0.314}$ (Prjt-Sps) $\xrightarrow{0.218}$ (Wrk-Amnt) $\xrightarrow{0.408}$ (Cst-Ovrn)	0.013	
(Glgcl) $\xrightarrow{0.458}$ (Chng-Sit) $\xrightarrow{0.1}$ (Con-Prfc) $\xrightarrow{0.246}$ (Coflt) $\xrightarrow{0.293}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.0003	
(Glgcl) $\xrightarrow{0.458}$ (Chng-Sit) $\xrightarrow{0.1}$ (Con-Prfc) $\xrightarrow{0.348}$ (Qlty) $\xrightarrow{0.671}$ (Wrk-Amnt) $\xrightarrow{0.408}$ (Cst-Ovrn)	0.004	

Table 6.1: Effect decomposition of identified risk paths (Continued)

Risk Paths Derived from Vulnerabilities	Effect of Each Path	Total Effect of Vulnerability
(Strct-Rqr) $\xrightarrow{0.06}$ (Con-Prfc) $\xrightarrow{0.246}$ (Coflt) $\xrightarrow{0.293}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.0004	0.007
(Strct-Rqr) $\xrightarrow{0.06}$ (Con-Prfc) $\xrightarrow{0.348}$ (Qlty) $\xrightarrow{0.671}$ (Wrk-Amnt) $\xrightarrow{0.408}$ (Cst-Ovrn)	0.006	
(Cont-Prblm) $\xrightarrow{0.577}$ (Coflt) $\xrightarrow{0.293}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.015	0.015
(Eng-Incpt) $\xrightarrow{0.158}$ (Clt-Prfc) $\xrightarrow{0.722}$ (Coflt) $\xrightarrow{0.293}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.003	0.019
(Eng-Incpt) $\xrightarrow{0.158}$ (Clt-Prfc) $\xrightarrow{0.718}$ (Prjt-Sps) $\xrightarrow{0.39}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.004	
(Eng-Incpt) $\xrightarrow{0.158}$ (Clt-Prfc) $\xrightarrow{0.718}$ (Prjt-Sps) $\xrightarrow{0.218}$ (Wrk-Amnt) $\xrightarrow{0.408}$ (Cst-Ovrn)	0.01	
(Clt-Incpt) $\xrightarrow{0.388}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.083	0.102
(Clt-Incpt) $\xrightarrow{0.202}$ (Dsgn-Prblm) $\xrightarrow{0.182}$ (Wrk-Amnt) $\xrightarrow{0.408}$ (Cst-Ovrn)	0.015	
(Sit-Condtn) $\xrightarrow{0.75}$ (Chng-Sit) $\xrightarrow{0.36}$ (Prdcty) $\xrightarrow{0.87}$ (Unt-Cst) $\xrightarrow{0.67}$ (Cst-Ovrn)	0.157	0.267
(Sit-Condtn) $\xrightarrow{0.75}$ (Chng-Sit) $\xrightarrow{0.314}$ (Prjt-Sps) $\xrightarrow{0.39}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.008	
(Sit-Condtn) $\xrightarrow{0.75}$ (Chng-Sit) $\xrightarrow{0.314}$ (Prjt-Sps) $\xrightarrow{0.218}$ (Wrk-Amnt) $\xrightarrow{0.408}$ (Cst-Ovrn)	0.021	
(Sit-Condtn) $\xrightarrow{0.75}$ (Chng-Sit) $\xrightarrow{0.1}$ (Con-Prfc) $\xrightarrow{0.246}$ (Coflt) $\xrightarrow{0.293}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.005	
(Sit-Condtn) $\xrightarrow{0.75}$ (Chng-Sit) $\xrightarrow{0.1}$ (Con-Prfc) $\xrightarrow{0.348}$ (Qlty) $\xrightarrow{0.671}$ (Wrk-Amnt) $\xrightarrow{0.408}$ (Cst-Ovrn)	0.007	
(Sit-Condtn) $\xrightarrow{0.72}$ (Con-Prfc) $\xrightarrow{0.246}$ (Coflt) $\xrightarrow{0.293}$ (Dely-Intrpt) $\xrightarrow{0.422}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.005	

Table 6.1: Effect decomposition of identified risk paths (Continued)

Risk Paths Derived from Vulnerabilities	Effect of Each Path	Total Effect of Vulnerability
(Sit-Condtn) $\xrightarrow{0.72}$ (Con-Prfc) $\xrightarrow{0.348}$ (Qlty) $\xrightarrow{0.671}$ (Wrk-Amnt) $\xrightarrow{0.408}$ (Cst-Ovrn)	0.069	
(Con-Expr) $\xrightarrow{0.167}$ (Prdcty) $\xrightarrow{0.87}$ (Unt-Cst) $\xrightarrow{0.67}$ (Cst-Ovrn)	0.097	0.139
(Con-Expr) $\xrightarrow{0.13}$ (Qlty) $\xrightarrow{0.671}$ (Wrk-Amnt) $\xrightarrow{0.408}$ (Cst-Ovrn)	0.036	
(Con-Res) $\xrightarrow{0.6}$ (Prdcty) $\xrightarrow{0.87}$ (Unt-Cst) $\xrightarrow{0.67}$ (Cst-Ovrn)	0.35	0.565
(Con-Res) $\xrightarrow{0.667}$ (Qlty) $\xrightarrow{0.671}$ (Wrk-Amnt) $\xrightarrow{0.408}$ (Cst-Ovrn)	0.183	
(Con-Mngt) $\xrightarrow{0.274}$ (Prdcty) $\xrightarrow{0.87}$ (Unt-Cst) $\xrightarrow{0.67}$ (Cst-Ovrn)	0.16	0.275
(Con-Mngt) $\xrightarrow{0.504}$ (Csh-Flw) $\xrightarrow{0.213}$ (Cst-Ovrn)	0.107	

Note: A) The abbreviations of the variables are given in Table 5.1.

B) All identified paths are mutually significant at 5% level.

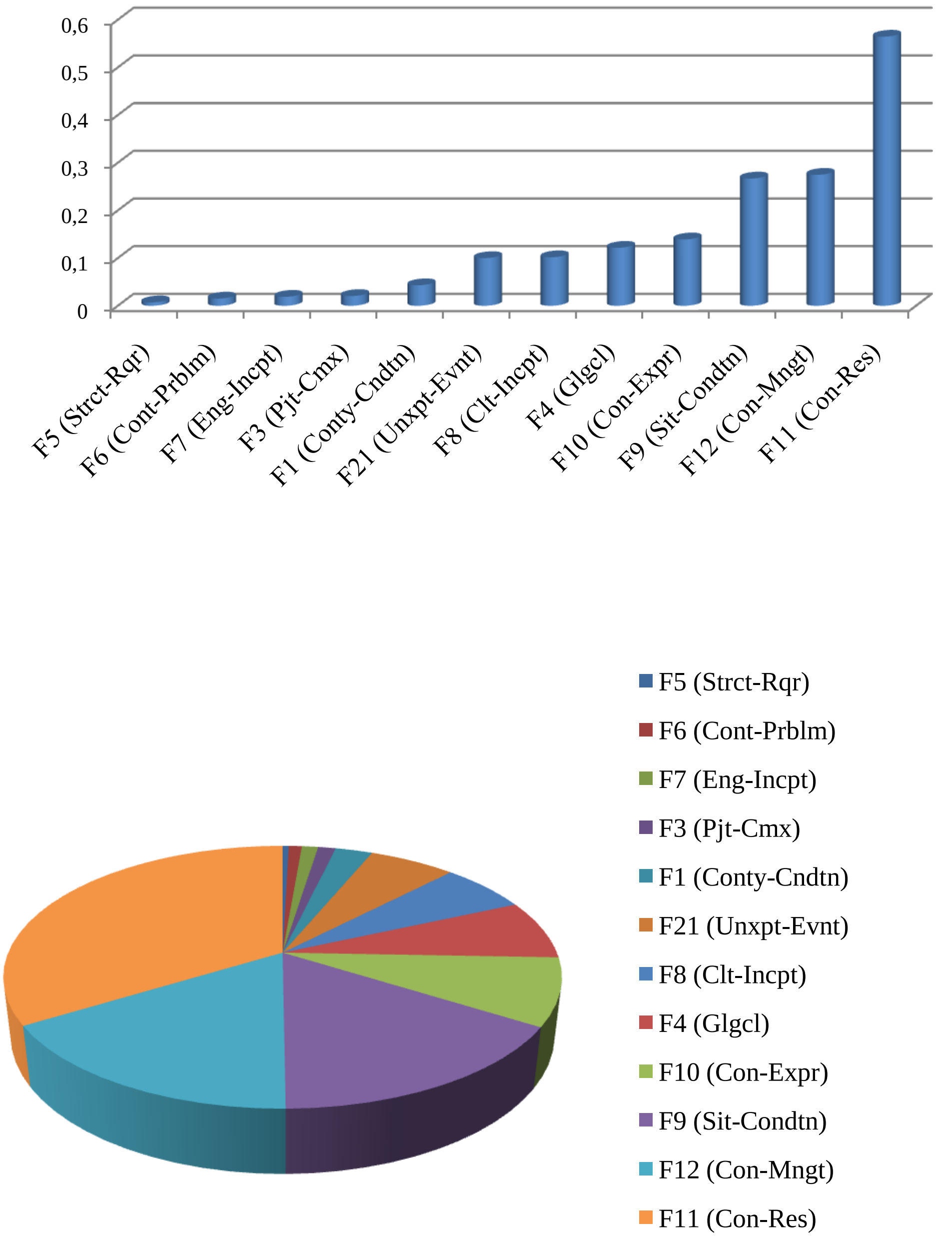


Figure 6.1: Ranking of total effects of vulnerability factors and unexpected events on project cost overrun

Note: The abbreviations of the variables are given in Table 5.1.

6.2.2 Experts' Comments about Vulnerability Effects

As mentioned in chapter 3, in part A of the developed questionnaire, interviewees were asked to weight various vulnerability variables in terms of their possible effects on project cost overrun and creating future risks. Figure 6.2 shows vulnerability factors with average weights of their underlying observed variables greater than or equal to 3, and with standard deviations less than or equal to 1. Figure 6.3 displays the ranking of all the vulnerability factors according to the average values of the assigned weights to their indicator variables. These figures illustrate that the results of the Risk-Path Model do not contradict with what have been mentioned by the experts. All of the vulnerability factors having been found through SEM analysis to have significant effects on project cost performance have also been considered as the most critical ones by industry practitioners.

However, there are some differences in the sequencing of the factors. Although contractors have claimed that the most effective factor is related to the client, results of the analysis show that high levels of contractor specific vulnerabilities will have more significant impacts on the cost performance of the project. Also, site and geological conditions whose probable risks and associated costs are mostly investigated and estimated at bidding stage of the projects, are the factors less emphasized by the contractors, but SEM results show that they have high effects on project cost performance.

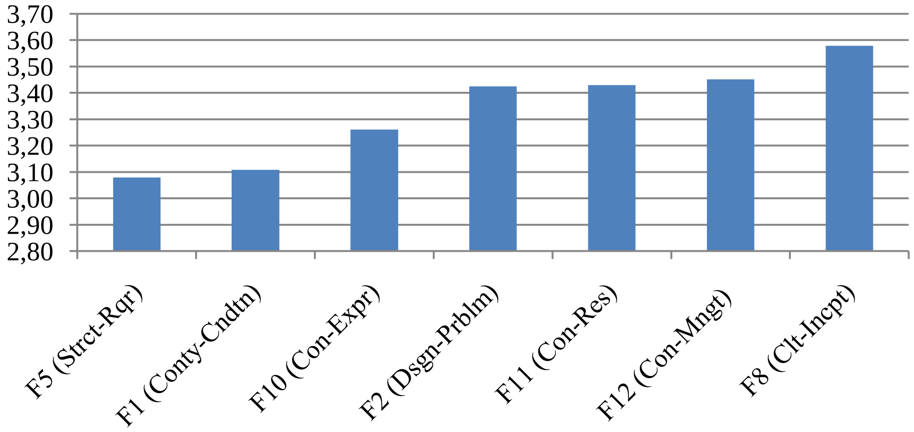


Figure 6.2: Ranking of the top vulnerability factors ranked as the most critical ones by experts (with Mean ≥ 3 and SD ≤ 1)

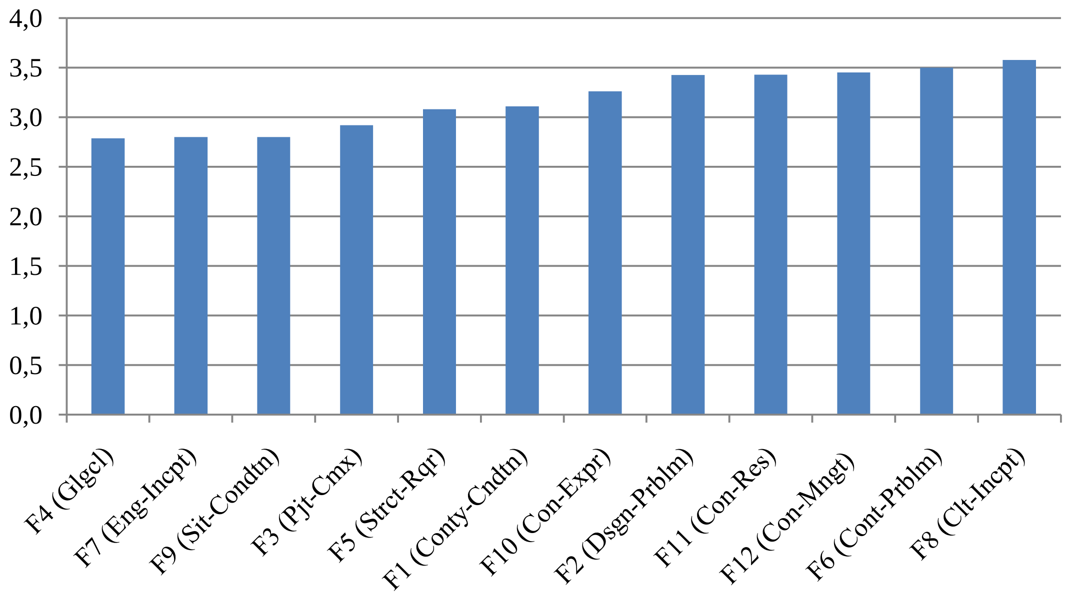


Figure 6.3: Ranking of the all vulnerability factors based on the average weights assigned by experts

Note: The abbreviations of the variables are given in Table 5.1.

6.3 Discussion on Risk Effects

As well as the decomposition of the effects of vulnerability factors, the impacts of various risk sources on each other can also be investigated based on the SEM findings. Investigating the impacts of vulnerability factors on cost overrun will mostly be helpful at the preliminary stages of the project. However, tracing the patterns of occurrence and effects of interdependent risks will provide adequate insights for the managers throughout the life cycle of the project. For instance, in the case of occurrence of adverse changes in site or ground conditions, possible future risk sources and subsequent risk events will be better estimated by looking at the risk paths that could be derived due to this problem, and the severity of the forthcoming events can be evaluated based on the magnitude of the occurred changes.

Effect decomposition of all the vulnerability and risk factors, which act as the building blocks of the Risk-Path Model, on each other, along with the direct and indirect proportion of these effects are demonstrated in table 6.2. Table 6.3 summarizes total counter effects of all the risk related factors in the form of an effect matrix. The values of this matrix include both direct and indirect effects of all interactive factors on each other. The value in each cell represents the total effect of the exogenous factor on the corresponding endogenous factors through all possible direct and indirect paths. For example, the total effect of “Adverse Site Condition” on “Decrease in Quality of Work” is 0.277; however, this effect is not through one direct path, and as can be traced from figure 5.10 and table 6.1, and as illustrated in table 6.2, two interactive risk paths contribute to this total effect;

1) Adverse Site Condition → AC in Site Condition → AC in Performance of Contractor → Decrease in Quality of Work
2) Adverse Site Condition → AC in Performance of Contractor → Decrease in Quality of Work

Therefore, by means of the contents of table 6.1, 6.2, and 6.3, the total effects of factors on each other can be interpreted, and the paths (scenarios) through which such effects come true can be identified. Furthermore, the final Risk-Path Model represented in figure 5.10 provides users with adequate virtual representation of the possible interactions and cross-impacts among such identified scenarios. Through this approach, various vulnerability and risk factors and their possible outcomes are not studied hierarchically but in an interactive, scenario-based, and more realistic manner.

Table 6.2: Effect decomposition of risk and vulnerabilities on each other

Effecting Factor	Path	Effect Type	Effect Coefficient
F1	(Conty-Cndtn)→ (Conty-Econ)	Direct	0.2
	(Conty-Cndtn)→ (Law-Reg)	Direct Indirect Total	0.122 0.131 0.253
	(Conty-Cndtn)→ (Clt-Prfc)	Indirect	0.139
	(Conty-Cndtn)→ (Avlb-Res)	Indirect	0.143
	(Conty-Cndtn)→ (Coflt)	Indirect	0.108
	(Conty-Cndtn)→ (Prjt-Sps)	Indirect	0.1
	(Conty-Cndtn)→ (Dely-Intrpt)	Indirect	0.071
	(Conty-Cndtn)→ (Prdcty)	Indirect	0.025
	(Conty-Cndtn)→ (Wrk-Amnt)	Indirect	0.022
	(Conty-Cndtn)→ (Unt-Cst)	Indirect	0.036
	(Conty-Cndtn)→ (Csh-Flw)	Indirect	0.03
	(Conty-Cndtn)→ (Cst-Ovrn)	Indirect	0.043
F2	(Dsgn-Prblm)→ (Wrk-Amnt)	Direct	0.182
	(Dsgn-Prblm)→ (Cst-Ovrn)	Indirect	0.087
F3	(Pjt-Cmx)→ (Dsgn-Prblm)	Direct	0.276
	(Pjt-Cmx)→ (Wrk-Amnt)	Indirect	0.05
	(Pjt-Cmx)→ (Cst-Ovrn)	Indirect	0.02
F4	(Glgcl)→ (Chng-Sit)	Direct	0.458
	(Glgcl)→ (Con-Prfc)	Indirect	0.046
	(Glgcl)→ (Coflt)	Indirect	0.003
	(Glgcl)→ (Prjt-Sps)	Indirect	0.144
	(Glgcl)→ (Dely-Intrpt)	Indirect	0.06
	(Glgcl)→ (Prdcty)	Indirect	0.165
	(Glgcl)→ (Qlty)	Indirect	0.016
	(Glgcl)→ (Wrk-Amnt)	Indirect	0.04
	(Glgcl)→ (Unt-Cst)	Indirect	0.143
	(Glgcl)→ (Csh-Flw)	Indirect	0.025
	(Glgcl)→ (Cst-Ovrn)	Indirect	0.122
F5	(Strct-Rqr)→ (Con-Prfc)	Direct	0.06
	(Strct-Rqr)→ (Coflt)	Indirect	0.015
	(Strct-Rqr)→ (Dely-Intrpt)	Indirect	0.004
	(Strct-Rqr)→ (Qlty)	Indirect	0.021
	(Strct-Rqr)→ (Wrk-Amnt)	Indirect	0.014
	(Strct-Rqr)→ (Csh-Flw)	Indirect	0.002
	(Strct-Rqr)→ (Cst-Ovrn)	Indirect	0.007
F6	(Cont-Prblm)→ (Coflt)	Direct	0.577
	(Cont-Prblm)→ (Dely-Intrpt)	Indirect	0.17
	(Cont-Prblm)→ (Csh-Flw)	Indirect	0.071
	(Cont-Prblm)→ (Cst-Ovrn)	Indirect	0.015
F7	(Eng-Incpt)→ (Clt-Prfc)	Indirect	0.158
	(Eng-Incpt)→ (Coflt)	Indirect	0.114
	(Eng-Incpt)→ (Prjt-Sps)	Indirect	0.113
	(Eng-Incpt)→ (Dely-Intrpt)	Indirect	0.078
	(Eng-Incpt)→ (Wrk-Amnt)	Indirect	0.025

Table 6.2: Effect decomposition of risk and vulnerabilities on each other (continued)

Effecting Factor	Path	Effect Type	Effect Coefficient
F7	(Eng-Incpt)→ (Csh-Flw)	Indirect	0.014
	(Eng-Incpt)→ (Cst-Ovrn)	Indirect	0.019
F8	(Clt-Incpt)→ (Dsgn-Prblm)	Direct	0.202
	(Clt-Incpt)→ (Wrk-Amnt)	Indirect	0.037
	(Clt-Incpt)→ (Csh-Flw)	Direct	0.388
	(Clt-Incpt)→ (Cst-Ovrn)	Indirect	0.102
F9	(Sit-Condtn)→ (Chng-Sit)	Direct	0.75
	(Sit-Condtn)→ (Con-Prfc)	Direct Indirect Total	0.72 0.075 0.795
	(Sit-Condtn)→ (Coflt)	Indirect	0.196
	(Sit-Condtn)→ (Prjt-Sps)	Indirect	0.235
	(Sit-Condtn)→ (Dely-Intrpt)	Indirect	0.149
	(Sit-Condtn)→ (Prdcty)	Indirect	0.27
	(Sit-Condtn)→ (Qlty)	Indirect	0.277
	(Sit-Condtn)→ (Wrk-Amnt)	Indirect	0.237
	(Sit-Condtn)→ (Unt-Cst)	Indirect	0.235
	(Sit-Condtn)→ (Csh-Flw)	Indirect	0.063
	(Sit-Condtn)→ (Cst-Ovrn)	Indirect	0.267
F10	(Con-Expr)→ (Prdcty)	Direct	0.167
	(Con-Expr)→ (Qlty)	Direct	0.13
	(Con-Expr)→ (Wrk-Amnt)	Indirect	0.087
	(Con-Expr)→ (Unt-Cst)	Indirect	0.145
	(Con-Expr)→ (Cst-Ovrn)	Indirect	0.139
F11	(Con-Res)→ (Prdcty)	Direct	0.6
	(Con-Res)→ (Qlty)	Direct	0.667
	(Con-Res)→ (Wrk-Amnt)	Indirect	0.448
	(Con-Res)→ (Unt-Cst)	Indirect	0.522
	(Con-Res)→ (Cst-Ovrn)	Indirect	0.565
F12	(Con-Mngt)→ (Prdcty)	Direct	0.274
	(Con-Mngt)→ (Unt-Cst)	Indirect	0.238
	(Con-Mngt)→ (Csh-Flw)	Direct	0.504
	(Con-Mngt)→ (Cst-Ovrn)	Indirect	0.275
F13	(Conty-Econ)→ (Law-Reg)	Direct	0.655
	(Conty-Econ)→ (Clt-Prfc)	Direct	0.693
	(Conty-Econ)→ (Avlb-Res)	Direct	0.715
	(Conty-Econ)→ (Coflt)	Indirect	0.522
	(Conty-Econ)→ (Prjt-Sps)	Indirect	0.498
	(Conty-Econ)→ (Dely-Intrpt)	Indirect	0.347
	(Conty-Econ)→ (Prdcty)	Indirect	0.066
	(Conty-Econ)→ (Wrk-Amnt)	Indirect	0.108
	(Conty-Econ)→ (Unt-Cst)	Indirect	0.128
	(Conty-Econ)→ (Csh-Flw)	Indirect	0.146
	(Conty-Econ)→ (Cst-Ovrn)	Indirect	0.174

Table 6.2: Effect decomposition of risk and vulnerabilities on each other (continued)

Effecting Factor	Path	Effect Type	Effect Coefficient
F14	(Law-Reg)→ (Coflt)	Direct	0.033
	(Law-Reg)→ (Dely-Intrpt)	Indirect	0.01
	(Law-Reg)→ (Prdcty)	Direct	0.1
	(Law-Reg)→ (Unt-Cst)	Indirect	0.087
	(Law-Reg)→ (Csh-Flw)	Indirect	0.004
	(Law-Reg)→ (Cst-Ovrn)	Indirect	0.067
F15	(Coflt)→ (Dely-Intrpt)	Direct	0.293
	(Coflt)→ (Csh-Flw)	Indirect	0.124
	(Coflt)→ (Cst-Ovrn)	Indirect	0.028
F16	(Clt-Prfc)→ (Coflt)	Direct	0.722
	(Clt-Prfc)→ (Prjt-Sps)	Direct	0.718
	(Clt-Prfc)→ (Dely-Intrpt)	Indirect	0.492
	(Clt-Prfc)→ (Wrk-Amnt)	Indirect	0.156
	(Clt-Prfc)→ (Csh-Flw)	Indirect	0.207
	(Clt-Prfc)→ (Cst-Ovrn)	Indirect	0.119
F17	(Prjt-Sps)→ (Dely-Intrpt)	Direct	0.39
	(Prjt-Sps)→ (Wrk-Amnt)	Direct	0.218
	(Prjt-Sps)→ (Csh-Flw)	Indirect	0.164
	(Prjt-Sps)→ (Cst-Ovrn)	Indirect	0.14
F18	(Con-Prfc)→ (Coflt)	Direct	0.246
	(Con-Prfc)→ (Dely-Intrpt)	Indirect	0.072
	(Con-Prfc)→ (Qlty)	Direct	0.348
	(Con-Prfc)→ (Wrk-Amnt)	Indirect	0.233
	(Con-Prfc)→ (Csh-Flw)	Indirect	0.03
	(Con-Prfc)→ (Cst-Ovrn)	Indirect	0.119
F19	(Avlb-Res)→ (Unt-Cst)	Direct	0.1
	(Avlb-Res)→ (Cst-Ovrn)	Indirect	0.067
F20	(Chng-Sit)→ (Con-Prfc)	Direct	0.1
	(Chng-Sit)→ (Coflt)	Indirect	0.025
	(Chng-Sit)→ (Prjt-Sps)	Direct	0.314
	(Chng-Sit)→ (Dely-Intrpt)	Indirect	0.13
	(Chng-Sit)→ (Prdcty)	Direct	0.36
	(Chng-Sit)→ (Qlty)	Indirect	0.035
	(Chng-Sit)→ (Wrk-Amnt)	Indirect	0.092
	(Chng-Sit)→ (Unt-Cst)	Indirect	0.313
	(Chng-Sit)→ (Csh-Flw)	Indirect	0.055
	(Chng-Sit)→ (Cst-Ovrn)	Indirect	0.266
F21	(Unxpt-Evnt)→ (Cst-Ovrn)	Direct	0.1
F22	(Dely-Intrpt)→ (Csh-Flw)	Direct	0.422
	(Dely-Intrpt)→ (Cst-Ovrn)	Indirect	0.09
F23	(Prdcty)→ (Unt-Cst)	Direct	0.87
	(Prdcty)→ (Cst-Ovrn)	Indirect	0.583
F24	(Wrk-Amnt)→ (Cst-Ovrn)	Direct	0.408
F25	(Qlty)→ (Wrk-Amnt)	Direct	0.671
	(Qlty)→ (Cst-Ovrn)	Indirect	0.322
F26	(Unt-Cst)→ (Cst-Ovrn)	Direct	0.67
F27	(Csh-Flw)→ (Cst-Ovrn)	Direct	0.213

Table 6.3: Total effects of model’s latent factors on each other

Endogenous Factors

Exogenous Factors		(Conty-Cndtn)	(Dsgn-Prblm)	(Pjt-Cmx)	(Glgcl)	(Strct-Rqr)	(Cont-Prblm)	(Eng-Incpt)	(Clt-Incpt)	(Sit-Condtn)	(Con-Expr)	(Con-Res)	(Con-Mngt)	(Conty-Econ)	(Law-Reg)	(Coflt)	(Clt-Prfc)	(Prjt-Sps)	(Con-Prfc)	(Avlb-Res)	(Chng-Sit)	(Unxpt-Evnt)	(Dely-Intrpt)	(Prdcty)	(Wrk-Amnt)	(Qlty)	(Unt-Cst)	(Csh-Flw)	(Cst-Ovrn)
		F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**	**F11**	**F12**	**F13**	**F14**	**F15**	**F16**	**F17**	**F18**	**F19**	**F20**	**F21**	**F22**	**F23**	**F24**	**F25**	**F26**	**F27**	**F28**
(Conty-Cndtn)	**F1**													0,2	0,253	0,184	0,139	0,100		0,143			0,093	0,025	0,022		0,036	0,039	0,043
(Dsgn-Prblm)	**F2**																								0,182				0,087
(Pjt-Cmx)	**F3**		0,276																						0,100				0,020
(Glgcl)	**F4**															0,011		0,144	0,046		0,46		0,059	0,165	0,042	0,016	0,143	0,025	0,122
(Strct-Rqr)	**F5**															0,148			0,6				0,043		0,140	0,209		0,018	0,007
(Cont-Prblm)	**F6**															0,577							0,169					0,071	0,015
(Eng-Incpt)	**F7**															0,114	0,158	0,113					0,078		0,025			0,033	0,019
(Clt-Incpt)	**F8**		0,22																						0,040			0,388	0,102
(Sit-Condtn)	**F9**															0,177		0,236	0,795		0,75		0,149	0,270	0,237	0,277	0,235	0,063	0,267
(Con-Expr)	**F10**																							0,167	0,087	0,13	0,145		0,139
(Con-Res)	**F11**																							0,600	0,448	0,667	0,522		0,565
(Con-Mngt)	**F12**																							0,274			0,238	0,54	0,275
(Conty-Econ)	**F13**														0,655	0,716	0,693	0,4976		0,715			0,404	0,066	0,108		0,128	0,144	0,174
(Law-Reg)	**F14**															0,33							0,097	0,1			0,087	0,041	0,067
(Coflt)	**F15**																						0,293					0,124	0,026
(Clt-Prfc)	**F16**															0,722		0,718					0,492		0,157			0,207	0,119
(Prjt-Sps)	**F17**																						0,39		0,218			0,165	0,140
(Con-Prfc)	**F18**															0,246							0,072		0,234	0,348		0,030	0,119
(Avlb-Res)	**F19**																										0,1		0,067
(Chng-Sit)	**F20**															0,025		0,314	0,1				0,130	0,36	0,092	0,035	0,313	0,055	0,266
(Unxpt-Evnt)	**F21**																												0,1
(Dely-Intrpt)	**F22**																											0,422	0,090
(Prdcty)	**F23**																										0,87		0,583
(Wrk-Amnt)	**F24**																												0,48
(Qlty)	**F25**																								0,671				0,322
(Unt-Cst)	**F26**																												0,67
(Csh-Flw)	**F27**																												0,213
(Cst-Ovrn)	**F28**																												

CHAPTER 7

USING THE IDENTIFIED RISK-PATH MODEL FOR PREDICTION PURPOSES

In this study, based on the underlying theory, numerous important hypotheses are developed. The hypothesized measurement models were tested in previous sections of this thesis through various validity and reliability tests. In the case of construct model, the reported fit indexes and the significance of the predicted paths support the main theorem of this research which is the existence of causality among various risk factors throughout the life cycle of a real construction project.

In addition to these achievements, the identified model can be utilized for estimation purposes. It means that the prediction capability of the SEM-based models can be applied to estimate the unknown magnitudes of the dependent factors of the Risk-Path Model, namely risk factors and the project’s cost overrun.

The applicability, completeness and generality of the Risk-Path Model can also be tested to check whether it is an adequate and comprehensive simulation of the real world. In other words, in this way, it can be examined whether the model and the hypothesized structure of the risk paths are able to sufficiently estimate the ultimate level of the project cost overrun using the available magnitudes of the project’s vulnerabilities.

Risk identification and assessment of their impacts on project outcomes are highly uncertain and tedious tasks since they are mostly conducted at preliminary stages of the construction projects when practitioners possess limited perception about the future due to lack of knowledge and necessary information. One of the main superiorities of this research is introduction of a theory for incorporation of project environment’s vulnerabilities into risk models which are utilized for identification and assessment purposes since they are the most certain knowledge sources accessible in these stages.

The aim of this chapter is to use the identified causalities connecting 12 vulnerability sources to other 16 risk-related factors, along with the estimated path coefficients, for prediction of the probable magnitude of the project cost overrun. The estimation capability of the SEM-based models is used in order to accomplish this task. It is also examined whether the magnitudes predicted through employing Risk-Path Model are good approximations of the actual values or not.

7.1 Application of the Risk-Path Model as a Prediction Tool: Case Studies

7.1.1 Case Studies Profile

The model will predict the magnitude of the projects’ cost overrun through 6 hierarchical estimation levels indicated in figure 5.10. The prediction process in a structural equation model is described in Appendix A through an illustrative example. In order to illustrate the application of the Risk-Path Model as a prediction tool, and to reinforce the validity of the Risk-Path Model, five test cases (not included in the SEM database) actually realized by Turkish contractors in foreign countries are randomly selected from the collected cases. Table 7.1 gives a brief description about the characteristics of these 5 cases.

Table 7.1: Characteristics of the test cases used for model implementation

Test Cases	Project Type	Project Region	Level of Actual Cost Overrun
Case 1	Transportation	Asia	2 (Low)
Case 2	Infrastructure	Asia	4 (High)
Case 3	Dam	Africa	3 (Medium)
Case 4	Industrial Plant	Africa	2 (Low)
Case 5	Building	Europe	1 (Very Low)

7.1.2 Prediction Process

As also defined in Appendix A, the magnitudes of the project's vulnerabilities are the known inputs of the Risk-Path Model. Based on the estimated counter-effects of the factors in each estimation level, the adjacency matrixes for each level are built. Finally, as the outputs of the prediction process, the likely magnitudes of the risk factors and the project cost overrun are estimated for each of the 5 test cases. Tables 7.2 to 7.7 summarize the effect decomposition of each prediction level. The adjacency matrixes for each prediction level are also presented in tables 7.8 to 7.13.

The magnitudes of different vulnerability variables related to the project environment will be inputted by the user in a 1-5 scale, and these values will act as the initial inputs of the Risk-Path Prediction Model. The inputted values are then standardized since standardized path coefficients are applied for estimation purposes. According to the factor loadings estimated through CFA, these inputted values are used for estimation of the corresponding latent vulnerability factors. Then, based on the process described in Appendix A, and by means of adjacency matrixes related to each prediction level, the standardized outputs of each level are predicted which will act as the inputs for the next level. The final output of the Risk-Path Model will be the de-standardized values estimated as the 6th level's output.

Table 7.2: Effect decomposition for the 1st prediction level of Risk-Path Model

LEVEL 1	(Conty-Cndtn) → (Conty-Econ)	**Direct Effect**	**0.2**
	(Pjt-Cmx) → (Dsgn-Prblm)	**Direct Effect**	**0.276**
	(Glgcl) → (Chng-Sit)	**Direct Effect**	**0.458**
	(Clt-Incpt) → (Dsgn-Prblm)	**Direct Effect**	**0.202**
	(Sit-Condtn) → (Chng-Sit)	**Direct Effect**	**0.75**

Table 7.3: Effect decomposition for the 2nd prediction level of Risk-Path Model

LEVEL 2	(Conty-Cndtn) → (Law-Reg)	**Direct Effect**	**0.122**
		Indirect Effect	**0.131**
		Total Effect	**0.253**
	(Conty-Econ) → (Avlb-Res)	**Direct Effect**	**0.715**
	(Conty-Econ) → (Law-Reg)	**Direct Effect**	**0.655**
	(Conty-Econ) → (Clt-Prfc)	**Direct Effect**	**0.693**
	(Eng-Incpt) → (Clt-Prfc)	**Direct Effect**	**0.158**
	(Sit-Condtn) → (Con-Prfc)	**Direct Effect**	**0.72**
		Indirect Effect	**0.078**
		Total Effect	**0.798**
	(Chng-Sit) → (Con-Prfc)	**Direct Effect**	**0.1**
	(Strct-Rqr) → (Con-Prfc)	**Direct Effect**	**0.06**

Table 7.4: Effect decomposition for the 3rd prediction level of Risk-Path Model

LEVEL 3	(Chng-Sit) → (Prjt-Sps)	**Direct Effect**	**0.314**
	(Con-Prfc) → (Coflt)	**Direct Effect**	**0.246**
	(Cont-Prblm) → (Coflt)	**Direct Effect**	**0.577**
	(Clt-Prfc) → (Prjt-Sps)	**Direct Effect**	**0.718**
	(Clt-Prfc) → (Coflt)	**Direct Effect**	**0.722**
	(Law-Reg) → (Coflt)	**Direct Effect**	**0.033**

Table 7.5: Effect decomposition for the 4th prediction level of Risk-Path Model

LEVEL 4	(Chng-Sit) → (Prdcty)	**Direct Effect**	**0.36**
	(Law-Reg) → (Prdcty)	**Direct Effect**	**0.1**
	(Con-Prfc) → (Qlty)	**Direct Effect**	**0.348**
	(Coflt) → (Dely-Intrpt)	**Direct Effect**	**0.293**

Table 7.5: Effect decomposition for the 4th prediction level of Risk-Path Model (Continued)

LEVEL 4	(Prjt-Sps) → (Dely-Intrpt)	**Direct Effect**	**0.39**
	(Con-Expr) → (Prdcty)	**Direct Effect**	**0.167**
	(Con-Expr) → (Qlty)	**Direct Effect**	**0.13**
	(Con-Res) → (Prdcty)	**Direct Effect**	**0.6**
	(Con-Res) → (Qlty)	**Direct Effect**	**0.667**
	(Con-Mngt) → (Prdcty)	**Direct Effect**	**0.274**

Table 7.6: Effect decomposition for the 5th prediction level of Risk-Path Model

LEVEL 5	(Clt-Incpt) → (Csh-Flw)	**Direct Effect**	**0.388**
	(Dsgn-Prblm) → (Wrk-Amnt)	**Direct Effect**	**0.182**
	(Avlb-Res) → (Unt-Cst)	**Direct Effect**	**0.1**
	(Prjt-Sps) → (Wrk-Amnt)	**Direct Effect**	**0.218**
	(Prdcty) → (Unt-Cst)	**Direct Effect**	**0.87**
	(Dely-Intrpt) → (Csh-Flw)	**Direct Effect**	**0.422**
	(Qlty) → (Wrk-Amnt)	**Direct Effect**	**0.671**
	(Con-Mngt) → (Csh-Flw)	**Direct Effect**	**0.504**

Table 7.7: Effect decomposition for the 6th prediction level of Risk-Path Model

LEVEL 6	(Wrk-Amnt) → (Cst-Ovrn)	**Direct Effect**	**0.408**
	(Csh-Flw) → (Cst-Ovrn)	**Direct Effect**	**0.213**
	(Unt-Cst) → (Cst-Ovrn)	**Direct Effect**	**0.67**
	(Unxpt-Evnt) → (Cst-Ovrn)	**Direct Effect**	**0.1**

Table 7.8: Adjacency matrix for 1st prediction level of Risk-Path Model

Effects Causes	(Conty-Cndtn)	(Dsgn-Prblm)	(Pjt-Cmx)	(Glgcl)	(Clt-Incpt)	(Conty-Econ)	(Sit-Condtn)	(Chng-Sit)
(Conty-Cndtn)	0	0	0	0	0	0.2	0	0
(Dsgn-Prblm)	0	0	0	0	0	0	0	0
(Pjt-Cmx)	0	0.276	0	0	0	0	0	0
(Glgcl)	0	0	0	0	0	0	0	0.458
(Clt-Incpt)	0	0.202	0	0	0	0	0	0
(Conty-Econ)	0	0	0	0	0	0	0	0
(Sit-Condtn)	0	0	0	0	0	0	0	0.75
(Chng-Sit)	0	0	0	0	0	0	0	0

Table 7.9: Adjacency matrix for 2nd prediction level of Risk-Path Model

Effects Causes	(Conty-Cndtn)	(Strct-Rqr)	(Eng-Incpt)	(Conty-Econ)	(Law-Reg)	(Clt-Prfc)	(Con-Prfc)	(Sit-Condtn)	(Avlb-Res)	(Chng-Sit)
(Conty-Cndtn)	0	0	0	0	0.122	0	0	0	0	0
(Strct-Rqr)	0	0	0	0	0	0	0.06	0	0	0
(Eng-Incpt)	0	0	0	0	0	0.158	0	0	0	0
(Conty-Econ)	0	0	0	0	0.655	0.693	0	0	0.715	0
(Law-Reg)	0	0	0	0	0	0	0	0	0	0
(Clt-Prfc)	0	0	0	0	0	0	0	0	0	0
(Con-Prfc)	0	0	0	0	0	0	0	0	0	0
(Sit-Condtn)	0	0	0	0	0	0	0.72	0	0	0
(Avlb-Res)	0	0	0	0	0	0	0	0	0	0
(Chng-Sit)	0	0	0	0	0	0	0.1	0	0	0

Table 7.10: Adjacency matrix for 3rd prediction level of Risk-Path Model

Effects / Causes	(Cont-Prblm)	(Law-Reg)	(Coflt)	(Clt-Prfc)	(Prjt-Sps)	(Con-Prfc)	(Chng-Sit)
(Cont-Prblm)	0	0	0.577	0	0	0	0
(Law-Reg)	0	0	0.033	0	0	0	0
(Coflt)	0	0	0	0	0	0	0
(Clt-Prfc)	0	0	0.722	0	0.718	0	0
(Prjt-Sps)	0	0	0	0	0	0	0
(Con-Prfc)	0	0	0.246	0	0	0	0
(Chng-Sit)	0	0	0	0	0.314	0	0

Table 7.11: Adjacency matrix for 4th prediction level of Risk-Path Model

Effects / Causes	(Con-Expr)	(Con-Res)	(Con-Mngt)	(Law-Reg)	(Coflt)	(Prjt-Sps)	(Con-Prfc)	(Chng-Sit)	(Dely-Intrpt)	(Prdcty)	(Qlty)
(Con-Expr)	0	0	0	0	0	0	0	0	0	0.167	0.13
(Con-Res)	0	0	0	0	0	0	0	0	0	0.6	0.667
(Con-Mngt)	0	0	0	0	0	0	0	0	0	0.274	0
(Law-Reg)	0	0	0	0	0	0	0	0	0	0.1	0
(Coflt)	0	0	0	0	0	0	0	0	0.293	0	0
(Prjt-Sps)	0	0	0	0	0	0	0	0	0.39	0	0
(Con-Prfc)	0	0	0	0	0	0	0	0	0	0	0.348
(Chng-Sit)	0	0	0	0	0	0	0	0	0	0.36	0
(Dely-Intrpt)	0	0	0	0	0	0	0	0	0	0	0
(Prdcty)	0	0	0	0	0	0	0	0	0	0	0
(Qlty)	0	0	0	0	0	0	0	0	0	0	0

Table 7.12: Adjacency matrix for 5th prediction level of Risk-Path Model

Effects **Causes**	(Dsgn-Prblm)	(Clt-Incpt)	(Con-Mngt)	(Prjt-Sps)	(Avlb-Res)	(Dely-Intrpt)	(Prdcty)	(Wrk-Amnt)	(Qlty)	(Unt-Cst)	(Csh-Flw)
(Dsgn-Prblm)	0	0	0	0	0	0	0	0.182	0	0	0
(Clt-Incpt)	0	0	0	0	0	0	0	0	0	0	0.388
(Con-Mngt)	0	0	0	0	0	0	0	0	0	0	0.504
(Prjt-Sps)	0	0	0	0	0	0	0	0.218	0	0	0
(Avlb-Res)	0	0	0	0	0	0	0	0	0	0.1	0
(Dely-Intrpt)	0	0	0	0	0	0	0	0	0	0	0.422
(Prdcty)	0	0	0	0	0	0	0	0	0	0.87	0
(Wrk-Amnt)	0	0	0	0	0	0	0	0	0	0	0
(Qlty)	0	0	0	0	0	0	0	0.671	0	0	0
(Unt-Cst)	0	0	0	0	0	0	0	0	0	0	0
(Csh-Flw)	0	0	0	0	0	0	0	0	0	0	0

Table 7.13: Adjacency matrix for 6th prediction level of Risk-Path Model

Effects **Causes**	(Unxpt-Evnt)	(Wrk-Amnt)	(Unt-Cst)	(Csh-Flw)	(Cst-Ovrn)
(Unxpt-Evnt)	0	0	0	0	0.1
(Wrk-Amnt)	0	0	0	0	0.408
(Unt-Cst)	0	0	0	0	0.67
(Csh-Flw)	0	0	0	0	0.213
(Cst-Ovrn)	0	0	0	0	0

Note: The abbreviations of the variables are given in Table 5.1.

7.1.3 Results of Case Studies

Table 7.14 summarizes the standardized input values for each test case in each estimation level, along with their final outputs. “Level 1” includes the input values of vulnerability factors for each test case. The values given for the “level 2” of each case show the input values that are going to be used for second prediction stage. These values comprise magnitudes which are initially inserted by the experts for vulnerability factors, along with estimated values for risk factors obtained from the first prediction stage. The same logic is true for all the subsequent prediction stages until acquisition of the final output values.

The estimated magnitudes of all the dependent factors and their comparison with their actual values are represented in table 7.15. The calculated rates (%) for prediction performance of the model show that it adequately covers significant risk-path scenarios leading to project cost overrun, and therefore, can be considered as a suitable simulation of a real construction projects.

For detailed explanations about the prediction process please refer to Appendix A.

Table 7.14: Standardized inputs in each prediction level and final estimated standardized outputs for each test case

Level	Cases	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23	F24	F25	F26	F27	F28
Level 1	**Case 1**	1.88	0	0.99	3	-1.15	0.3	-1.33	-0.81	-0.71	1.67	-1.35	-1.34	0	0	0	0	0	0	0	0	-0.39	0	0	0	0	0	0	0
	Case 2	-1.31	0	-1.02	3	-1.15	-0.26	0.82	0.31	-0.7	0.77	1.42	0.92	0	0	0	0	0	0	0	0	-0.39	0	0	0	0	0	0	0
	Case 3	-0.34	0	0.99	-2.86	-1.34	-1.42	-0.11	-1.37	0.28	1.91	-1.35	1.74	0	0	0	0	0	0	0	0	-0.39	0	0	0	0	0	0	0
	Case 4	0.41	0	-0.25	0.07	0.79	0.3	-0.73	0.08	0.86	-0.76	-0.75	-0.28	0	0	0	0	0	0	0	0	-0.39	0	0	0	0	0	0	0
	Case 5	-2.47	0	-1.64	-2.86	-1.36	-2	-0.43	-1.65	-1.53	-1.03	-0.49	-0.52	0	0	0	0	0	0	0	0	-0.39	0	0	0	0	0	0	0
Level 2	**Case 1**	1.88	0.11	0.99	3	-1.15	0.3	-1.33	-0.81	-0.71	1.67	-1.35	-1.34	0.38	0	0	0	0	0	0	1.92	-0.39	0	0	0	0	0	0	0
	Case 2	-1.31	-0.27	-1.02	3	-1.15	-0.26	0.82	0.31	-0.7	0.77	1.42	0.92	-0.26	0	0	0	0	0	0	0.83	-0.39	0	0	0	0	0	0	0
	Case 3	-0.34	0	0.99	-2.86	-1.34	-1.42	-0.11	-1.37	0.28	1.91	-1.35	1.74	-0.07	0	0	0	0	0	0	-1.08	-0.39	0	0	0	0	0	0	0
	Case 4	0.41	-0.05	-0.25	0.07	0.79	0.3	-0.73	0.08	0.86	-0.76	-0.75	-0.28	0.08	0	0	0	0	0	0	0.7	-0.39	0	0	0	0	0	0	0
	Case 5	-2.47	-0.79	-1.64	-2.86	-1.36	-2	-0.43	-1.65	-1.53	-1.03	-0.49	-0.52	-0.49	0	0	0	0	0	0	-2.5	-0.39	0	0	0	0	0	0	0
Level 3	**Case 1**	1.88	0.11	0.99	3	-1.15	0.3	-1.33	-0.81	-0.71	1.67	-1.35	-1.34	0.38	0.48	0	0.05	0	0.77	0.27	1.92	-0.39	0	0	0	0	0	0	0
	Case 2	-1.31	-0.27	-1.02	3	-1.15	-0.26	0.82	0.31	-0.7	0.77	1.42	0.92	-0.26	-0.33	0	-0.05	0	-0.63	-0.19	0.83	-0.39	0	0	0	0	0	0	0
	Case 3	-0.34	0	0.99	-2.86	-1.34	-1.42	-0.11	-1.37	0.28	1.91	-1.35	1.74	-0.07	-0.09	0	-0.06	0	0.08	-0.05	-1.08	-0.39	0	0	0	0	0	0	0
	Case 4	0.41	-0.05	-0.25	0.07	0.79	0.3	-0.73	0.08	0.86	-0.76	-0.75	-0.28	0.08	0.1	0	-0.06	0	0.91	0.06	0.7	-0.39	0	0	0	0	0	0	0
	Case 5	-2.47	-0.79	-1.64	-2.86	-1.36	-2	-0.43	-1.65	-1.53	-1.03	-0.49	-0.52	-0.49	-0.62	0	-0.41	0	-1.74	-0.35	-2.5	-0.39	0	0	0	0	0	0	0
Level 4	**Case 1**	1.88	0.11	0.99	3	-1.15	0.3	-1.33	-0.81	-0.71	1.67	-1.35	-1.34	0.38	0.48	0.41	0.05	0.64	0.77	0.27	1.92	-0.39	0	0	0	0	0	0	0
	Case 2	-1.31	-0.27	-1.02	3	-1.15	-0.26	0.82	0.31	-0.7	0.77	1.42	0.92	-0.26	-0.33	-0.36	-0.05	0.22	-0.63	-0.19	0.83	-0.39	0	0	0	0	0	0	0
	Case 3	-0.34	0	0.99	-2.86	-1.34	-1.42	-0.11	-1.37	0.28	1.91	-1.35	1.74	-0.07	-0.09	-0.85	-0.06	-0.39	0.08	-0.05	-1.08	-0.39	0	0	0	0	0	0	0
	Case 4	0.41	-0.05	-0.25	0.07	0.79	0.3	-0.73	0.08	0.86	-0.76	-0.75	-0.28	0.08	0.1	0.36	-0.06	0.18	0.91	0.06	0.7	-0.39	0	0	0	0	0	0	0
	Case 5	-2.47	-0.79	-1.64	-2.86	-1.36	-2	-0.43	-1.65	-1.53	-1.03	-0.49	-0.52	-0.49	-0.62	-1.9	-0.41	-1.08	-1.74	-0.35	-2.5	-0.39	0	0	0	0	0	0	0
Level 5	**Case 1**	1.88	0.11	0.99	3	-1.15	0.3	-1.33	-0.81	-0.71	1.67	-1.35	-1.34	0.38	0.48	0.41	0.05	0.64	0.77	0.27	1.92	-0.39	0.37	-0.16	0	-0.42	0	0	0
	Case 2	-1.31	-0.27	-1.02	3	-1.15	-0.26	0.82	0.31	-0.7	0.77	1.42	0.92	-0.26	-0.33	-0.36	-0.05	0.22	-0.63	-0.19	0.83	-0.39	-0.02	1.5	0	0.83	0	0	0
	Case 3	-0.34	0	0.99	-2.86	-1.34	-1.42	-0.11	-1.37	0.28	1.91	-1.35	1.74	-0.07	-0.09	-0.85	-0.06	-0.39	0.08	-0.05	-1.08	-0.39	-0.4	-0.42	0	-0.63	0	0	0
	Case 4	0.41	-0.05	-0.25	0.07	0.79	0.3	-0.73	0.08	0.86	-0.76	-0.75	-0.28	0.08	0.1	0.36	-0.06	0.18	0.91	0.06	0.7	-0.39	0.17	-0.39	0	-0.29	0	0	0
	Case 5	-2.47	-0.79	-1.64	-2.86	-1.36	-2	-0.43	-1.65	-1.53	-1.03	-0.49	-0.52	-0.49	-0.62	-1.9	-0.41	-1.08	-1.74	-0.35	-2.5	-0.39	-0.98	-1.57	0	-1.06	0	0	0
Level 6	**Case 1**	1.88	0.11	0.99	3	-1.15	0.3	-1.33	-0.81	-0.71	1.67	-1.35	-1.34	0.38	0.48	0.41	0.05	0.64	0.77	0.27	1.92	-0.39	0.37	-0.16	-0.12	-0.42	-0.11	-0.84	0
	Case 2	-1.31	-0.27	-1.02	3	-1.15	-0.26	0.82	0.31	-0.7	0.77	1.42	0.92	-0.26	-0.33	-0.36	-0.05	0.22	-0.63	-0.19	0.83	-0.39	-0.02	1.5	0.56	0.83	1.29	0.47	0
	Case 3	-0.34	0	0.99	-2.86	-1.34	-1.42	-0.11	-1.37	0.28	1.91	-1.35	1.74	-0.07	-0.09	-0.85	-0.06	-0.39	0.08	-0.05	-1.08	-0.39	-0.4	-0.42	-0.51	-0.63	-0.37	0.18	0
	Case 4	0.41	-0.05	-0.25	0.07	0.79	0.3	-0.73	0.08	0.86	-0.76	-0.75	-0.28	0.08	0.1	0.36	-0.06	0.18	0.91	0.06	0.7	-0.39	0.17	-0.39	-0.16	-0.29	-0.34	-0.04	0
	Case 5	-2.47	-0.79	-1.64	-2.86	-1.36	-2	-0.43	-1.65	-1.53	-1.03	-0.49	-0.52	-0.49	-0.62	-1.9	-0.41	-1.08	-1.74	-0.35	-2.5	-0.39	-0.98	-1.57	-1.09	-1.06	-1.4	-1.32	0
Output	**Case 1**	1.88	0.11	0.99	3	-1.15	0.3	-1.33	-0.81	-0.71	1.67	-1.35	-1.34	0.38	0.48	0.41	0.05	0.64	0.77	0.27	1.92	-0.39	0.37	-0.16	-0.12	-0.42	-0.11	-0.84	-0.34
Output	**Case 2**	-1.31	-0.27	-1.02	3	-1.15	-0.26	0.82	0.31	-0.7	0.77	1.42	0.92	-0.26	-0.33	-0.36	-0.05	0.22	-0.63	-0.19	0.83	-0.39	-0.02	1.5	0.56	0.83	1.29	0.47	1.15
Output	**Case 3**	-0.34	0	0.99	-2.86	-1.34	-1.42	-0.11	-1.37	0.28	1.91	-1.35	1.74	-0.07	-0.09	-0.85	-0.06	-0.39	0.08	-0.05	-1.08	-0.39	-0.4	-0.42	-0.51	-0.63	-0.37	0.18	-0.45
Output	**Case 4**	0.41	-0.05	-0.25	0.07	0.79	0.3	-0.73	0.08	0.86	-0.76	-0.75	-0.28	0.08	0.1	0.36	-0.06	0.18	0.91	0.06	0.7	-0.39	0.17	-0.39	-0.16	-0.29	-0.34	-0.04	-0.34
Output	**Case 5**	-2.47	-0.79	-1.64	-2.86	-1.36	-2	-0.43	-1.65	-1.53	-1.03	-0.49	-0.52	-0.49	-0.62	-1.9	-0.41	-1.08	-1.74	-0.35	-2.5	-0.39	-0.98	-1.57	-1.09	-1.06	-1.4	-1.32	-1.71

Note: All numbers are standardized values

Table 7.15: Comparison of actual and estimated magnitudes of risk factors and project cost overrun for each of the test cases

Cases	Outputs	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23	F24	F25	F26	F27	F28
Case 1	**St**	1.88	0.11	0.99	3	-1.15	0.3	-1.33	-0.81	-0.71	1.67	-1.35	-1.34	0.38	0.48	0.41	0.05	0.64	0.77	0.27	1.92	-0.39	0.37	-0.16	-0.12	-0.42	-0.11	-0.84	-0.34
	Estimated (rounded)	NA	4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4	4	4	3	4	4	4	5	NA	3	2	2	2	2	2	2
	Actual	5	3	5	5	2	4	1	2	5	5	1	1	4	2	4	4	5	5	4	5	1	4	2	2	1	2	2	2
	Prediction Performance %	NA	81	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	87	68	89	77	79	82	90	100	NA	79	95	97	78	92	94	90
Case 2	**St**	-1.31	-0.27	-1.02	3	-1.15	-0.26	0.82	0.31	-0.7	0.77	1.42	0.92	-0.26	-0.33	-0.36	-0.05	0.22	-0.63	-0.19	0.83	-0.39	-0.02	1.5	0.56	0.83	1.29	0.47	1.15
	Estimated (rounded)	NA	3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3	2	3	3	3	2	3	5	NA	3	4	3	3	4	3	4
	Actual	3	3	2	5	2	3	4	3	2	5	5	4	3	3	3	3	2	2	2	3	1	2	4	3	4	4	4	4
	Prediction Performance %	NA	92	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	95	77	91	88	73	97	84	57	NA	82	99	99	81	99	84	93
Case 3	**St**	-0.34	0	0.99	-2.86	-1.34	-1.42	-0.11	-1.37	0.28	1.91	-1.35	1.74	-0.07	-0.09	-0.85	-0.06	-0.39	0.08	-0.05	-1.08	-0.39	-0.4	-0.42	-0.51	-0.63	-0.37	0.18	-0.45
	Estimated (rounded)	NA	4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3	3	2	3	2	3	3	1	NA	2	2	2	2	2	3	2
	Actual	5	1	5	1	1	2	3	1	4	5	1	5	2	1	2	3	3	4	3	3	1	2	3	2	3	2	3	3
	Prediction Performance %	NA	47	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	82	62	86	98	91	92	90	52	NA	92	73	92	66	100	97	82
Case 4	**St**	0.41	-0.05	-0.25	0.07	0.79	0.3	-0.73	0.08	0.86	-0.76	-0.75	-0.28	0.08	0.1	0.36	-0.06	0.18	0.91	0.06	0.7	-0.39	0.17	-0.39	-0.16	-0.29	-0.34	-0.04	-0.34
	Estimated (rounded)	NA	3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3	3	4	3	3	4	3	4	NA	3	2	2	2	2	3	2
	Actual	5	3	3	3	4	4	2	3	5	2	2	3	3	2	3	2	2	3	2	3	1	1	2	1	2	2	1	2
	Prediction Performance %	NA	84	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	92	74	86	84	71	65	76	63	NA	51	99	73	100	99	52	90
Case 5	**St**	-2.47	-0.79	-1.64	-2.86	-1.36	-2	-0.43	-1.65	-1.53	-1.03	-0.49	-0.52	-0.49	-0.62	-1.9	-0.41	-1.08	-1.74	-0.35	-2.5	-0.39	-0.98	-1.57	-1.09	-1.06	-1.4	-1.32	-1.71
	Estimated (rounded)	NA	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2	2	1	2	1	1	3	1	NA	2	1	1	1	1	2	1
	Actual	1	1	1	1	1	1	3	1	1	2	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Prediction Performance %	NA	63	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	68	87	100	66	90	100	63	100	NA	83	100	100	96	100	80	100
Average Prediction Performance %		NA	73	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	85	74	90	83	81	87	81	74	NA	77	93	92	84	98	81	91

St: Standardized values

NA: Not Applicable

CHAPTER 8

CONCLUSION AND FURTHER WORKS

International construction projects are high risk endeavors influenced by diverse external and internal factors. Dynamic and complex interactions among these factors call for development of comprehensive models capable for identification of these interrelations and for realistic simulation of the project environment. This study is an attempt to mitigate the shortcomings of existing approaches commonly applied for the identification of potential risk factors for an unknown construction project at its initial stages. This is done through introduction of an alternative risk identification method which takes two types of relationships among risk factors into account;

1) *Source-Event relationships*: The possible causal relationships among risk factors, their initiative sources and their probable consequences which will lead to generation of distinct *Risk Paths*

2) *Interactions among Scenarios*: The possible interactions among diverse risk-path scenarios and incorporating their *cross-impacts* into the estimation processes

Considering the importance of realistic approximation of the future at early stages of the international construction projects, through which several critical decisions have to be made based on lots of unknowns and uncertainties, major aims of this study can be summarized as follows;

1) Introduction of an alternative methodology for risk identification of international construction projects through which critical ***interactive risk paths***, rather than ***independent individual risk factors*** are identified as the most probable scenarios that may lead to cost overrun of the project.

2) Analyzing the *cross-impacts* of the combination of such *risk-path scenarios* on the project cost overrun, and determination of the most effective sources, risk factors, and risk paths.
3) Incorporating the effects of system *vulnerabilities* into the identification processes as the initiatives of the possible risks and scenarios; The vulnerability factors inherent in each project's environment, and are initially known with more certainty than potential risks, are assumed to act as the derivation of the future risks, the types and magnitudes of which can be predicted through estimation of their interrelationships.

A network of diverse interactive risks is considered to be a better reflection of the complex nature of multiple risk sources in real construction projects rather than hierarchical lists. In other words, in this study, it is claimed that; 1) Identification and assessment of "*interactive risk paths*", rather than "*independent individual risks*", is a more realistic and accurate approach, and 2) Investigating the innate characteristics of project environment and incorporating vulnerability in risk identification and assessment lead to a better picture of risk emergence patterns and cost overrun. Therefore, a Risk-Path Model consisting of several risk paths, each of which deriving from diverse vulnerability factors was constructed based on a comprehensive literature review and conducted expert interviews. Using the data associated with 166 projects carried out by Turkish contractors in international markets, 36 interrelated risk-path scenarios were identified. The total effect of each vulnerability factor and each identified risk path on the projects' cost overrun was calculated based on the estimated path coefficients. The results were discussed and compared with previous research findings and with the comments of the interviewed experts.

The results of the validation tests illustrates that, although the developed Risk-Path Model does not cover all of the possible risk-path scenarios leading to cost overrun, it incorporates the most significant and effective ones since it can predict the cost overrun range with a good approximation.

8.1 Major Advantages of the Identified Risk-Path Model

Current risk identification methods commonly applied by industry practitioners provide their users with hierarchical checklists of independent risk factors the impacts of which on project objectives are assessed in further steps through qualitative or quantitative approaches. Such estimations form the basis for decision making of the managers in forthcoming stages of the project. Inaccurate or unreliable models will lead to biased estimations and will increase the probability of mistakes. The developed Risk-Path Model offers a comprehensive look at the risk patterns that may emerge throughout the project since it contains; 1) *Vulnerabilities* 2) *Risk Sources*, 3) *Potential Risk Events/Problems*, and 4) *The Impacts of Problems on Project's Cost Performance.* As the model demonstrates the *cross-impacts* of distinct *risk paths*, it simulates a project environment in a more realistic way.

It is believed that using SEM as a risk identification tool and particular SEM results may provide the following additional benefits for researchers:

- The Risk-Path Model can be used to answer "what-if" questions in early stages of the project. Employing this model, the magnitude of each dependent risk factor can be predicted based on the known severity of its predecessor vulnerabilities or estimated values for its predecessor risk factors. The effects of factors, and identified risk paths, on each other and on the cost performance of the project can be evaluated. Therefore, the most critical risk paths can be identified, and the contribution of each risk factor on the estimated cost overrun can be determined for the upcoming project. Considering the controllability level of critical risks, and the risk sharing of project parties concluded from related contract clauses, the intensity of future losses can be assessed. Various managerial strategies can be developed in order to improve the system's vulnerabilities, and the amelioration of the outcomes may be examined.

- This model can act as a decision support tool at the early stages of the project, when no comprehensive outlook of the project is available due to limited information.

The identified risk paths, the size of their effects, and the model's predictive capability can help decision makers in assessing the advantages and disadvantages of candidate projects. Therefore, through simultaneous consideration of the outcomes of the risk network and probable losses, of their company's capabilities and competitive advantages, and of the expected benefits from the project, this model can assist decision makers through their go-no-go decisions.

Traditionally, contractors assign high mark-ups to cover all possible risks and uncertain conditions, however, these methods are no longer effective (Baloi and Price, 2003). A realistic identification of risks, and hence, accurately estimated cost overruns will lead contractors to selection of fair bid mark-ups which are quantified based on all un-compensable costs for which the contractor is responsible, and also on cost of all necessary responses. This will provide companies with competitive advantages at bidding stages of the candidate international construction projects.

- The influence of alternative mitigation strategies can be traced not only on a specific risk and possibly on its outcomes, but also on the whole network of interrelated risks. The statement of "*missed opportunity*", mentioned by Ward (1999), being generated from the ignorance of such interdependencies, refers to the existing gap of various risk checklists that are improper in clarifying the effects of any response strategy on the whole system of risks. It is believed that by considering the whole network of risk paths at different stages of the project risk management, more cost, time and resource-effective strategies can be established. In addition, a life-long tracing of the effects of such strategies and made decisions will be possible which will enhance the monitoring phase of the risk management cycle.

- Being one of the biggest problems of international construction projects, cost overruns are also the reasons of various disputes and conflicts among project parties. The resolution of such disagreements and the allocation of the additional costs among project parties are highly tedious and time/cost consuming. In most cases, amicable solutions based on negotiation are firstly tried. However, highly complex structure of interrelated risk events makes the negotiation process a tedious task. Studying risks as a network of interrelated events will provide parties with the necessary argumentations to support their arguments during the negotiation process. The main causes of raised cost overruns can be easily traced in each level, scenarios can be identified, the effects of each event and their contribution on the raised overrun can be determined and documented, and hence, negotiations for more fair allocation of the risks will be facilitated. This will also assist project parties during the claim negotiation processes. Moreover, knowledge about potential problems ahead and their causes and effects will help project parties to avoid or reduce disagreements and further claims (Semple et al., 1994).

Although the identified risk paths reflect the experience of Turkish contractors, the methodology used in this research is also applicable to other countries. Also, it is believed that although the levels of vulnerability and risk change from country to country, the risk paths are generic in nature.

8.2 Recommendations for Further Works

8.2.1 Integration of the Model with Contract Clauses for Claim Negotiation Purposes

The complex and interrelated nature of the occurred events makes identification of the responsible party for a specific loss, and determination of the contribution rate of each party on the raised overruns, a tedious task which is usually the subject of time/cost consuming disagreements.

According to the related clauses of the binding contract conditions, each of the risk factors forming the Risk-Path Model is under the responsibility of one of the project parties, or is shared among them based on their contribution to its occurrence. It is believed that integrating these risk paths with contract clauses and assignment of responsibilities to each risk factor will provide an assisting tool for negotiation of the parties over the sharing of the raised cost overrun. Having knowledge about their approximate fault rate in the occurred scenarios will assist project parties during negotiation process in determination of their reservation values, in getting ideas about the reasonable offers, and in estimation of counter offers.

This thesis is part of a larger research project with the ultimate aim of development of a Multi-Agent System for simulation of argumentation-based negotiations. It is believed that the identified and validated Risk-Path Model, integrated with related clauses of different contract types, will form an adequate supportive document which will act as an independent agent providing arguments and information required for estimation of the negotiation offers and counter offers, and for generation of argumentations.

As an initial effort in this regard, the FIDIC (International Federation of Consulting Engineers) contract conditions are reviewed in detail in order to find the risk sharing related to each of the risk variables included in the Risk-Path Model. The results of this investigation reveal that the considered risk variables are either 1) Contractor Risks, 2) Client Risks, 3) Shared Among Parties, or 4) Not Shared by FIDIC contract conditions. Table 8.1 summarizes the results of this initial investigation for identification of risk sharing of 30 variables based on FIDIC contract conditions along with the corresponding clauses.

Using the multiple regression functions, estimated path coefficients, and the predicted magnitudes for dependent factors of a specific project, this SEM model can estimate the contribution rate of each factor on the magnitude of its successor factors. For a real sample project, these contribution percentages are estimated and reported in Appendix B.

It is believed that integration of the corresponding contract clauses with the estimated contribution rates will provide valuable reasoning and argumentations for determination of parties' risk sharing.

Table 8.1: Risk Sharing of Risk Variables according to FIDIC contract conditions

	Expression	Client	Contractor	Risk Sharing
(Conty-Econ)	Changes in Currency Rate			Not Shared
	Change in Economic Indicators			Not Shared
(Law-Reg)	Change in Taxation Policies			Not Shared
	Change in Laws & Regulations	70.2/71.1/		Client
(Coflt)	Conflicts with Government			Not Shared
	Conflicts with Engineer			Not Shared
	Conflicts with Client			Not Shared
	Poor Public Relations		19.1(b) (c)/29.1/	Contractor
(Clt-Prfc)	Change in Performance of Client Representative	6.4/17.1/20.4(f)/22.2/22.3/24.1/25.4/36.5/40.3/48.5/49.3/50.1/60.10/69.1/69.4/		Client
	Change in Client's Staff/Organization			Not Shared
	Change in Financial Situation of Client	69.1/ (a) (c) (d)		Client
(Prjt-Sps)	Scope Changes	18.1/44.1(a)/51.1/		Client
	Design Changes	17.1/20.4/51.1/		Client
(Con-Prfc)	Change in Site/Project Organization		15.1/16.2/34.1/	Contractor
	Change in Functional Performance of Contractor		6.5/8.2/10.1/14.2/17.1/25.3/25.4/29.1/30.1/36.4/37.4/39.2/40.1/46.1/47.1/49.2/49.3/49.4/50.1/51.1/52.4/53.4/56.1/59.5/60.4/63.1/63.3/63.4/64.1/	Contractor

Table 8.1: Risk Sharing of Risk Variables according to FIDIC contract conditions (Continued)

	Expression	Client	Contractor	Risk Sharing
(Avlb-Res)	Change in Availability of Labour		8.1/16.1/17.1(c)/34.1/	Contractor
	Change in Availability of Material		8.1/17.1(c)	Contractor
	Change in Availability of Equipment		8.1/17.1(c)	Contractor
	Change in Availability of Subcontractors		16.1/	Contractor
(Chng-Sit)	Change in Geological Conditions		11.1/12.1/	Contractor
	Change in Site Conditions		11.1/12.1/	Contractor
(Unxpt-Evnt)	War/ Hostilities	20.4(a)/44.1(e)/50.1/65.1/65.2/65.3/65.5/65.8/		Client
	Rebellion/ Terrorism	20.4(b)/44.1(e)/50.1/65.1/65.2/65.3/65.5/		Client
	Natural Catastrophes	12.2/20.4(h)(c)/44.1(c)/50.1/65.1/65.2/65.3/65.5/		Client
(Dely-Intrpt)	Delays/Interruptions	42.1/42.2/60.10/69.1(a)/69.3/69.4/	11.1/30.2/42.3/	Shared
(Prdcty)	Decrease in productivity	69.4/	46.1/	Shared
(Wrk-Amnt)	Increase in Amount of Work	36.5/38.2/44.1(a)/51.1/	36.4/ 38.2/39.1/51.1/	Shared
(Qlty)	Decrease in quality of work	50.1/	36.4/37.4/39.1/49.2/50.1/60.4/	Shared
(Unt-Cst)	Increase in Unit Cost of Work			Not Shared
(Csh-Flw)	Lags in Cash Flow			Not Shared

Note: The abbreviations of the variables are given in Table 5.1.

8.2.2 Integration of the Identified Risk Paths with Risk-Related Knowledge

Risk management, like most of the project management tasks in construction projects, is mostly conducted based on past experiences rather than standard guidelines, instructions or textbooks (Maqsood et al., 2006, and Tserng et al., 2009). Therefore, "the risk manager is required to possess knowledge in order to conduct risk management" (Tserng et al., 2009). The importance of such knowledge repositories is even much more obvious in the pre-construction phases of risk management process including identification and assessment of potential risks for an unknown project. Such uncertainties call for some applicable experience/knowledge-based risk management approaches.

Existing information tools developed for hierarchical documentation and retrieval of the captured risk knowledge are not sufficient for learning–based identification and feasibility practices in today's complex construction projects, since as Busby (1999) also stated, in complex projects there is "not a simple set of problematic issues but a complicated web of interdependent matters". Practically, checklist-based risk repositories do not draw clear pictures of what have actually happened (know-what), the reasons of occurred events and the taken actions (know-why), the way events occur and works are done (know-how), and their impacts on different project phases and activities (Gulliver, 1987; Cooper et al., 2002; Newell et al., 2006, and Dikmen et al., 2008a). Risk-relate knowledge is mostly stored in complicated documents which are not easily found by future users who do not have adequate insight about the case. Lin et al. (2006) stated the major shortcoming of available knowledge-based tools for construction projects to be the fact that "they do not address where to place acquired knowledge for users to find easily, or relationships among knowledge". Such inadequacies and ambiguities may be the reason for the fact that construction practitioners usually hesitate to refer to such tools for extracting related knowledge other than some explicit ones like statistic and reports. Therefore, vast amounts of know-how knowledge are either not considered by knowledge re-users, or even lost because of no registration.

With the aim of facilitating *knowledge-based risk-path identification* at pre-construction and early stages of the construction projects, and in order for past risk-related knowledge assets to be understandable, and hence, reusable for future knowledge users, a *Risk Map Repository* can be established based on a *Risk-Path Ontology* which documents all of the possible risk paths obtained from the Risk-Path Model, from conducted literature review, and from some expert interviews.

Some of the features of such a virtual risk memory are its compatibility to what is happened in real world, its simplicity, understandability, and hence, applicability in construction projects. Users may easily store the captured risk-related knowledge under appropriate heading through the offered classifications, may find desired knowledge related to diverse risk path scenarios through various filtering capabilities of the tool, may be able to trace the risk occurrence paths of previous projects for learning purposes, and in the case of risk path identification of new projects, may be recommended with a set of possible scenarios acquired from the repository.

8.2.3 Development of a Computer-Based Tool for Application of the Risk-Path Model

Based on the prediction capability of the SEM-based models, the identified Risk-Path Model can be used for estimation of the following parameters for a specific project;

1) Prediction of the probable magnitudes of the risk sources, risk events and cost overrun based on the known vulnerability severities and the estimated interrelationships.

2) Identification of the critical risk paths that have the highest impact on any specified factor.

3) Determination of the contribution percentage of each risk factor on the magnitude of any specified factor.

These capabilities provide industry practitioners with useful information in various stages of the projects. Therefore, development of a computer-based tool which facilitates utilization of such possibilities offered by the SEM-based Risk-Path Model will be highly beneficial. Currently, within the context of this thesis, the estimation process is formulated in an Excel worksheet through which following functions are conducted;

1) The probable standardized and un-standardized magnitudes of all the endogenous factors in each prediction level are estimated,
2) The prediction performance of each estimation is measured based on their comparison with the actual values,
3) The contribution percentages of each predecessor factor on the magnitude of its successor factors are estimated.

First and second functions and the corresponding processes are demonstrated in Appendix A for a sample real project. The results of the third function are shown in Appendix B for the same sample project.

It is also believed that computerization of such capabilities will facilitate the integration of Risk-Path Model with the multi-agent argumentation-based negotiation system in order to provide practitioners with required information and arguments throughout the negotiation process. On the other hand, by itself, such a computer-based tool will facilitate early stages practices like risk identification, feasibility studies, cost and mark-up estimations, bidding decisions and so on.

8.3 Research Limitations and Recommendations for its Improvement

The identified risk paths in this study are the most significant ones realized in 166 international construction projects. However, Structural Equation Modeling is a large-sample method which is highly sensitive to the number of the cases. The larger the sample size, the higher parameters can be estimated. Therefore, in this study, due to sample size limitations, only paths derived from Country, Project, Contractor, Engineer, and Client vulnerabilities are estimated and the paths related to other project parties such as Partners, Designer, and Subcontractors are not considered. In order for incorporating higher number of risk variables, and for covering higher range of possible risk-path scenarios, more cases should be collected.

On the other hand, in its current structure, the SEM-based Risk-Path Model can be used to estimate the level of cost overrun in forthcoming projects if the magnitude of vulnerabilities is inserted into the model. However it cannot be used to assess probability of occurrence of risk paths. Research findings can be improved by combining SEM results with probabilistic techniques such as Cross Impact Analysis (CIA) in which conditional probabilities are defined and probability of occurrence of risk paths can be assessed.

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APPENDIX A

AN ILLUSTRATIVE EXAMPLE FOR PREDICTION PROCESS IN THE SEM-BASED RISK-PATH MODEL

Consider the SEM-based Risk-Path Model given in figure 5.10. The independent factors of this model comprise of 11 "vulnerability" factors along with 1 "unexpected event" factor. This means that the observed variable indicating them should be inputted as the known parameters in the estimation process. The knowledge about the vulnerability factors is obtainable even at bidding or preconstruction stages through scanning of the candidate project, country, and project parties. However, the unexpected events are less predictable, and hence, their probable magnitudes won't be known with certainty. This may be one of the limitations of this model that the possible values for this factor can't be estimated and experts should input their estimated values based on their experiences in similar projects and countries.

Here, for illustration purposes, the prediction process of the 1st test case will be explained in detail. Suppose that table A.1 shows the standardized magnitudes calculated for independent factors (IF) by means of inputted values for their indicator observed variables:

Table A.1: Standardized magnitudes calculated for model independent factors

IF	Standardized Magnitudes
F1	1.88
F3	0.986
F4	2.998
F5	-1.15
F6	0.298
F7	-1.33

Table A.1: Standardized magnitudes calculated for model independent factors (Continued)

IF	Standardized Magnitudes
F8	-0.819
F9	0.705
F10	1.676
F11	-1.353
F12	-1.341
F21	-0.393

Therefore, considering these values and the factors included in the 1st level, the input matrix for the 1st level of the prediction will be as shown in table A.2:

Table A.2: Input matrix for 1st level

Input 1 Matrix							
F1	**F2**	**F3**	**F4**	**F8**	**F9**	**F13**	**F20**
1.88	0	0.986	2.998	-0.819	0.705	0	0

Multiplying this input matrix with the adjacency matrix of the 1st level (Table 6.9) the output matrix of the 1st prediction level will be obtained as follows:

[Input 1 Matrix] x [1st Adjacency Matrix] = [Output 1 Matrix]

Table A.3: Output matrix for 1st level

Output 1 Matrix							
F1	**F2**	**F3**	**F4**	**F8**	**F9**	**F13**	**F20**
0	0.11	0	0	0	0	0.38	1.92

The parameters included in the input matrix for the 2nd level will be those that are active in this level. The values of this input matrix will be obtained from the sum of the expanded form of the Input 1 and Output 1 matrixes.

[Input 1 Matrix] + [Output 1 Matrix] = [Input 2 Matrix]

Table A.4: Input matrix for 2nd level

Input 2 Matrix									
F1	**F5**	**F7**	**F9**	**F13**	**F14**	**F16**	**F18**	**F19**	**F20**
1.88	0.11	-1.33	0.705	0.38	0	0	0	0	1.92

The process mentioned above will be repeated for each prediction level and the Input and Output matrixes will be obtained as listed below.

Table A.5: Output matrix for 2nd level

Output 2 Matrix									
F1	**F5**	**F7**	**F9**	**F13**	**F14**	**F16**	**F18**	**F19**	**F20**
0	0	0	0	0	0.48	0.05	0.77	0.27	0

Table A.6: Input matrix for 3rd level

Input 3 Matrix						
F6	**F14**	**F15**	**F16**	**F17**	**F18**	**F20**
0.3	0.48	0	0.05	0	0.77	1.92

Table A.7: Output matrix for 3rd level

Output 3 Matrix						
F6	**F14**	**F15**	**F16**	**F17**	**F18**	**F20**
0	0	0.41	0	0.64	0	0

Table A.8: Input matrix for 4th level

Input 4 Matrix										
F10	**F11**	**F12**	**F14**	**F15**	**F17**	**F18**	**F20**	**F22**	**F23**	**F25**
1.68	-1.35	-1.34	0.48	0.41	0.64	0.77	1.92	0	0	0

Table A.9: Output matrix for 4th level

Output 4 Matrix										
F10	**F11**	**F12**	**F14**	**F15**	**F17**	**F18**	**F20**	**F22**	**F23**	**F25**
0	0	0	0	0	0	0	0	0.37	-0.16	-0.42

Table A.10: Input matrix for 5th level

Input 5 Matrix										
F2	**F8**	**F12**	**F17**	**F19**	**F22**	**F23**	**F24**	**F25**	**F26**	**F27**
0.11	-0.82	-1.34	0.64	0.27	0.37	-0.16	0	-0.42	0	0

Table A.11: Output matrix for 5th level

Output 5 Matrix										
F2	**F8**	**F12**	**F17**	**F19**	**F22**	**F23**	**F24**	**F25**	**F26**	**F27**
0	0	0	0	0	0	0	-0.12	0	-0.11	-0.84

Table A.12: Input matrix for 6th level

Input 6 Matrix				
F21	**F24**	**F26**	**F27**	**F28**
-0.39	-0.12	-0.11	-0.84	0

Table A.13: Output matrix for 6th level

Output 6 Matrix				
F21	**F24**	**F26**	**F27**	**F28**
0	0	0	0	-0.34

The last predicted standardized values for all the latent factors will be obtained from the summation of the expanded Input 6 and Output 6 matrixes which are obtained from 6th level calculations. After un-standardizing the estimated values, the magnitudes of all the depended factors, namely risk factors and project cost overrun, will be converted to 1-5 scale and can be compared to the actual values (see table A.14).

Table A.14: Estimated values of dependent risk factors and project cost overrun for the 1st case

Output	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23	F24	F25	F26	F27	F28
St	1.88	0.11	0.99	3	-1.15	0.3	-1.33	-0.81	-0.71	1.67	-1.35	-1.34	0.38	0.48	0.41	0.05	0.64	0.77	0.27	1.92	-0.39	0.37	-0.16	-0.12	-0.42	-0.11	-0.84	-0.34
Estimated	NA	4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4	4	4	3	4	4	4	5	NA	3	2	2	2	2	2	2
Actual	5	3	5	5	2	4	1	2	5	5	1	1	4	2	4	4	5	5	4	5	1	4	2	2	1	2	2	2
Accuracy%	NA	81	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	87	68	89	77	79	82	90	100	NA	79	95	97	78	92	94	90

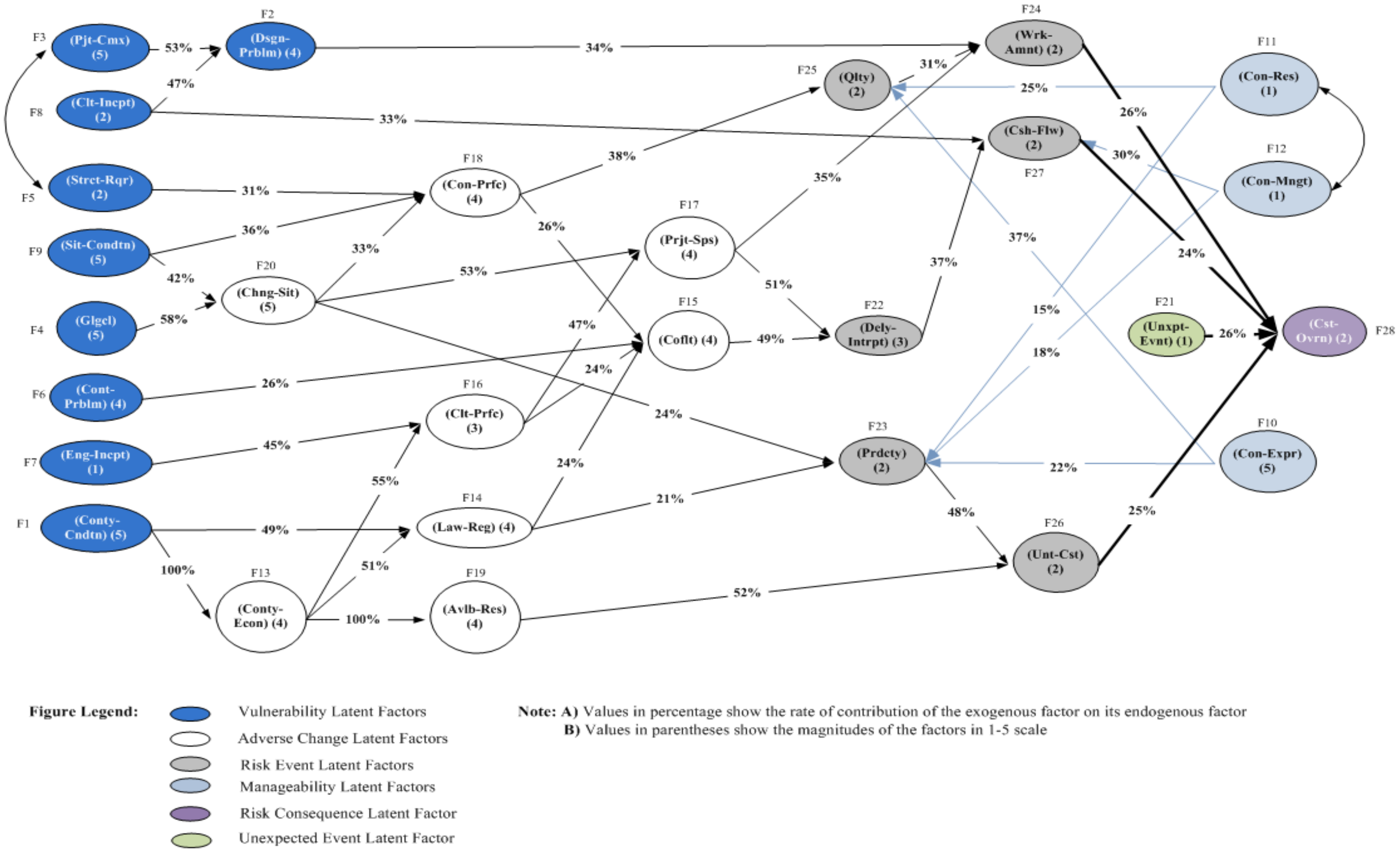
APPENDIX B

AN EXAMPLE FOR CONTRIBUTION RATE OF FACTORS ON THE MAGNITUDE OF THEIR SUCCESSOR FACTORS

The predicted standardized path coefficients indicate the number of standard deviations that the magnitude of endogenous factor will increase if the magnitude of the exogenous factor increases by 1 standard deviation. For example, the predicted coefficient value of 0.276 for the path connecting “Project Complexity” and “Design Problems” (Project Complexity→ Design Problems) means that if the magnitude of the “Project Complexity” increases by 1 standard deviation, then the magnitude of the “Design Complexity” will increase by 0.276 standard deviations.

Considering these definitions the magnitudes of the dependent factors can be estimated through the process described in Appendix A. After estimation of the magnitudes, and based on the predicted counter-effects, the contribution rate of each factor on the estimated magnitude of its successor factors can be calculated.

Figure B.1 demonstrates the inputted and estimated magnitudes of the Vulnerability/Risk factors, along with the contribution rates of their counter-effects, for a sample project that is already discussed in Appendix A.



Note: A) Values in percentage show the rate of contribution of the exogenous factor on its endogenous factor
B) Values in parentheses show the magnitudes of the factors in 1-5 scale

Figure B.1: Virtual representation of contribution rates and predicted magnitudes for factors of the sample project