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An Ontology Framework for Addressing Cost Overrun through Risk Modeling: A Risk Path Approach

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AN ONTOLOGY FRAMEWORK FOR ADDRESSING COST OVERRUN THROUGH RISK MODELING: A RISK PATH APPROACH

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ABSTRACT

Whether forced by economic conditions or internal motivations, contractors may choose to minimize their mark-up margins in order to maximize their chances of winning a bid. Such bidding conditions render contractors sensitive towards all types of risks associated with executing a project. This research aims at providing contractors with a framework through which they can reduce their bid prices to be able to compete in low biding conditions. This aim is realized through identifying risk elements that have the greatest impact on projects' costs in the Egyptian construction industry. Work on this research follows a risk path approach consisting of risk sources, risk events, and risk consequences, and vulnerability factors consisting of robustness factors, resistance factors and sensitivity factors, whose relationships and risk paths are mapped through an ontology model. The weights characterizing that relationship between each of these elements is estimated through a three-phase model that utilizes both optimization and Artificial Neural Networks (ANN), through 52 risks cenarios collected from 35 experts in the Egyptian Construction industry. Outputs generated by the model comprise of five sets of weights. Each set represents the effect of one risk path element on a subsequent element, collectively demonstrating the relations connecting the risk path elements to cost overruns. The model's outputs showed that that 35 percent of the top 20 Robustness factors are related to project design. Lack of contractor's technical resources rank higher than that of contractor's financial resources in terms of their effect on Risk events. Project type has the most impact on project cost overrun, followed by Project delivery method. Further, delays due to bureaucracy whether from the owner or the government's side rank at the bottom of the list.

This is dedicated to my family Sherif Elbashbishy, Shereen Elzeiny, and
Dana Elbashbishy for their patience, faith, and encouragement.
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Chapter 1: Introduction

1.1. Background

The Construction industry is considered one of the leading industries in Egypt. According to the Central Bank of Egypt, it contributed with approximately 11.2% to Egypt's national GDP in 2015/2016 (Central Bank of Egypt, 2017). To put that in perspective, the agriculture sector contributed 3.1% to Egypt's national GDP in 2015/2016 (Central Bank of Egypt, 2017). Thus, it can be understood that the development of the construction industry is directly affected by and highly sensitive to the progress of the economic conditions in Egypt.

Over the past few years, the Egyptian government has started implementing a bold economic reform program, which includes amongst others introducing Value Added Tax (VAT), reducing energy subsidies, and liberation of the Egyptian Pound. While these reforms aim at stimulating the economy towards balanced sustainable growth and enhancing the country's business environment, they also have adverse effects that include currency fluctuation and inflation. These adverse effects impact not only small businesses and start-ups, but also Egypt's leading industries, one of which is the construction industry.

The construction industry's sensitivity towards events that take place either inside or outside projects' boundaries renders it a highly dynamic environment. This is why contractors are always faced with a new challenge each time they are estimating a project's price. This is because estimating the price of a project involves a number of variables that together form a project's total price. These variables are project dependent and are commonly divided into cost and the markup. The project's cost is the summation of direct costs and indirect costs. Direct costs include materials, labor, equipment, and other expenses that contractors pay directly in order to execute the project, while indirect costs consist of overheads such as site and office overheads. On the other hand, the contractor's markup is usually calculated as a percentage of the project's cost, and it includes the profit and contingency the contractor needs to realize in order to execute the project. Contingency covers uncertainties and unknown risk exposure associated with the project.

Contractors often encounter situations where they are obliged to submit the lowest bid possible. This can be due to a number of reasons ranging from economic conditions, such as an economic recession or the economic reform policies discussed earlier, to bidding conditions, such as bidding on public projects where the projects are sometimes rewarded strictly to the lowest bidder. As a result, contractors sometimes resort to drastic actions such as bidding at cost as a strategy to cover their operational overheads and maintain their presence in the market.

1.2. Problem Statement

Whether forced by economic conditions or internal motivations, contractors may choose to minimize their mark-up margins in order to maximize their chances of winning a bid. In such cases, they are often more focused on submitting bids with the lowest price possible with less regard to appropriate profit and/or contingency margins needed to execute the project. Some contractors, even, resort to more extreme measures of submitting bids at zero percent profit and/or zero percent contingency.

Such drastic bidding conditions render contractors sensitive towards all types of potential risks associated with executing a project. This is why, it is important for contractors to learn new risk management techniques and the mechanics of applying them effectively and efficiently in projects in which they are involved. Otherwise, given the continuously evolving nature of the industry, ignorance or negligence can be costly for contractors who are of dire need to cut costs, especially in low bidding situations.

Still, the process of effective risk management proves to be challenging for a number of reasons. First, the lack of comprehensive understanding of the interrelated relations between projects risks, which may lead to inaccurate risk identification and assessment. Typically, risk is defined as static factors that are independent of one another. Each risk factor is derived by a particular risk source and its magnitude is measured through traditional approaches such as the severity of impact approach, also known as Severity Index (SI). Severity of impact approach is an assessment tool used to evaluate and prioritize project risks. According to this approach, each risk is assigned two arbitrary values, one for its probability of accruing and the other for its impact if occurred (Norrman & Jansson, 2004). Those values are then used to calculate the SI, which remains static throughout the duration of the project. Such traditional approaches understate the dynamic nature of risks by not taking into account the interdependency of their relations. Conversely, in practice risk factors and their relations are witnessed to be highly interdependent. For example, unlike the popular notion that risk factors' probability and impact values are independent of one another, it is often seen that risk factors not only affect each other but also affect the magnitude of probability and impact of one another depending on the project conditions (Fidan et al., 2011); (Liu et al., 2016). Further, a risk factor can have multiple risk drivers or sources.

A second reason why implementing effective risk management techniques can be a challenge is lack of project-based data. Due to the difficulties most researchers face when collecting comprehensive project based information, a large number of studies focusing on the construction industry in Egypt are based primarily on data collected through surveys and questionnaires (Hassanein & Afify, 2007). While these questionnaires often target field experts and professionals, the collected data is an amalgamation of subjective options and interpretations of real life events or experiences. Such subjectivity undermines research's findings, and limits its applicability. On the other hand, project based data enables researchers to impartially analyze and understand important industry trends. It allows them to realize educated estimations and reliable predictions. Since risk management practices depend vastly on predictions and estimations, the outcomes of such practices are greatly affected by the subjectivity, quality, and comprehensiveness of collected information.

In other words, enhanced understanding of risks, their properties, and their interconnectivities shall lead to the development of innovative risk management techniques with higher effectiveness in responding to project's risks as well as proactively mitigate their effects on project's cost, time, and quality. Otherwise, contractors may find themselves facing situations, such as those of low bidding projects, where they have underestimated the values of those risks, and lack the knowledge required to deal with them as they occur.

1.3. Objectives

The main objective of this research is to identify risk elements with the greatest impact on projects' costs in the Egyptian construction industry. Such information allows contractors to minimize costs incurred along the project life in relation to these risks, thus minimize their contingency estimates, and consequently reduce their bid prices.

This objective is fulfilled through the pursuit of further secondary objectives that aim at developing a better understanding of project risk elements, their interdependencies, and their effect on cost overruns. The secondary objectives are:

- Develop a risk path model that simulates various project's risk scenarios and their corresponding cost overruns.
- Develop an ontology model that defines and represents the developed risk path elements, components, relations, and properties.

1.4. Scope of Work

The scope of work of this research aims at providing contractors with a framework through which they can reduce their bid prices so they would be able to compete in low biding situations. This aim is realized through identifying risk elements that have the greatest impact on projects' costs to help contractors minimize costs associated with those elements and consequently reduce their contingency.

The scope of work of this research is a comprehensive process that starts with establishing a risk path that represents the lifecycle of a risk in a project from its realization as an uncertainty to its manifestation as an impact on project outcomes (Cost, Time, and Quality). Once the risk path and main elements forming it are defined, relationships between those elements are also identified.

Second, a database of project-based information is created. The database covers different construction projects risk scenarios as well as corresponding project characteristics. This databse form the base upon which further simulations and investigations are to be conducted.

Third, it follows to create a model to assess cost overruns corresponding to projects' various risk scenarios based on a number of identifiable risk elements and project vulnerabilities that together formulate the established risk path. The purpose of the model is to identify the risk elements with the greatest impact on cost overruns.

Fourth, collected data and outputs generated from the model are analyzed to understand risk propagation patterns or trends as well as other findings constructed based on these outputs.

Following the analysis, the process concludes with producing the following:

- Lists of the risk path elements ranked as per their effect on subsequent path elements and on cost overruns, highlighting the elements with the greatest impact on projects' cost overruns.
- A number of risk paths constructed to show the propagation patterns of some of the most common risk scenarios in the Egyptian construction industry, along with weights assigned to each of the risk path elements included to highlight the degree of influence the elements have on subsequent elements and on cost overruns.

The process prescribed above aims at providing contractors with an overview on risk elements that have the greatest impact on projects' costs in the Egyptian construction industry and the interconnected relationship between them, as well as their degree of contribution to the total contract price. Ultimately, it provides contractors with means that can help them understand those risks, their impact, and how to deal with them in low bidding conditions.

1.5. Research Methodology

The methodology of this research aims to fulfill the research objectives and complete its scope of work as explained hereinbefore. The methodology depends on both qualitative and quantitative approaches and is as follows.

a. Establish a risk path that can represent construction project's risks as well as identify the main elements forming it and the relation between those elements. All three tasks are interrelated and are to be retrieved from the literature.

b. Create a risk path ontology that can model projects' risk elements in relation to cost overruns for various risk scenarios based on the risk path and risk elements identified in the previous step using Protégé, an open source ontology editing software.

c. Collect information regarding patterns of dependencies amongst the identified risk elements as well as the degrees of significance of these dependencies in terms of their effect on projects' cost in the Egyptian construction industry through surveying industry professionals in Egypt.

d. Construct an integrated framework that ranks risk path elements according to their impact on cost overruns. The framework consists of three sub-models (two optimization models and one prediction (artificial neural network (ANN)) model) based on the information logged in the ontology model. Data collected from the survey is used to train and test the model. the model is used to investigate the various combinations of risk path elements and dependencies in relation to their impact on cost overruns and identify the elements that have the greatest impact on cost overruns.

e. Conduct a comprehensive analysis on the outputs generated by the model to understand risk propagation patterns or trends.

f. Produce the following based on the examination of the collected data and analyzed information:
   - Lists of the risk path elements ranked as per their effect on subsequent path elements and on cost overruns, highlighting the elements with the greatest impact on projects' cost overruns.
   - A number of risk paths constructed to show the propagation patterns of some of the most common risk scenarios in the Egyptian construction industry, along with weights assigned to each of the risk path elements included to highlight the degree of influence the elements have on subsequent elements and on cost overruns.

The above is a brief summary of the research methodology adopted in this research, while Chapter 3 provides further detailed description.

1.6. Research Organization

This research is organized into five chapters. This section summarizes the contents of each of the chapters.

Chapter 1 – Introduction: This chapter includes the research background and problem statement, followed by the research objectives, scope of work, and methodology.

Chapter 2 – Literature Review: This chapter explores three main areas that support the context of this research, which are:

- Identification and categorization of construction projects risks.
- Investigation of risk mapping techniques to identify a risk path and its main components.
- Investigation of previous research efforts relevant to integrated approaches to presenting and processing risk data.

Chapter 3 – Methodology and Proposed Approach: This chapter explains the framework adopted to tackle the research objectives and scope. It also presents the proposed methodology and the reasons for using such approaches.

Chapter 4 – Results and Analysis: This chapter presents the research findings as well as the analysis and investigations conducted to comprehend these findings. It also describes the verification and validations procedures adopted in this research.

Chapter 5 – Conclusion and Recommendations: This chapter provides an overview of the research, and a summary of its main contributions. It concludes with some recommendations for future research.

Chapter 2: Literature Review

2.1. Introduction

Risk can be defined as an uncertain event or condition that if happens may have a positive or negative effect on a project. It can be perceived as either a threat or an opportunity (Ward & Chapman, 2003). Instead of the obsolete notion that risk is “the potential for unwanted or negative consequences of an event or activity” (Zou et al., 2007), research, nowadays, tends to emphasize on the two-edged nature of risk and define it as an event that may have a positive or a negative impact. Similarly, this research shall follow this recent practice and take into consideration both positive risks (opportunities) and negative risks (threats).

This chapter explores three main areas that support the context of this research. These areas are as follows:

- Identification and categorization of construction projects risks.
- Investigation of risk mapping techniques to identify a risk path and its main components.
- Investigation of previous research efforts relevant to integrated approaches to presenting and processing risk data.

2.2. Risks Identification and Categorization

Risk management is a process of identifying risks, assessing their impacts, and developing mitigation strategies to ensure project success (Fidan et al., 2011). Risk Identification is considered one of the most known and practiced steps of Risk Management worldwide (Uher & Toakley, 1999). One reason this is the case is that risks, by definition, have a direct impact on project goals namely cost, time and quality. Therefore, lack of effective and comprehensive risk identification results in ineffective risk management, which leads to failure in achieving project goals (Beltrão & Carvalho, 2019). Flyvbjerg et al. (2002) investigated 258 public projects in Europe and North America and found that 86% of the examined projects suffered from cost overruns due to poor risk management during cost estimation.

Another reason risk identification is important is concerned with the field of contract drafting and administration. Wording of contract conditions have the potential to give rise to some risks and diminish others. Therefore, efficient risk identification early on when preparing bids and contract documents can play a major role in drafting contract conditions (Hassanein & Afify, 2007).

Accordingly, as demonstrated later in this section, researchers from numerous countries have been working on identifying the most significant risks in the construction industry in their countries over the years. Yet, despite the booming of the Egyptian construction sector (Central Bank of Egypt, 2017), such research may not be given equivalent attention in Egypt.

Another practice that is closely associated with risk identification is risk categorization. Risk classification is an imperative risk management practice as it provides an indication of the categories of risks where common approaches to risk analysis, risk treatment, and risk monitoring and control can be utilized (Bing et al., 2005). As evident by the information presented hereunder, there are several approaches for classifying construction projects risks. There is no sole correct way for categorizing risks, but rather the categorizing methodology depends on the approach that serves the purpose of a project, or a research in this case the best.

The following presents a summary of the literature survey findings in relation to:

- The most significant risks in construction projects in a number of countries including Egypt.
- The various categorizing techniques of these risks.

In his book "Managing risk in construction projects", Smith et al. (2014) divide project risks into 15 type according to their sources. These sources of risk, or risk drivers, include both engineering and non-engineering project-specific risks. The authors describe these sources of risk as generic and boundary-less. Thus, it is the responsibility of the project team to define the boundaries of these sources and to breakdown these sources into exact risk elements. This process ensures a common understanding amongst project teams involved in the risk management process, while, at the same time, allows for a project-based risk management process that is more flexible compared to a typical risk management process, hence tailored to the specific project characteristics. A list of the most common sources of risk as identified by Smith et al. (2014) is illustrated in Figure 1.

Figure 1: Common risk sources (Smith et al., 2014)

Similarly, Shen et al. (2001) opted to classify project risks according to their nature. In their research, they identified the most significant risks in the Chinese construction industry and examined their level of significance. They concluded that risks can be divided into six main categories: Financial, Legal, Management, Market, Policy and political, and Technical risks. Table 1 shows the most common project risks in China and their classification as presented by Shen et al. (2001).

Table 1: Common project risks in China and their classifications (Shen et al., 2001)

Risk Classification	Risk
Financial Risks	Bankruptcy of project partner. Difficult convertibility of RMB. Loss due to fluctuation of inflation rate. Loss due to fluctuation of interest rate. Loss due to fluctuation of RMB exchange rate. Low credibility of shareholders and lenders.
Legal Risks	Breach of contracts by other participants Breach of contracts by project partner Lack of enforcement of legal judgment Loss due to insufficient law for joint ventures Uncertainty and unfairness of court justice
Management Risks	Change of organization within local partner. Improper project feasibility study. Improper project planning and budgeting. Improper selection of project location. Improper selection of project type. Inadequate choice of project partner.

	Inadequate project organization structure. Incompetence of project management team. Incomplete contract terms with partner. Increase in project management overheads. Poor relation and disputes with partner. Poor relation with government departments. Problems associated with culture difference. Project delay.
Market Risks	Competition from other similar projects. Fall short of expected income from project use. Increase in accessory facilities price. Increase in labor costs. Increase in materials price. Increase in resettlement costs. Inadequate forecast about market demand. Local protectionism. Unfairness in tendering.
Policy and Political Risks	Cost increase due to changes of policies. Loss incurred due to corruption and bribery. Loss incurred due to political changes. Loss due to bureaucracy for late approvals.
Technical Risks	Accidents on site. Design changes. Equipment failure. Errors in design drawings. Hazards of environmental regulations. Incompetence of transportation facilities. Increase in site overheads. Industrial disputes. Local firm's incompetence and low credibility. Materials shortage. Obsoleteness of building equipment. Poor quality of procured accessory facilities. Poor quality of procured materials. Problems due to partners' different practice. Shortage in accessory facilities. Shortage in skillful workers. Shortage in supply of water, gas, and electricity. Subcontractor's low credibility. Unknown site physical conditions. Unusual weather and force majeure.

Alternatively, Bing et al. (2005) proposed to classify project risks based on the relation between risks and their impact, and the project itself. This technique comprises of three levels of risk categories, where risks in each level share the same source and relation to the project. The three levels are macro level risks, meso level risks, and micro level risks (Bing et al., 2005). Macro level risks are defined as risks that are external to a project. They are risks that take place outside the project boundaries, but whose consequences take place inside the project boundaries to influence both the project and its outcomes. Macro level risks may include natural risks, political and governmental risks, and economic and social risks. On the other hand, meso level risks are risks that take place within project boundaries, and they may include constructability risks, design risks, and operation risks. While, micro level risks as risks related to the relationship between the stakeholders and the various parties involved in the project. Similar to meso level risks, micro level risks take place within project boundaries as well. However, they are party related rather than technical related. For example, meso level risks include: delay in project approvals and permits and construction cost overrun, while micro level risks include: inadequate distribution of responsibilities and risks and level of demand for project. Following the macro, meso, and micro risk grouping, risks are further subcategorized into risk factor groups based on the nature of each risk. “The benefit of grouping and classifying project risks in this way is that it facilitates a strategic approach to risk management for public and private sector project stakeholders” (Bing et al., 2005). Table 2 shows the identified risk factor groups and corresponding risks for each risk level based on data collected through opinion surveys from experts in the UK construction industry.

Table 2: Risk factor groups and corresponding risks for each risk level accroding to the UK Construction Industry (Bing et al., 2005)

Risk level	Risk Source	Risk Factor
Macro level risks	Political and government policy	• Unstable government • Expropriation or nationalization of assets • Poor public decision-making process • Strong political opposition/hostility
	Macroeconomics	• Poor financial market • Inflation rate volatility • Interest rate volatility • Influential economic events
	Legal	• Legislation change • Change in tax regulation • Industrial regulatory change
	Social	• Lack of tradition of private provision of public services • Level of public opposition to project
	Natural	• Force majeure • Geotechnical conditions • Weather • Environment
Meso level risks	Project selection	• Land acquisition • Level of demand for project
	Project finance	• Availability of finance • Financial attraction of project to investors • High finance costs
	Residual risk	• Residual risks
	Design	• Delay in project approvals and permits • Design deficiency • Unproven engineering techniques

	Construction	• Construction cost overrun • Construction time delay • Material/labor availability • Late design changes • Poor quality workmanship • Excessive contract variation • Insolvency/default of sub-contractors or suppliers
	Operation	• Operation cost overrun • Operational revenues below expectation • Low operating productivity • Maintenance costs higher than expected • Maintenance more frequent than expected
Micro level risks	Relationship	• Organization and co-ordination risk • Inadequate experience • Inadequate distribution of responsibilities and risks • Inadequate distribution of authority • Differences in working method and know-how • Lack of commitment
	Third party	• Third Party Tort Liability • Staff Crises

Building on both Shen et al. (2001) and Bing et al. (2005)'s work, Chou and Pramudawardhani (2015) further developed their risks list to include the most identified project risks across several countries not just China. Their surveyed countries include the United Kingdom, Singapore, Taiwan, China, Australia, Tehran, and India. Table 3 presents a summary of their results. As can be seen in the table, a total of 69 risks has been identified across the 7 surveyed countries. Unsurprisingly, some of the identified risks were country based, meaning that they are not common worldwide, but rather prevail in certain countries as a result of specific home-based characteristics. Such risks include immature juristic system, which was identified in Taiwan; scope variation, which was identified in Singapore; and inadequate distribution of responsibilities and risks, which was identified in both the UK and Singapore. On the other hand, risks such as inflation and interest rates volatility, changes in legislation and tax regulations, and delays in project approvals and permits from authorities having jurisdiction were found to be common across most countries included in the study.

Table 3: Most common risks and their classifications (Chou & Pramudawardhani, 2015)

Risk group	**Risk Factor**	**UK [8]**	**Sing-apore [9]**	**Taiwan [10]**	**China [11]**	**Austr-alia [12]**	**Iran [13]**	**India [14]**
	• Unstable government	*	*					

Political and government policy	• Expropriation or nationalization of assets	*	*	*	*			
	• Poor public decision-making process	*		*	*			
	• Strong political opposition/hostility	*	*	*	*			
	• Lack of support from government		*			*		
	• Corruption and bribery		*	*	*			
	• Government's intervention			*	*			
	• Government's reliability			*				
	• Withdrawal of government support network					*		
	• Termination of concession by government						*	
Macroeconomics	• Inflation rate volatility	*	*	*	*	*	*	
	• Interest rate volatility	*	*	*	*	*		*
	• Influential economic events	*					*	
	• Foreign exchange and convertibility			*	*			
	• Financial risk	*	*	*	*	*		
Legal	• Legislation change	*	*	*	*	*	*	*
	• Change in tax regulation	*	*	*	*	*		
	• Industrial regulatory change	*						
	• Lack of legal/regulatory framework		*					
	• Excessive contract variation	*	*					
	• Immature juristic system			*				
	• Improper contract			*				
	• Lack of standard model for agreement						*	
Social	• Lack of tradition of private provision of public services	*						
	• Level of public opposition to project	*	*					
	• Market demand change	*	*	*	*		*	
Natural	• Force majeure	*	*	*		*	*	*
	• Geotechnical conditions	*	*	*				
	• Weather	*	*				*	
	• Environment	*	*	*	*		*	
Project selection	• Land acquisition	*	*	*	*	*	*	*
	• Uncompetitive tender			*	*			
Project finance	• Availability of finance	*	*					
	• Financial attraction of project to investors	*	*					
	• High finance costs	*	*					
Residual risk design	• Residual risks	*	*	*	*	*		
	• Delay in project approvals and permits	*	*	*	*	*		*
	• Design deficiency	*	*			*		
	• Unproven engineering techniques	*	*		*			
	• Scope variation		*					
	• Supporting facilities risk			*				
Construction	• Construction cost overrun	*	*				*	*
	• Construction time delay	*	*					
	• Material/labor availability	*	*	*	*	*		

	• Poor quality workmanship	*	*					
	• Insolvency/default of sub-contractors or suppliers	*						
	• Site safety and security		*					
Operation	• Operation cost overrun	*	*	*	*		*	*
	• Operation revenues below expectations	*						
	• Low operating productivity	*	*					
	• Maintenance costs higher than expected	*	*				*	
	• Maintenance more frequent than expected	*	*					
	• Technological risk			*				
	• Operation default						*	
Relationship	• Organization and co-ordination risk	*	*	*	*		*	
	• Inadequate distribution of responsibilities and risks	*	*					
	• Inadequate distribution of authority	*	*					
	• Differences in working method and know-how	*	*					
	• Lack of commitment	*	*					
	• Private investor change			*				
Third party	• Third Party Tort Liability	*		*				
	• Staff Crises	*						
Unidentified	• Competition			*		*		
	• Tariff change			*			*	
	• Payment risk			*	*			
	• Lack of consortium experience	*	*	*	*			
	• Subjective evaluation			*				
	• Insufficient financial audit			*				
	• Construction/operation change	*			*			

Potential Risk Breakdown Structure (PRBS) (Mojtahedi et al., 2010) is another technique used to identify and classify project risks. PRBS is where project risks are identified and classified in accordance with a project's Work Breakdown Structure (WBS). A WBS is a hierarchal decomposition of a project's scope of works (Work Breakdown Structure, n.d.), where the entire works of the project is visually represented as separate, smaller packages. Each level in the WBS provides further definition and detail than the one above it. In PRBS, risks are "grouped in adhere to project WBS" (Mojtahedi et al., 2010) in order to study potential risks in different levels and work packages. Allocating areas of uncertainty in any project can be a lengthy process that involves an ample of data production. Thus, according to the authors of the PRBS technique, employing a structuring method is essential to ensure that all the important information is generated and processed. Since WBS is the most used structuring method in project management practices, it was deemed by the authors as suitable for providing the basis for identifying and categorizing risks according to the PRBS technique (Mojtahedi et al., 2010).

PRBS technique is a source oriented method of grouping of project potential risks to demonstrate the total risk exposure of the project based on its WBS. Similar to levels in a WBS, each level in the PRBS represents an increasingly detailed definition of potential risks compared to the one above it with the lowest level demonstrating all potential project risks. Thus, understandably, in the PRBS technique, risks are not categorized according to their nature or their drivers, but rather according to the project work packages they belong with.

Lastly, Afify and Hassanein (2007) studied 16 contract packages related to power station projects in Egypt with the aim of identifying the most significant risks in the Egyptian construction industry. The analysis of the contracts included identification of exception clauses, modification related clauses, and claim related clauses, where the compilation of these three sets of clauses led to the production of a checklist of the most significant risks. According to Afify and Hassanein (2007), checklists are one of the most used methods of risk identification and classification. Thus, checklist was their chosen approach to present and classify the identified risks. As shown in Table 4, the generated checklist consists of 25 risks classified into seven risk groups based on the risks nature.

Table 4: Checklist of the most significant risks in the Egyptian construction industry (Hassanein & Afify, 2007)

	Risks Checklist
1	Owner obligations risks • Transmittal of design deliverables • Procurement of permits • Drawing/design approval • Payment of invoices • Opening letter of credit • Handing over of the site • Supply of owner furnished equipment • Handing over of owner furnished utilities (such as access roads, lay down area and other utilities)
2	Risks related to interface with other contractors • Delay of milestones to which payment to contractor is tied • Delay of start and completion of the warranty period • Delay in issuance of project completion certificates
3	Liability risks • Non-exclusion of normal wear and tear from warranty provisions • Non-termination of the contract in the event of a force majeure i.e. contract remains binding even though no work is being performed • Lack of total cap on liability of contractor to owner i.e. contractor's liability is open ended • Non-exclusion of consequential damages from contractor's liability to owner.

	• Lack of grace period in liquidated damages clauses i.e. liquidated damages are computed from the first day of delay by contractor • Unclear allocation of responsibility in the event of differing site conditions
4	Financial risks • Unclear allocation of responsibility for payment of certain taxes such as sales tax on contracting services. The applicability of this tax is still under dispute in Egyptian courts. • Stipulation of certain specific banks for financial interactions such as opening of letters of credit. • Lack of provisions which allow partial payment i.e. all payments are linked to one milestone which greatly increases the risk of non-payment. • Retention of advance payment guarantee even though advance payment has been fully credited to owner to cover other obligations of the owner.
5	Risks related to changes • Deletion of work scope after its construction/fabrication has commenced
6	Technical risks • Stipulation of specific codes and standards
7	Consortium risks • Stipulation that all payments are to be made to one consortium partner only • Allowing the designated lead partner to commit and incur liabilities on behalf of all partners

The purpose of this section is not to develop a new risk categorization technique or establish a reformed list of construction projects risks, but rather to investigate the risks found in the literature and utilize previous work in the field as a way of maintaining a common language. Further, it aims to understand the various forms of risk categorization and classification utilized by researchers and experts in the field and select the most suitable classification approach as per the objectives and methodology of this research.

2.3. Risk Relations

Following the information presented in the previous section, it can be seen that advances have been made in identifying and categorizing projects' most significant risks. However, this alone is not sufficient to understand project risks .Work remains to be done in identifying the relations between those risks as well as developing risk paths that explain those relations.

Regardless of whether risks are classified as per their source, scale, or any of the methods discussed hereinbefore, traditional risk management approaches define risks as separate factors that are independent of one another. Each risk is defined as per its capacity to result in a project's failure and its magnitude is measured through traditional approaches such as the severity of impact approach, also known as Severity Index (SI). According to the severity of impact approach, each risk is assigned two arbitrary values, one for its probability of occurring and the other for its impact if occurred. Those values are then used to calculate the SI, a static value that is maintained throughout the duration of the project. Typically, each risk is assigned a corresponding risk strategy that is implemented to effectively manage it (C´ardenas et al., 2012).

Such traditional approaches depend heavily on traditional risk identification tools such as risk breakdown structures or checklists, which fail to provide a comprehensive understanding of the dynamic nature of project risks. They discard the interdependent relations between risks and the effect of those relations on project outcomes. Therefore, they should not be relied upon exclusively to understand project risks.

On the contrary, in practice project risks are found to be interconnected through a series of relations throughout a project's life. These relationships can be described as cause-and-effect, or source event relationships (Fidan et al., 2011) depending on the description of the risks elements themselves (i.e. risk event, risk source, or risk consequence). Unlike the popular notion that risks' probability and impact values are independent of each other, it is often seen that risks not only affect one another but also affect the magnitudes of each other's probability and impact in varying ranges depending on prevailing project conditions. A risk event can have multiple risk drivers or sources and the relation between those risk events, drivers and sources are witnessed to be highly interdependent thus forming a risk path. A risk path is a pattern through which risks propagate in a project from the point of risk's inception at project initiation to the point of its materialization as a risk event and subsequently a risk consequence that has an impact on one or more the project's goals. A well-established risk path should be capable of representing different risks under different occurrence scenarios, leading to a network structure instead of a one-way hierarchal structure (Fidan et al., 2011). Risk paths can take various forms depending on the elements forming them.

The following section presents a summary of the literature survey findings in relation to:

- Project risk paths that simulate risks' journey throughout a project's life from their point of inception to the point where they materialize as variations in project objectives.
- Types and categories of risk elements that form project risk paths and the patterns of dependencies that link those elements.

2.4. Risk Path Identification and Modeling

In their work, Fidan et al. (2011) focus on creating an information model the represents the relation between project risks and cost overruns through utilizing the risk path approach describes the statistical link between risk events and their consequences as limited for two main reasons. First, it ignores the cause-and-effect relationships among the risk elements. Each project uncertainty is a risk source that is accompanied by one or more cause, consequence and potential risk event. Naturally, these risk sources, events, and consequences are not independent of one another and therefore should not be grouped together in the same checklist or risk breakdown structure. Instead, they should be demonstrated in cognitive maps that highlight their interrelations. Second, it neglects the influence of a "Project System". According to the same study, a project system is a set of project vulnerabilities which represent the project's characteristics. Knowing that project characteristics differ from one project to the other, it is natural that project vulnerabilities also change and thus have varying influence on the severity of risks and accordingly project outcomes across different projects (Fidan et al., 2011). To solve for the identified shortcomings of the linear portrayal of project risks relationships, the authors developed a risk path that integrates both risk relations mapping and project vulnerabilities as shown in Figure 2.

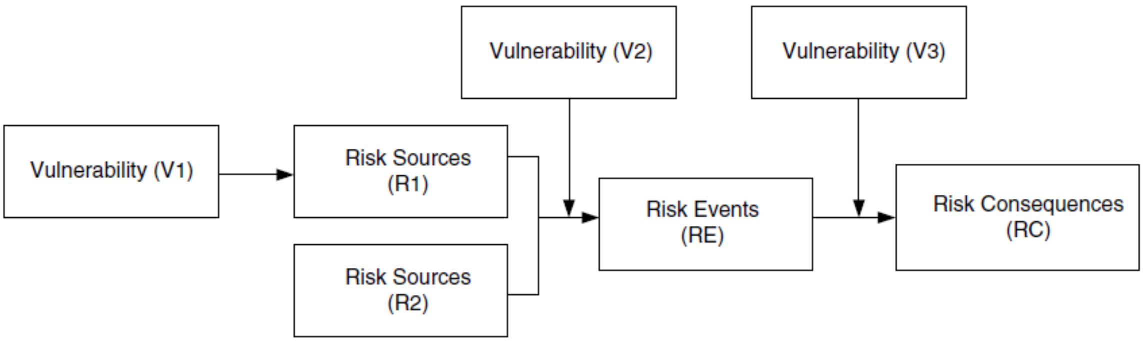

Figure 2: Risk-Vulnerability Path (Fidan et al., 2011)

As can be seen in Figure 2, risk elements are categorized according to their role within the risk path as either risk sources, risk events, or risk consequences, where one or more risk sources affect the occurrence of a risk event and one or more risk events affect the occurrence of a risk consequence. Risk sources are defined as aspects that have the potential to cause harm to a project and it is further subcategorized into adverse changes and unexpected situations, where adverse change is a negative variance from original project conditions, while unexpected situations are unforeseen problems that can lead to variance form original project conditions as well. Risk events are defined as negative incidents that take place in a project and they mainly include variation and delays in project proceedings such as productivity, quantity, or quality. Lastly, risk consequences are defined as the deviations from the original project objectives as caused by the occurrence of the risk events.

Similar to the risk elements, project vulnerabilities are also categorized based on their effect on the risk path along its different stages across a project's life into Robustness factors (V1), Resilience factors (V2), and Sensitivity factors (V3). Robustness factors are those which represent the project weaknesses and they include attributes that describe the status of the project, its parties, and the country where and when it is executed. Resilience factors are those which affect the manageability of risk sources and they include attributes that describe the status of the project's contractor. Lastly, sensitivity factors are characteristics that describe a project and they include several attributes such as project delivery system, contract type, and project type. While robustness factors influence the probability of occurrence of an adverse change (risk source), resilience factors influence the degree to which a risk source can cause a risk event and sensitivity factors influence the magnitude of a risk consequence caused by a risk event.

Another study that focuses on the observability of risk drivers as an indication of potential risk scenarios uses the risk path mapping approach to study the relationship between a driver's observability and possible risk scenarios. The authors use the DEMATEL technique to create a risk path, determine its main components, and establish the features of the risk path according to each of the identified risk scenarios (Charkhakan & Heravi, 2018). The developed risk path, as seen in Figure 3, is composed of risk sources, drivers, and events and it aims to highlight the relationship between each observed risk driver and a risk scenario's source and event. Unlike the risk path described in Figure 2, this risk path is linear with a risk source as its starting point and a risk event at its end. According to the authors, the construction of this risk path is based on a series of relations that link observable risk drivers to a chain of risk elements, namely the risk scenario, which consists mainly of sources and events (Charkhakan & Heravi, 2018). Even though the authors support the concept that a risk scenario can be due to a number of drivers not strictly one, risk drivers in the below risk path are presented in series where their order signifies their relevance to risk scenario in question and may vary from one scenario to the other (Charkhakan & Heravi, 2018).

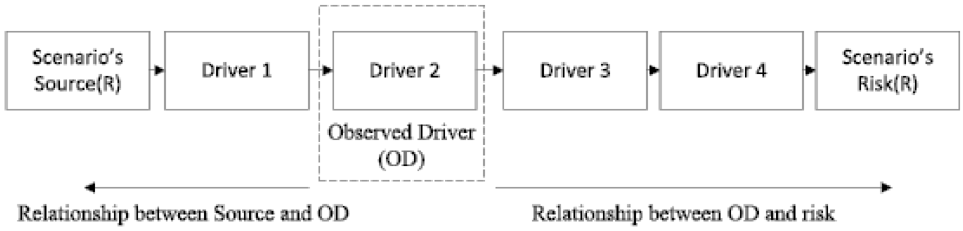

Figure 3: Source-Driver-Cause risk path (Charkhakan & Heravi, 2018)

As described in Figure 3, the first of these relations is between a risk source and an observed risk driver, and it is measured by the degree to which an observed risk driver is likely to occur as a result of a risk source. This relation defines the importance of an observed driver in relation to a risk scenario and accordingly it decides the position of that driver in the risk path. While the second relation is between a risk cause and an observed risk driver. It is measured by the degree to which observing a risk driver can help effectively manage a risk scenario (risk cause). Similarly, this relation also defines the importance of an observed driver in relation to a risk scenario as it decides the position of that driver in the risk path as well.

Similarly, Liu et al. (2016) in their study rely on the concept of risk observability to construct risk paths in relation to international construction projects performed by Chinese contracts and examine the effects of those risk paths on project objectives. First, the authors established a list of 60 risks based on the covered literature review. The 60 risks are divided into three levels: country, market, and project; and 21 categories (Liu et al., 2016).

According to the authors, the risk path is composed of two variables: directly measured variables which are observable variables, and hypothetical variables which are inferred from the observable variables named latent variables.

Furthermore, the relations between the variables can be described as either measurement or structural models, where a measurement model describes the relationship between a risk (observable variable) and its corresponding risk category (latent variable) and a structural model describes the relationship amongst risks categories. Accordingly, a tentative risk network was developed to describe possible risk paths founded based on the identified 60 risks and their corresponding 21 categories. Following, Confirmatory Factor Analysis was adopted to test the constructed measurement model relationships and confirm their validity, while the bootstrapping technique was adopted to estimate the significance of the developed path coefficients. Consequently, a total of 20 risk paths were developed and proven to be statistically valid. Figure 4 shows the developed risk path.

2.5. Integrated Approaches to Presenting and Processing Risk Data

Although in recent years increasing focus has been directed towards developing integrated approaches where data relevant to risk causes, conditions, and failures is collected and processed comprehensively in an effort to determine effective and efficient risk strategies. For instance, various tools such as Failure mode and effects analysis, hazard analysis, top level event tree, and fault tree analysis have been developed to represent risks comprehensively for different purposes depending on the desired investigation (Bedford et al., 2006). Further, numerous codes and guidelines mandated by unions or associations, such as the Guidelines for Tunneling Risk Management from the International Tunneling Association, recommend the use of risk analysis to identify, quantify risks and visualize their causes and effects as well as the course (chain) of events (C´ardenas et al., 2012).

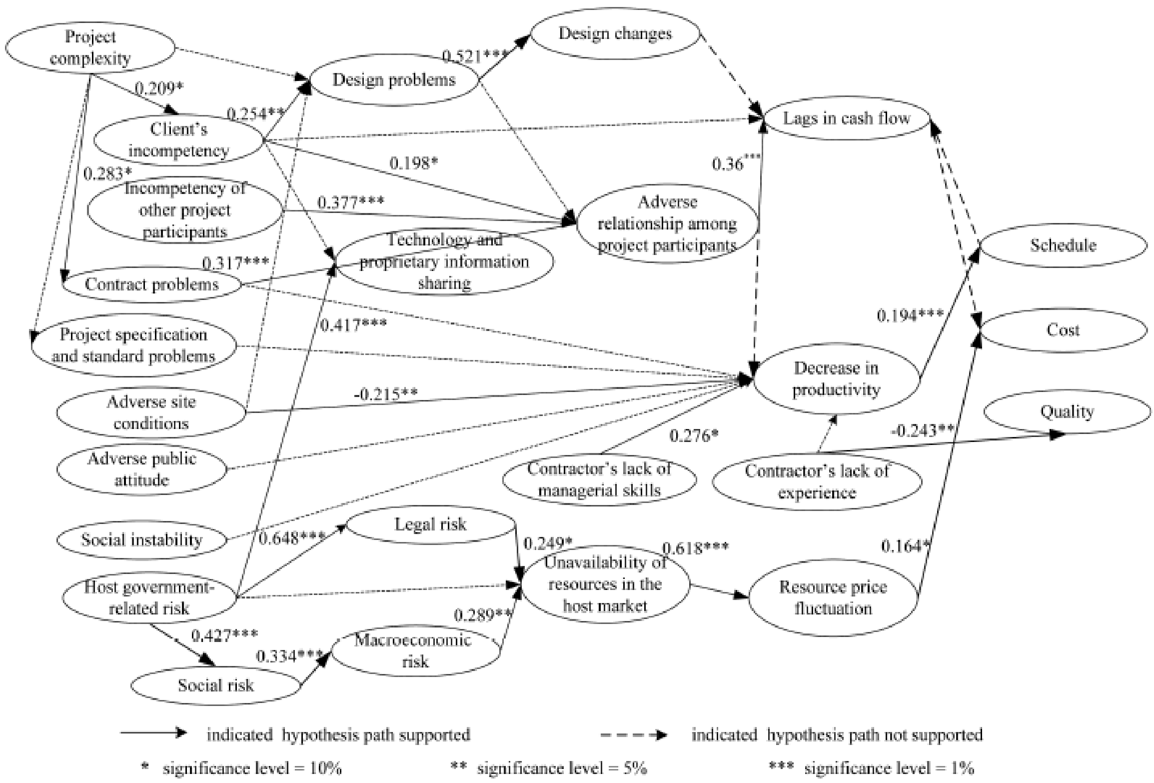

Figure 4: Developed risk path (Liu et al., 2016)

Still such approaches to effective risk management proves to be challenging for a number of reasons, the most prominent of which is the lack of project based data. Raw and comprehensive data in relation to causes and conditions that lead to major risk events and consequences is often absent (C´ardenas et al., 2012). Even if it exists, such information is usually scare, confidential, and not available until many years later after the project's completion. As a result, information regarding the conditions under which risk events and consequences took place are often not recorded (Wearne, 2008); (C´ardenas et al., 2012).

One tool that has proven effective in storing and presenting information is Ontological models. An ontology is a data modeling tool used to “represent unstructured information” (Jiang et al., 2018) in an organized form through defining information categories, properties, as well as relations between information concepts and entities. Over the past decade, ontologies have been utilized in various fields ranging from Medicine (Bickmore et al., 2011) and Chemistry (Hastings, et al., 2011) to Computer Science (Boonyoung & Mingkhwan, 2014) and Information Technology (Zhu et al., 2012). Its wide popularity across different trades is credited to a number of reasons. First, its representation form allows for easy transfer of knowledge amongst users even those who do not possess a comprehensive understanding of the information’s domain. Second, it has a flexible structure that enables users to modify and add information to the model. Third, it can be used to describe specific sets of information allowing for a more systematic revival of information when needed (Xiao et al., 2017).

Realizing the importance of ontologies in creating domain information, researchers in the construction field have been increasingly relying on ontologies in their studies in applications such as conformance checking and knowledge management (Xiao et al., 2017). For example, Venugopal et al. (2012) use an ontological frame work to create formal, consistent definitions for the precast/pre-stressed concrete industry to be used in the implementation of Industry Foundation Class (IFC) schema by software companies.

While in contract management, Niu and Issa (2013) built an ontology to fulfill the conceptualization work for the domain knowledge of construction claims whereas Ahmed et al. (2014) conducted an ontology-based investigation to determine the level of awareness, frequency of usage, and success rate of each of the critical path method delay analysis methodologies within the Egyptian construction industry. Jiang and Zhang (2013) created an ontology that document information concerning risk management collected from previous construction projects then designed a retrieval system framework to allow for project parties to query desired information among numerous project documents efficiently.

Furthermore, Ontologies are heavily utilized in the Building Information Modeling (BIM) field. Jiang et al. (2018) combined BIM and ontology modeling to facilitate the process of green building evaluation. While Mohammadi et al. (2018) created a BIM-based ontological framework for developing construction method statements for single construction products, thus providing an alternative method for effective construction planning taking into consideration required resources, available resources, their specifications and the specifications of desired product.

As for this study, creating an ontology model is an integral part of the research for a number of reasons. First, an ontology model can capture, manage, represent, and reuse domain knowledge in a machine-readable format (Mohammadi et al., 2018). Therefore, it is capable of representing not only the components of the risk path elements but also the relations between those elements. Second, it is an effective way to solve the problem of information fragmentation (Xiao et al., 2017) since the model allows for storing domain information classes, instances, properties, and data constraints. Third, it can be easily shared amongst research communities, which help preserve a common language among researchers and thus facilitate future research and development.

Chapter 3: Methodology and Proposed Approach

3.1. Introduction

This chapter provides a detailed account of the research methodology adopted to achieve the research objectives and scope. As previously stated, this research aims at providing contractors with a framework through which they can reduce their bid prices to be able to compete in low biding conditions. This aim is realized through identifying risk elements that have the greatest impact on projects' costs in the Egyptian construction industry. Work on this research is divided into the below five phases as demonstrated in Figure 5.

- Phase One: Literature review.
- Phase Two: Risk path and its components.
- Phase Three: Ontology model.
- Phase Four: Surveying professionals.
- Phase Five: Modeling the risk path

3.2. Phase One: Literature Review

In the first phase of this research, a literature review was conducted to investigate and gather information regarding the following:

- The most significant construction projects risks and relevant categorization methods
- Common risk mapping techniques in the risk management field
- Integrated approaches to presenting and processing comprehensive risk data.

The work conducted and findings realized in relation to this phase are as detailed in Chapter 2. It is believed that these findings are best retrieved from the literature for a number of reasons. First, the repeated use of some terminologies and definitions help establish a common language in the field, which facilitates future research and development amongst researchers. Second, as evident by the work presented in Chapter 2 of this study, most of the required information is abundantly available and has been covered extensively in the literature. Therefore, it is rational to take such previous work into consideration and build on it, especially when it includes relevant work based in Egypt.

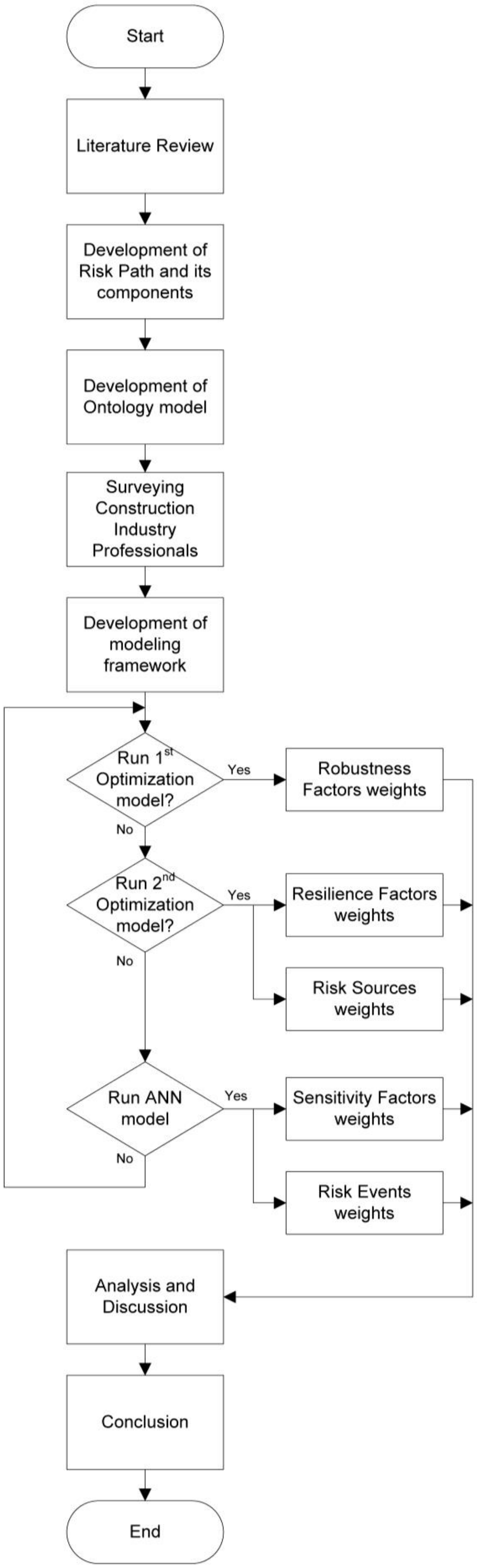

Figure 5: Proposed methodology flowchart

In conclusion, based on findings realized from the reviewed literature a list of the most significant project risks was established, a risk path model along with its main components was determined, and a method for representing the retrieved risk data was identified. The following subsections provide detailed descriptions of the collected information.

3.2.1. Significant Construction Projects Risks

Based on the extensive literature review presented and analyzed in Chapter 2 concerning identifying the most significant projects risks and their categorization approaches, a comprehensive list of 131 most common construction project risks was identified in phase one of the research. This list was developed based on studies conducted in 8 countries including the UK, China, India, and Egypt by various authors including LY et al. (2001), Bing et al. (2005), Clou and Pramudawardhani (2015), as well as Afify and Hassanein (2007).

As shown in Table 5, the identified risks are classified into five categories based on their drivers or source in relation to the project as Country level, Project level, Owner level, Contractor level, and Project participants level. Then, each of the five categories is further divided into sub-categories based on their nature.

The first category is the Country level and it is composed of risks that materialize due to the conditions of the country in which the project is executed. Typically, these risks usually take place outside project boundaries. However, their consequences take place inside the project boundaries and affect its objectives. Country level risks are divided into four sub-categories: Economic, Political, Social, and Legal conditions. Whereas, the second category is Project level and it is composed of risks that materialize as a result of the specific project characteristics such as its type, location, or size. Project level risks are divided into five sub-categories, which are Design, Construction, Management, Contract, and Market, and they can take place either inside project boundaries such as design and construction risks or outside project boundaries such as market risks.

As for the third, fourth, and fifth categories, they are concerned with risks related to the main parties involved in the project and their relationship to the project. These three categories take place and affect a change within project boundaries and they are: Owner level, Contractor level, and project participants level. Owner level risk are further divided into three sub-categories which are Objectives, Resources, and Managerial abilities. Likewise, Contractor level risks are divided into three sub-categories which are Experience, Resources, and Managerial abilities.

Lastly, Project participants level risks are divided into two sub-categories: Designer and Engineer.

Table 5: Risks Checklist

Risks Checklist

Level	Category	Risk Code	Risk
Country	Economic conditions	R001	Instability of economic conditions
		R002	Change in currency exchange rates
		R003	Change in inflation rates
		R004	Change in interest rates
		R005	Change in tax rates
		R006	Difficult convertibility of local currency
	Political conditions	R007	Instability of government
		R008	Instability of international relations
		R009	Change in laws, policies, or regulations
		R010	Change in level of bureaucracy
		R011	Delays due to government bureaucracy
	Social conditions	R012	Instability of social conditions
		R013	Change in level of bribery and corruption
		R014	Change in public reaction
	Legal conditions	R015	Immaturity of legal system
		R016	Restrictions for foreign companies
		R017	Lack of enforcement of legal judgment
		R018	Uncertainty and unfairness of court justice
Project	Design	R019	Incomplete design
		R020	Complexity of design
		R021	Errors in Design/Design Drawings
		R022	Low constructability
		R023	Change in project design
	Construction	R024	Complexity of construction method
		R025	Poor accessibility of site
		R026	Unknown site physical conditions
		R027	Inadequate geotechnical investigation
		R028	Inadequate climate conditions
		R029	Hazards of environmental regulations
		R030	Change in geological conditions
		R031	Change in availability of labor
		R032	Change in availability of material
		R033	Change in availability of equipment
		R034	Change in availability of subcontractor
		R035	Change in availability of accessory facilities
		R036	Accidents on site
		R037	Obsoleteness/failure of equipment
		R038	Incompetence of transportation facilities
		R039	Poor quality of procured accessory facilities
		R040	Poor quality of procured materials
		R041	Shortage in supply of water, gas, and electricity
		R042	Change in weather conditions
		R043	Change in site organization
		R044	Change in work quality
		R045	Change in site conditions
		R046	Change in construction method/technology
		R047	Increase in quantity of work
	Management	R048	Strict quality management requirements
		R049	Strict environmental management requirements

		R050	Strict safety management requirements
		R051	Strict project management requirements
		R052	Change in relation between parties
		R053	Change in communication between parties
		R054	Problems associated with culture difference
		R055	Change in project scope
		R056	Unfairness in tendering.
		R057	Difference in practices amongst project participants
		R058	Change in original schedule
		R059	Increase in labor costs.
		R060	Increase in materials prices
		R061	Increase in accessory facilities prices
		R062	Increase in resettlement costs
		R063	Delay in work progress
		R064	Delay in project logistics
	Contract	R065	Vagueness in contract clauses
		R066	Errors in Contractual agreement
		R067	Incomplete contract terms
		R068	Disputes between project parties
	Market	R069	Competition from other similar projects
		R070	Fall short of expected income from project use
		R071	Inadequate forecast about market demand
Owner	Owner objectives	R072	Unclarity of Owner's objectives
		R073	Improper project feasibility study.
		R074	Improper project planning and budgeting.
		R075	Improper selection of project location.
		R076	Improper selection of project type.
		R077	Inadequate project organization structure.
	Owner resources	R078	Lack of financial resources
		R079	Technical incompetency of project team
		R080	Change in Owner top management
		R081	Change in project team
		R082	Change in company organizational structure
		R083	Level of bureaucracy of Owner
		R084	Change in financial situation of Owner
		R085	Change in Owner's relations with government
		R086	Change in performance of Owner
		R087	Delays due to Owner bureaucracy
		R088	Delay in Owner payments
	Owner managerial ability	R089	Negative attitude of Owner
		R090	Managerial incompetency of project team
		R091	Low credibility of Owner
		R092	Breach of contracts by Owner
		R093	Increase in project overheads costs
Contractor	Contractor experience	R094	Lack of experience in similar projects
		R095	Lack of experience in country
		R096	Lack of experience in deliver system
		R097	Lack of experience with Owner
		R098	Lack of experience with other project parties
	Contractor resources	R099	Lack of financial resources
		R100	Lack of technical resources
		R101	Lack of Contractor staff
		R102	Change in project team
		R103	Technical incompetency of project team
		R104	Managerial incompetency of project team
		R105	Change in company organizational structure
		R106	Change in financial situation of Contractor
		R107	Change in performance of Contractor

	Contractor managerial ability	R108	Lack of project scope management
		R109	Lack of project time management
		R110	Lack of project human resources management
		R111	Lack of project cost management
		R112	Lack of project communication management
		R113	Lack of project risk management
		R114	Lack of project procurement management
		R115	Low credibility of Contractor
		R116	Low credibility of Subcontractor
		R117	Breach of contracts by Contractor
		R118	Increase in site overheads costs
Project participants	Designer	R119	Technical incompetency of project team
		R120	Managerial incompetency of project team
		R121	Lack of financial resources
		R122	Lack of technical resources
		R123	Change in project team
		R124	Change in performance of designer
	Engineer	R125	Technical incompetency of project team
		R126	Managerial incompetency of project team
		R127	Lack of financial resources
		R128	Lack of technical resources
		R129	Change in project team
		R130	Lack of Engineer staff
		R131	Change in performance of Engineer

3.3. Phase Two: Risk Path and its Elements

In the second phase, the risk path model as well as the main elements forming it are developed. This stage is considered to be one of the most important stages of this research, as the created risk path shall constitute the base model upon which risk simulations are conducted to investigate the impact of various combinations of risk elements on project cost overruns. In other words as one study states “poor definition of risks and patterns of risk propagation in a project decreases the reliability of risk models that are constructed to simulate project outcomes under different risk occurrence scenarios” (Fidan et al., 2011).

Following the requirements of this research, the required risk path should be able to describe the pattern through which risks propagate throughout the project life starting from its realization at project initiation to its materialization as a risk event and subsequently a risk consequence that has an impact on one or more the project’s objectives.

The risk path developed in this research is influenced by the risk path developed in Fedan, et al. (2011)’s work. It takes on the concept of project vulnerabilities and combines risk elements and project vulnerability factors in one integrated risk path that accounts for and describes the relation between both components. Still, this research introduces a few alterations and modifications on Fidan et al. (2011)’s “Risk-Vulnerability Path.” First, while this research adopts the same terminology introduced in Fidan et al. (2011)’s work, the definitions of those terms are redefined to serve the purpose of this study. They were reconstructed to focus on more specific context and provide a clearer representation of the propagation of a risk scenario across project duration. Accordingly, it introduces an enhanced paradigm for the relationship between vulnerability factors and risk elements as well as the relationships governing the cause-effects relations between them. Second, this research does not take into consideration adverse or force majeure risk sources. The purpose of simulating risk scenarios in this research is to study their impact on cost overruns and accordingly develop strategies that can help decision makers address those risks. However, force majeure risks are unforeseen by definition. Therefore, they can neither be expected nor monitored and their consequences cannot be gauged or controlled. Accordingly, it was decided not to include force majeure risk sources as part of the risk path elements and instead focus more on elements that can be monitored, gauged, and addressed. Lastly

To that end, the risk path developed in this research is comprised of two main components: risk elements and vulnerability factors. Elements of the risk path can be described by one or more of three properties: probability of occurrence, magnitude of occurrence, and impact of occurrence, where probability of occurrence is the likelihood of a certain event to take place, while magnitude of occurrence is the measure of the size of a certain element when it actually occurs. As for impact of occurrence, it is the extent of the magnitude of occurrence of a certain element on subsequent elements in the risk path.

3.3.1. Risk Elements

Risk elements are risk factors that can be identified before project commencement then monitored and controlled during the project life as part of a project's risk management plan. Naturally, risk elements are project specific and thus may differ from one project to the other depending on project characteristics such as project size, location, or delivery method. Nonetheless, common risks such as the ones described in section 2.2 are likely to be common across projects that share the same characteristics. In this research, three subgroups of risk elements were created and defined according to their role and sequence in the risk path as risk sources, risk events, and risk consequences.

Risk sources are defined as changes or uncertainties in a project's system or properties, which have the potential to cause variance in project proceedings. These uncertainties can be attributed to project circumstances either within or outside of project boundaries, or changes in the relation between both. Risk sources are observable risks that may lead to one or more risk events. Likewise, risk events can be due to one or more risk sources. However if realized, risk sources can help effectively manage a risk scenario and thus prevent a risk event from taking place. As for Risk events, they are defined as incidents that take place within project boundaries and cause variations in project proceedings. Such variations have the potential to alter the project's original program upon which project goals (time, cost, and quality) were decided. Risk events may lead to one or more risk consequences. Lastly, Risk consequences are defined as the impact of one or more risk events that took place in the project on one or more project outcomes, namely cost, time or quality. Therefore, risk consequences may be changes in the project's total cost, duration, or quality of work. Since this research focuses on the effect of project risks on cost overruns, risk consequences in this case are limited to changes in project cost, while the remaining project outcomes (time and quality) are out of the scope of this research.

3.3.2. Vulnerability Factors

As for the second component of the risk path, vulnerability factors are the innate characteristics of a project's system. They define the project system's ability to either drive or resist risks. Unlike risk elements, vulnerability factors are a set of influences that cannot be controlled or managed since they describe independent, known project conditions that are established either before or at project initiation. However given their influence on all three categories of risk elements, vulnerability factors should be identified, monitored and taken into consideration in a project's risk management plan. Similar to risk elements, vulnerability factors are also project specific and therefore may change from one project to the other depending on two aspects. The first aspect is project properties such as size, location, or delivery method, while the second aspect is project circumstances such as involved parties abilities or country conditions. In this research, three subgroups of vulnerability factors were created and defined according to their role and sequence in the risk path as robustness factors, resilience factors, and sensitivity factors.

Robustness factors are defined as project system characteristics that stem from country, project, owner, designer, and engineer conditions. Accordingly, they include factors found within as well as outside of project boundaries. Generally, robustness factors determine the project's vulnerability towards the occurrence of risk sources and thus they are concerned with issues such as the financial, technical, and managerial abilities of each of the project parties as well as the relationship between them. In other words, the higher the number of weak robustness factors in a project system the higher the probability of occurrence of associated risk sources. As for Resilience factors, they are the same as robustness factors. However, they are concerned with project system characteristics that stem from contractor conditions such as the contractor's technical abilities, financial resources, and relation with the rest of the project parties. They determine the project's ability to resist the occurrence of risk event. Thus the better the contractor's conditions, the more resistant is the project to potential risk events. The last category of vulnerability factors is Sensitivity factors. As suggested by the name, sensitivity factors determine how sensitive a project is to risk events. They are concerned with the magnitude of the risk consequences following a risk event taking place in the project. Sensitivity factors describe project properties such as scale, type, contract type, and delivery method.

3.3.3. Risk Path Elements Properties

Generally, only risk events are described by all three properties defined earlier: probability, magnitude, and impact of occurrence. Whereas, risk sources are described in terms of magnitude and impact of occurrence, while risk consequences are described only in terms of probability and magnitude of occurrence. Reasonably, risk sources cannot be described in terms of their probability because they are either recognized as project risk sources with identified magnitudes or not in which case they have a magnitude of zero. Likewise, risk consequences cannot be described in terms of their impact as they are an impact themselves. Also, they are the last element in the risk path so there are not further elements on which they may have an impact.

As for the vulnerability factors' properties, all vulnerability factors are defined in terms of two properties only: magnitude of occurrence and impact of occurrence. The reason why none of the vulnerability factors can be attributed by their probability of occurrence is that by definition vulnerability factors cannot be controlled or monitored. They are either recognized as project system conditions, in which case their probability of occurrence is a hundred percent, or not in which case their probability of occurrence is zero. Therefore, they cannot be described in terms of probability of occurrence. Table 6 summarizes the risk path elements and the corresponding properties assigned to each one.

Table 6: Risk Path Elements Properties

Risk Path Elements	**Assigned Properties**
Risk Sources	Magnitude, Impact

Risk Events	Probability, Magnitude, Impact
Risk Consequences	Probability, Magnitude
Robustness Factors	Magnitude, Impact
Resilience Factors	Magnitude, Impact
Sensitivity Factors	Magnitude, Impact

3.3.4. Risk Path Relations

Following defining the risk path's components and their properties, the risk path's relations are constructed. The path starts with robustness factors as its initiation point, where the magnitude of robustness factors (M_{V1}) are identified based on recognized project system characteristics. These magnitudes (M_{V1}) then materialize into impacts of occurrence (I_{V1}) that influence the magnitudes of risk sources (M_{RS}). Following, the magnitude of risk sources (M_{RS}) materialize into an impact of occurrence (I_{RS}) that influence the magnitude (M_{RE}) and probability (P_{RE}) of occurrence of risk events. Further along the path between risk sources and risk events, the magnitude of occurrence of resilience factors (M_{V2}) materialize into an impact of occurrence (I_{V2}) that influences the impact of risk sources (I_{RS}) on the magnitude (M_{RE}) and probability (P_{RE}) of occurrence of risk events.

Moving to risk events, they are linked to risk consequences in two ways. First, the probability of occurrence of a risk event (P_{RE}) has an effect on and is directly proportional with the probability of occurrence of a risk consequence (P_{RC}). Second, the magnitude of the risk events (M_{RE}) materialize into impact of occurrence (I_{RE}) that influence the magnitude of risk consequences (M_{RC}). Further along the path between risk events and risk consequences, the magnitude of occurrence of sensitivity factors (M_{V3}) materializes into impact of occurrence (I_{V3}) that also influences the impact of risk events (I_{RE}) on the magnitude of risk consequences (M_{RC}). Figure 6 demonstrates the developed risk path and the relationship between its elements as described above.

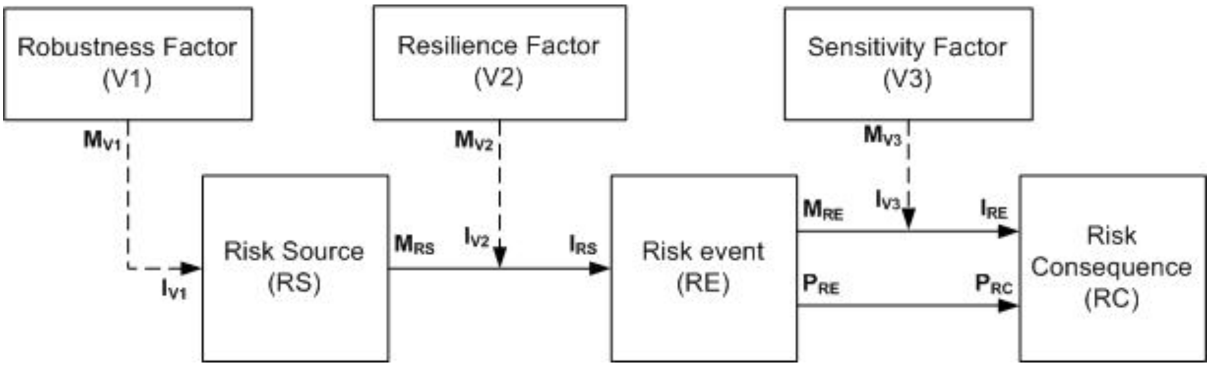

Figure 6: The Developed Risk Path

3.3.5. Risk Path Elements Components

After defining the risk path's risk elements and vulnerability factors, as well as the relations connecting them, the 131 common construction project risks identified in Table 5 were distributed amongst the identified risk path elements. This re-categorization aims at defining risk path components according to their role in the risk path.

First concerning the risk elements, risk sources were classified based on their nature into eleven categories: Financial, Contractual, Legal, Political, Social, Environmental, Communications, Geotechnical, Market, Project, and Construction risks. Further, 14 risk events were identified and grouped in one group as Risk Events. Lastly as mentioned earlier, cost overruns is the only risk consequence taken into consideration, as this research is concerned with only cost, not time nor quality. Tables 7 and 8 show the identified risk sources and events respectively.

Table 7: Risk Sources

Risk Sources

Category	Risk
Financial Risks	Change in financial situation of owner
	Change in financial situation of contractor
	Change in currency exchange rates
	Change in inflation rates
	Change in interest rates
	Change in tax rates
	Low credibility of Owner
	Low credibility of Contractor
	Low credibility of Subcontractor
	Difficult convertibility of Local Currency
Contractual Risks	Breach of contracts by Owner
	Breach of contracts by Contractor
	Disputes between project parties
Legal Risks	Uncertainty and unfairness of court justice

Political Risks	Change in relations with government
	Change in level of bureaucracy
Social Risks	Change in level of bribery and Corruption
	Change in public reaction
Environmental Risks	Hazards of environmental regulations
Communications Risks	Change in relation between parties
	Change in communication between parties
	Problems associated with culture difference
Geotechnical Risks	Change in geological conditions
Market Risks	Competition from other similar projects.
	Fall short of expected income from project use
	Inadequate forecast about market demand.
	Change in availability of labor
	Change in availability of material
	Change in availability of equipment
	Change in availability of subcontractor
	Change in availability of accessory facilities
Project Risks	Improper project feasibility study
	Improper project planning and budgeting
	Improper selection of project location
	Improper selection of project type.
	Inadequate project organization structure
	Increase in project overheads.
	Change in project scope
	Change in project design
	Change in performance of Owner
	Change in performance of designer
	Change in performance of engineer
	Change in performance of contractor
	Unfairness in tendering
	Difference in practices amongst project participants
Construction Risks	Accidents on site
	Obsoleteness/failure of Equipment
	Incompetence of transportation facilities
	Increase in site overheads
	Poor quality of procured accessory facilities
	Poor quality of procured materials.
	Shortage in supply of water, gas, and electricity
	Change in weather conditions
	Change in site organization
	Change in work quality
	Change in site conditions
	Change in construction method/technology
	Change in original schedule

Table 8: Risk Events

Risk Events
Decrease in productivity
Increase in quantity of work
Decrease in quality of work
Increase in labor costs.
Increase in materials prices
Increase in accessory facilities prices
Increase in project overheads costs
Increase in site overheads costs
Increase in resettlement costs
Delays due to client bureaucracy
Delays due to government bureaucracy
Delay in work progress
Delay in project logistics
Delay in client payments

As for the vulnerability factors, they were selected and re-categorized in a manner similar to that described in subsection 3.2.1. First, the identified factors were classified into categories based on their driver or relation to the project. Then, factors in each category were further divided into sub-categories based on their nature. Robustness factors were divided into four categories: Country conditions level, Project conditions level, Owner conditions level, and Project participants conditions level, while Resilience factors comprised of only one category: Contractor conditions level. Lastly, sensitivity factors were grouped in one group as Sensitivity Factors. Tables 9-11 show the identified robustness, resilience, and sensitivity factors respectively.

Table 9: Robustness Factors (V1)

V1: Robustness Factors

Level	Category	Risk
Country conditions	Economic conditions	Instability of economic conditions
	Political conditions	Instability of government
		Instability of international relations
		Change in laws, policies, or regulations
	Social conditions	Instability of social conditions
	Legal conditions	Immaturity of legal system
		Restrictions for foreign companies
		Lack of enforcement of legal judgment
Project conditions	Design conditions	Incomplete design
		Complexity of design
		Errors in Design/Design Drawings
		Low constructability
	Construction conditions	Complexity of construction method

		Poor accessibility of site
		Unknown site physical conditions.
		Inadequate geotechnical investigation
		Inadequate climate conditions
	Management conditions	Strict quality management requirements
		Strict environmental management requirements
		Strict safety management requirements
		Strict project management requirements
	Contract conditions	Vagueness in contract clauses
		Errors in Contractual agreement
		Incomplete contract terms
Owner conditions	Owner objectives	Unclarity of Owner's objectives
	Owner resources	Lack of financial resources
		Technical incompetency of project team
		Change in Owner top management
		Change in project team
		Change in company organizational structure
		Level of bureaucracy of Owner
	Owner managerial ability	Managerial incompetency of project team
		Negative attitude of Owner
Project participants conditions	Designer conditions	Technical incompetency of project team
		Managerial incompetency of project team
		Lack of financial resources
		Lack of technical resources
		Change in project team
	Engineer conditions	Technical incompetency of project team
		Managerial incompetency of project team
		Lack of financial resources
		Lack of technical resources
		Change in project team
		Lack of Engineer staff

Table 10: Resilience Factors (V2)

V2: Resilience Factors

Level	Category	Risk
Contractor Conditions	Contractor experience	Lack of experience in similar projects
		Lack of experience in country
		Lack of experience in delivery system
		Lack of experience with Owner
		Lack of experience with other project parties
	Contractor resources	Lack of financial resources
		Lack of technical resources
		Lack of contractor staff
		Change in project team
		Technical incompetency of project team

		Managerial incompetency of project team
		Change in company organizational structure
	Contractor managerial ability	Lack of project scope management
		Lack of project time management
		Lack of project human resources management
		Lack of project cost management
		Lack of project communication management
		Lack of project risk management
		Lack of project procurement management

Table 11: Sensitivity Factors (V3)

V3: Sensitivity Factors
Project Size
Project Type
Project Delivery Method
Project Contract Type
Project Contract Form

3.4. Phase Three: Ontology Model

In the third phase, an ontology model is created based on the risk path developed in phase two. While it may seem that creating an ontology model is not an essential part of this research's scope of work since it does not directly influence later phases. Nonetheless, an ontology model is important relative to this frame of work due to its ability to create and preserve an information domain that is easy to share and modify as highlighted hereinbefore in subsection 2.5 of the Literature Review.

The literature offers different approaches to construct an ontology model. This research follows one of the most known and used methods to develop an ontology called "Methontology." Developed by Ferndndez et al. (1997) in the 1990s, Methontology is a structured method to build ontologies based on the experience acquired in developing ontologies in the domain of chemicals. As demonstrated in Figure 7, Methontology consists of eight steps when combined form an ontology's life cycle. The eight steps are specification, knowledge acquisition, conceptualization, integration, implementation, documentation, maintenance, and evaluation.

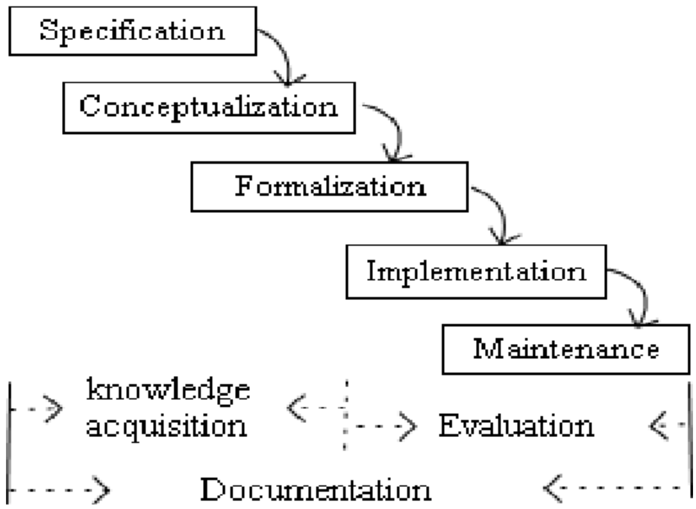

Figure 7: Methontology process (Sawsaa & Lu, 2012)

Although each of these steps are further broken down into sub steps, delving into such details is not the focus of this study. Instead, these steps serve as guidelines that were followed while developing the model.

3.4.1. Specification

The first step to create an ontology is to define ontologies main characteristics which entails determining the purpose of the ontology, its scope, and the intended end users. According to Ferndndez et al. (1997) a well-established specification must be concise, comprehensive, and consistent.

The ontology model created in this research serves to provide information regarding the path of a construction project risk, starting from its point of initialization as a risk source to the point of its materializing as a risk consequence in the form of cost overruns.

The scope of the ontology include 3 classes: risk elements, vulnerability factors and risk path elements properties. Information regarding the following properties is also included: relations amongst risk path elements and relations between the risk path elements and their properties.

This ontology can be used by risk management and cost management professionals in varying roles in the Egyptian market including Owners, Developers, Project Managers, Consultants, and Contractors in price estimation activities.

3.4.2. Knowledge Acquisition

In this step, information about the ontology concepts, their properties and their relationships is gathered. According to Ferndndez et al. (1997), knowledge acquisition techniques may include formal and informal analysis of information sources such as books, graphs, or even other ontologies, in addition structured and non-structured interviews with experts and field professionals.

As for this research, information regarding the most common construction risks was collected from the literature in phase one of this methodology. Then, this information was analyzed and processed as demonstrated in phase two into risk path elements where the identified construction risks were categorized and distributed according their role in the risk path. The output of phase two form the base upon which the ontology was build.

3.4.3. Conceptualization

Conceptualization is the step where the Ontology's domain structure and vocabulary are constructed. It consists of two main activities, the first of which is building a complete Glossary of Terms. An ontology's Glossary of Terms (GT) consists of defined sets of concepts, instances, verbs, and attributes, where a concept represents a set or class of entities within a domain and an instance represents an entity such that when similar entities are grouped together, they form classes of concepts. Whereas attributes represent the properties of concepts and instances, and verbs represent the relations between concepts. These terms are collected and identified based on the domain of information to be represented in the ontology. A complete, well-established GT should include comprehensive and useful information regarding the domain of knowledge the ontology is representing.

The second activity is constructing concept classification trees and verb diagrams. Terms identified in the GT can be broadly categorized as either concepts or verbs (Ferndndez et al., 1997). In this step, concepts should be grouped in hierarchy structures such that concepts that are closely related to one another are grouped together as subsets of other concepts. For each group of related sets and subsets, a concept classification tree is constructed. Likewise, verbs are structured in the same manner, forming verb diagrams. After building needed concept classification trees and verb diagrams, further ontology development progresses as per the guidelines proposed by Ferndndez et al. 1997) in Figure 8. First concerning the GT concepts, after establishing the concept classification trees, Data dictionaries, Tables of instance attributes, along with other data representation tools are developed. Data dictionaries are used to describe domain concepts, their descriptions as well as their corresponding attributes and instances. Tables of instance attributes describe the domain attributes and their values at the instance level, while Tables of class (concept) attributes describe the values of the domain attributes at the concept level. Lastly, Tables of instances describe the domain instances. Tables of constants and Attributes classification trees are not used in this study and thus are neglected. As for the GT verbs, they include Verbs diagrams, which include Verbs dictionary and Table of conditions. However, Verbs diagrams are not used in this study and thus are neglected.

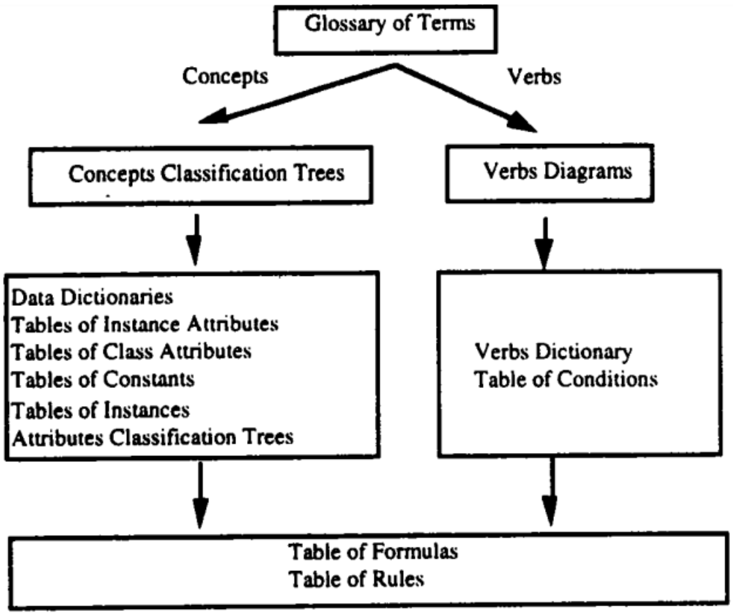

Figure 8: Ontology development processes (Ferndndez et al., 1997)

Although often considered the methontology's most challenging step (Noy, 1997), conceptualization in this research was quite the opposite since most of the work needed to complete this step was performed in the previous phase of this study. First, the ontology's GT was constructed following the risk path developed in section 3.3. Risk path elements identified in Tables 7 to 11 constitute the GT's concepts and instances, whereas risk path elements' properties (probability of occurrence, magnitude of occurrence, and impact of occurrence) constitute the GT's attributes as illustrated in Table 12. Lastly, the relations between the risk path elements constitute the GT's verbs. Since the relations between the elements of the risk path are mainly a series of events that impact subsequent events, this ontology's verbs glossary consists of only two terms "impacts" and "is impacted by'.

Table 12: Table of class attributes

Class	Attributes (Data Properties)

Risk Source	Magnitude, Impact
Risk Event	Probability, Magnitude, Impact
Risk Consequence	Probability, Magnitude
Robustness Factor	Magnitude, Impact
Resilience Factor	Magnitude, Impact
Sensitivity Factor	Magnitude, Impact

In order to follow the structural model of ontologies, the GT concepts are organized in a superclass-subclass hierarchy based on the same categorization technique adopted before. Concepts in the hierarchy are grouped under one top level class called Risk Path Elements, followed by two subclasses Risk Elements and Vulnerability Factors, after which the risk of the hierarchy follows as can be seen in Figure 9. According to this ontology's GT, both the classes and instances share the same attributes and they are as illustrated in the UML diagram in Figure 10.

3.4.4. Integration

This step proposes the reuse of definitions already built into other ontologies if applicable as an alternative to starting from scratch. However, since the number of ontologies that focus on construction risks in the literature is limited, reusing other ontologies is not an applicable option and this step is omitted.

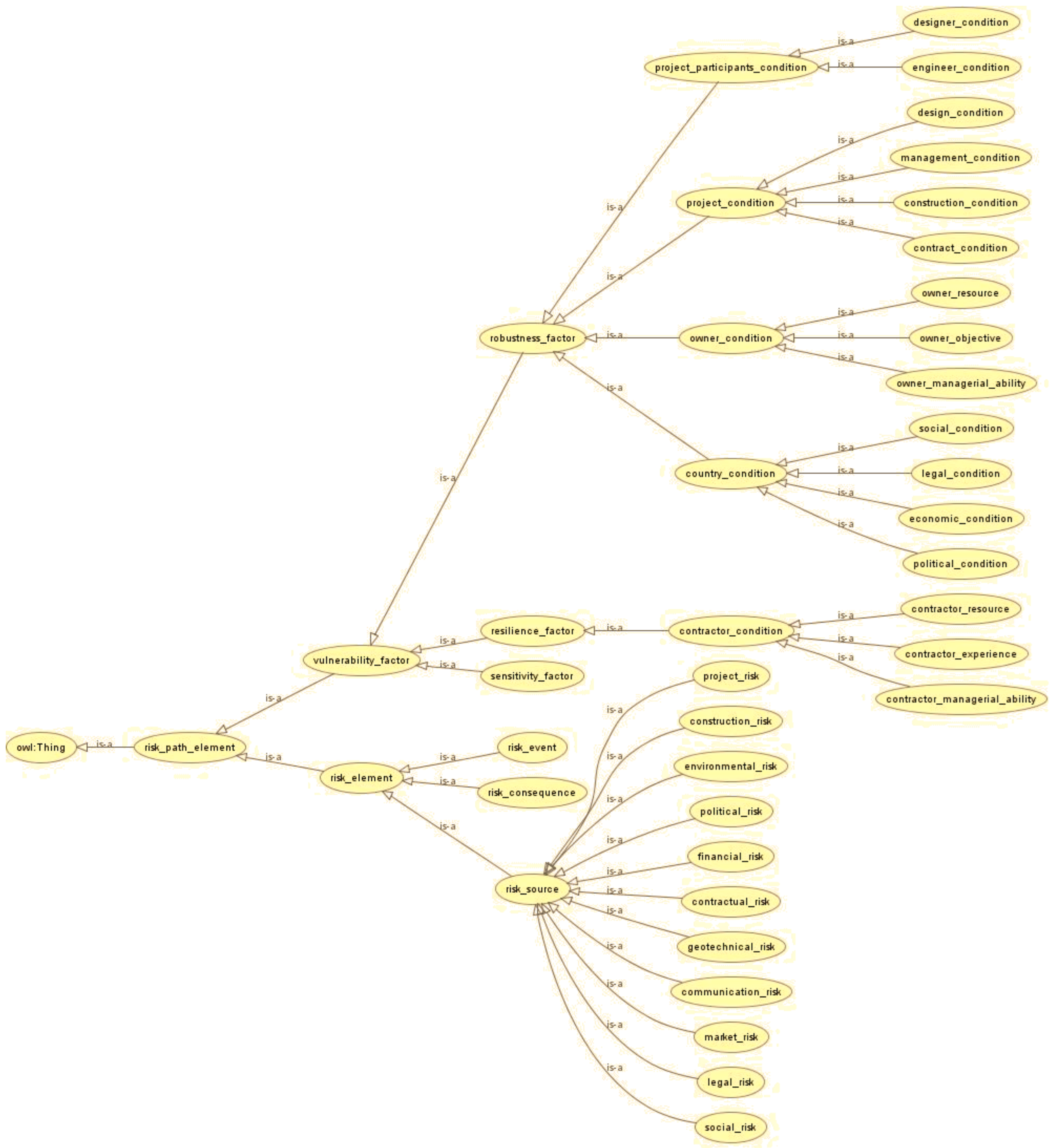

Figure 9: Concepts superclass-subclass hierarchy diagram

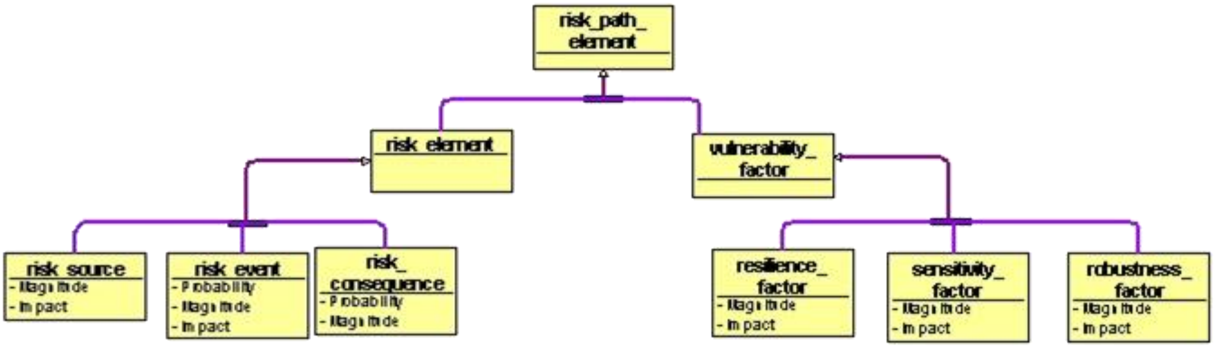

Figure 10: UML attributes diagram

3.4.5. Implementation

As indicated by its name, implementation is the application of the domain information collected in the knowledge acquisition, conceptualization, and integration steps into a machine-processable ontology language (Breitman et al., 2007). In this research, "implementation was conducted using the Protégé resource. Protégé is a free, open-source ontology editor and framework for building intelligent systems developed by Stanford Center for Biomedical Informatics Research at the Stanford University School of Medicine (Musen, 2015).

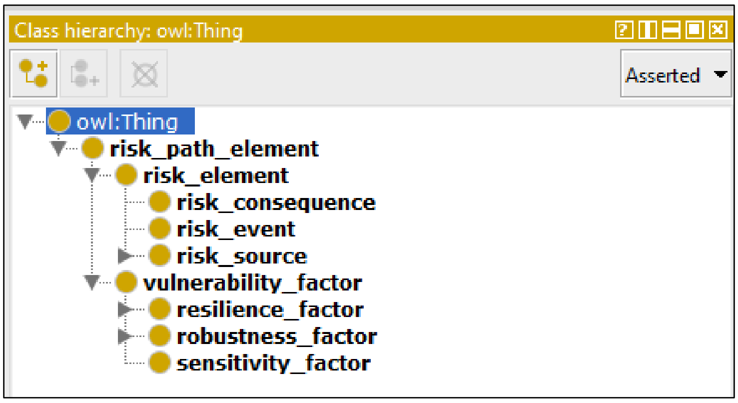

Figure 11: Concepts class hierarchy in Protégé

Edition 5.2.0 of Protégé Desktop was used. Details regarding how the software was used is out of the scope of this study. However, snapshots of the program are included below to demonstrate achieved work. Figures 11 to 13 demonstrate the ontology's concepts class hierarchy as implemented in Protégé. Further, Figure 14 shows the ontology's attributes class hierarchy after implementing in Protégé as Data Properties. Lastly, Figures 15 to 17 show some of the ontology's instances grouped as per their parent classes.

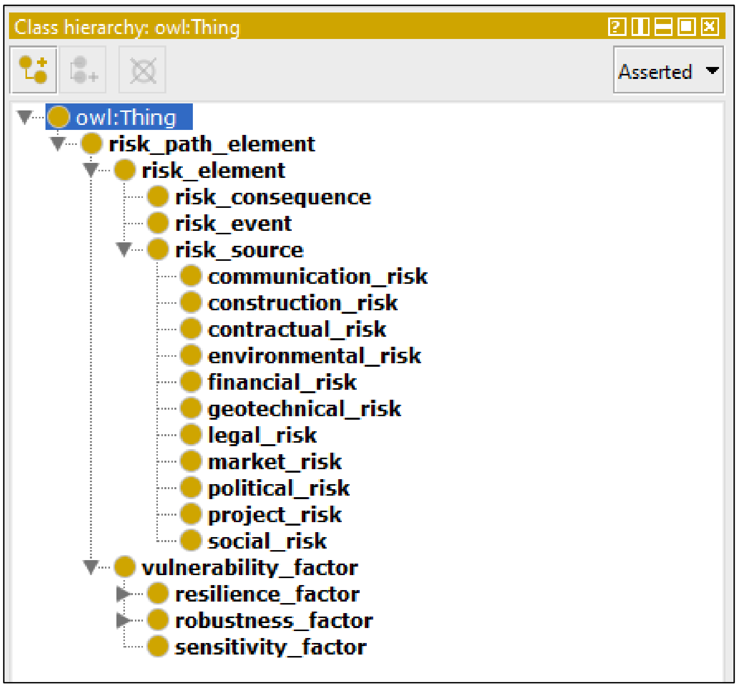

Figure 12: Concepts class hierarchy in Protégé (Risk Elements)

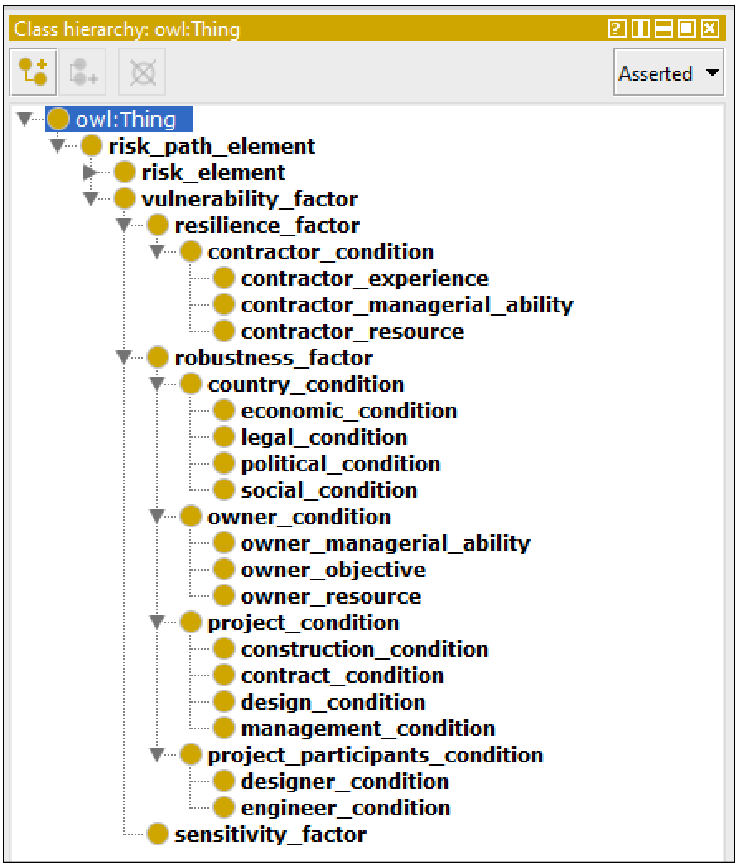

Figure 13: Concepts class hierarchy in Protégé (Vulnerability Factors)

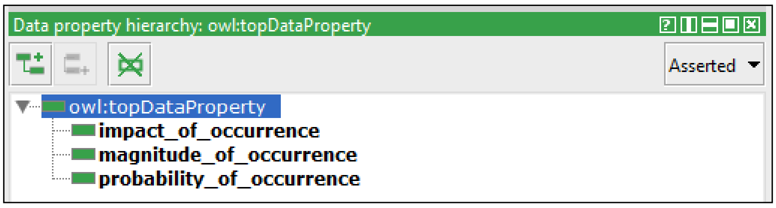

Figure 14: Attributes (Data Properties) class hierarchy in Protégé

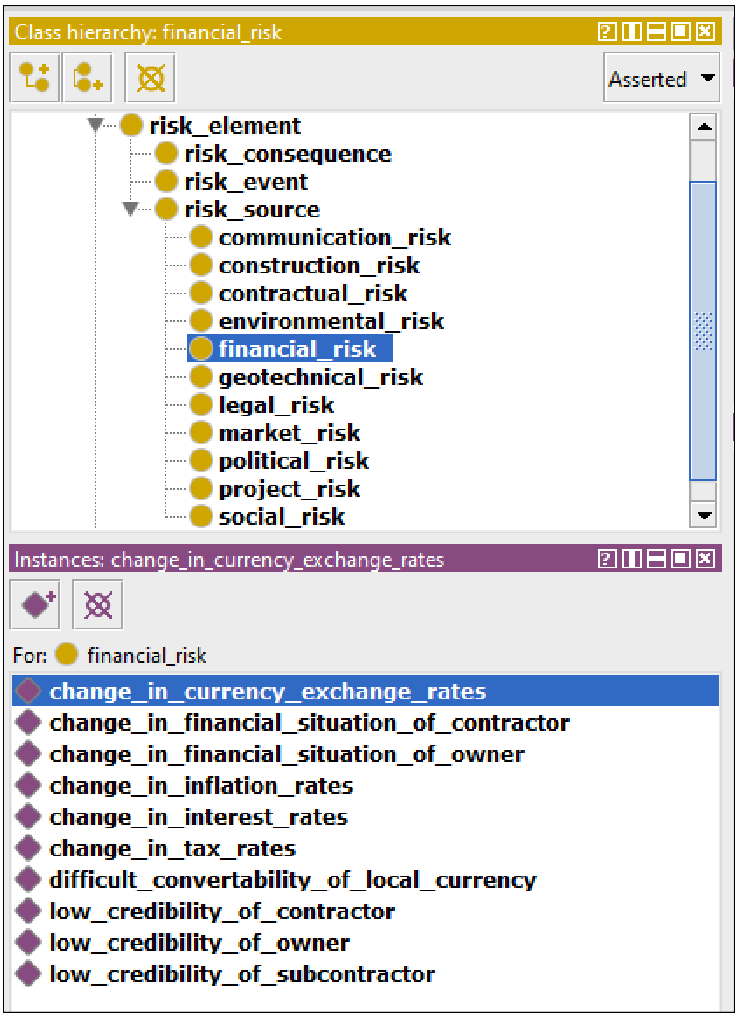

Figure 15: Financial risk instances in Protégé

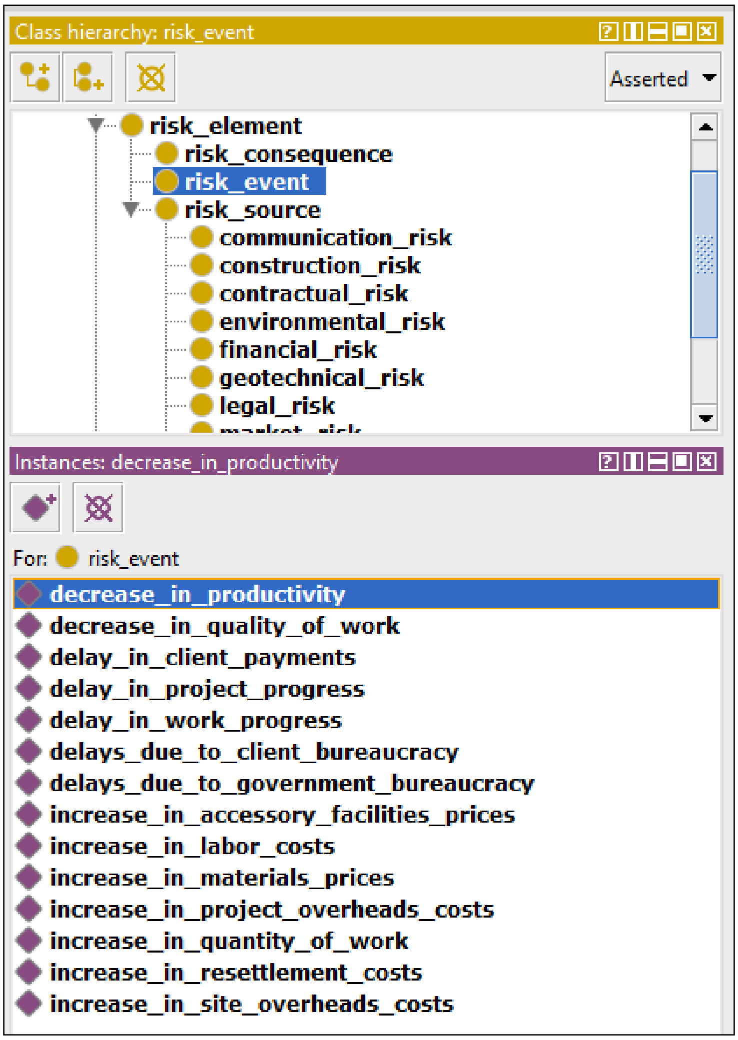

Figure 16: Risk event instances in Protégé

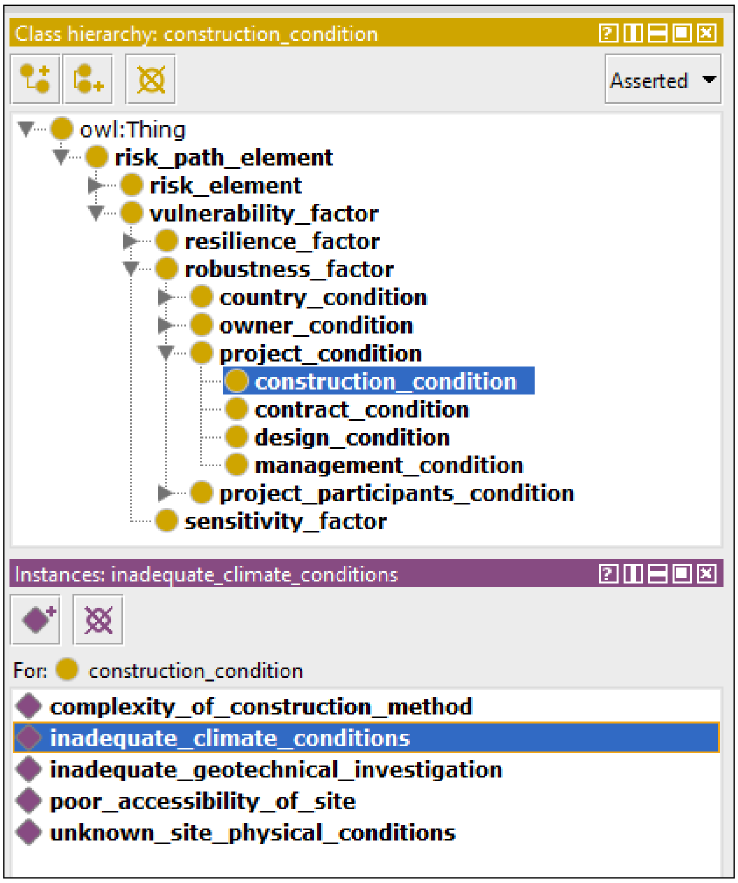

Figure 17: Construction condition instances in Protégé

3.4.6. Documentation

According to Ferndndez et al. (1997) there are two types of documentation. The first is concerned with documenting the steps a developer goes through to create an ontology. Sub-sections 3.4.1 to 3.4.5 cover in detail the steps performed to develop the ontological model of this research, which satisfies the requirements of the first type of documentation. Whereas, the second type of documentation is concerned with documenting the developed ontology itself. The developers of the software Protégé have constructed an online library platform where users can upload and share the ontology codes they create. The ontological model developed in this research can be found on the Protégé Ontology Library webpage under the name “Riskpathontology”

3.5. Phase Four: Surveying Professionals: Patterns of Dependencies

Moving to the fourth phase of the methodology, this section provides a detailed account of how the research survey was planned, developed and executed. Serving the purpose of this research, a surveying process is tailored to collect project-based information in relation to the patterns of dependencies amongst the identified risk path elements (risk elements and project vulnerabilities) as well as the degrees of significance of these dependencies in terms of their effect on projects' cost in the Egyptian construction industry. The survey was conducted through a questionnaire. Using questionnaires to collect project performance data has been widely utilized in research of similar nature (Liu et al., 2016); (Bing et al., 2005); (Shen et al., 2001).

Kulzy and Fricker (2015)'s describe the six stages of conducting a survey as follows:

- Planning and development: in this stage the survey objective is defined, survey questions and their associated response scales are drafted, and a sampling methodology is created where the number of respondents and how they will be selected from the population is specified.
- Pretesting: in this stage, the survey questions drafted in stage 1 are filled out by respondents who are as similar as possible to the intended survey respondents. One or more cycles of revision are conducted to edit the questions as per the pretesters' feedback.
- Final design and planning: in this stage the final questionnaire, sampling plan, and analysis plan are developed and ready for execution.
- Implementation/Fielding: this is the execution stage where the survey respondents are asked to complete the questionnaire.
- Data coding: this is the stage where raw survey data is transformed into analytical data that is useful for analysis.
- Analysis and reporting: in this stage the analytical data produced in stage 5 is used to make assumptions, construct algorithms, and craft insights. Analysis findings are presented in a clear and concise manner.

Although each of these stages are further broken down into sub stages, delving into such details is not the focus of this study. Instead, these stages serve as guidelines that were followed while conducting the survey.

3.5.1. Survey Objectives

The survey has primarily two objectives. The first is to collect information regarding patterns of dependencies among the risk elements (sources, events, consequences) and project vulnerabilities (robustness factors, resilience factors, and sensitivity factors) discussed and identified in the previous section. The second objective is to investigate the relation between these patterns of dependencies and projects' cost overruns according to construction projects in Egypt. In other words, it aims to identify the degrees of significance of these dependencies in terms of their effect on projects' cost in the Egyptian construction industry.

3.5.2. Survey Architecture

The questionnaire consists of four main sections: an introductory paragraph, respondent profiling questions, Project 1, and Project 2. It is project-based meaning that respondents are asked to provide information pertaining to a specific project with a maximum of two projects per questionnaire. Instructions on how to fill out the questions and explanations of the questions types and scales preceded each section. A sample of the questionnaire distributed to respondents is provided in Appendix A.

In the first section, the research and survey objectives are presented in an introductory paragraph. The second section consists of five questions regarding the respondents' educational background, profession, years of work experience, and current role and position. These questions are multiple choice questions meant to profile the respondents.

In the third section, respondents are asked to answer three sets of questions based on their experience in a certain project in which they have been involved. The first set of questions asks respondents to rank the vulnerability factors identified in Tables 9 to 11 with respect to their relevance to the project's conditions using a five-point scale (1= Not relevant; 2= Slightly relevant; 3= Relevant; 4= Very relevant; 5= Extremely relevant). The second set asks respondents to rank the risk elements identified in Tables 7 and 8 with respect to their effect on the project's cost overruns using a five-point scale as well (1= Not significant; 2= Slightly significant; 3= Significant; 4= Very significant; 5= Extremely significant). As for the third set, it consists of six questions that request respondents to provide specific project characteristics including project type, contract type, delivery method, contract form, project budget estimate and cost overrun percentage. Four out of the six questions are multiple choice, while the remaining two are short answer questions.

The fourth section is exactly the same as section 3 so that it allows the respondents to provide information for a second project if applicable. However, unlike section 3, section 4 is not obligatory and respondents have to the option whether to fill it out or not.

3.5.3. Survey Sampling

The survey's target population consists of professionals at different positions ranging from engineers and architects to manager and executive level personnel with varying roles in the Egyptian market including Owners, Developers, Project Managers, Consultants, Domestic and International Contractors, and Sub-Contractors.

As for the survey sampling, there are a number of methods to select a sample from the target population. A sample selection method is important because it directly influences the survey results which directly influence the researches findings and conclusion. According to the literature, there are numerous sampling techniques that can be adopted to render an appropriate survey sample with some more commonly used than others. Examples of common sampling techniques include Bernoulli sampling, Cluster sampling, Systematic sampling, and Stratified sampling, while other less common techniques include Snowball sampling, Acceptance-Rejection sampling, Experience sampling, and Demon algorithm (Hibberts, Johnson, & Hudson, 2012). The following is a brief description of the sampling methods adopted for sample selection while conducting this survey. A mix of the below three methods was used to select the sample of the survey respondents.

Snowball sampling: it is a non-probability sampling method where the researcher identifies potential participants for the survey, and ask those participants to recruit further participants. Those steps are repeated until the needed sample size is found (Hibberts, Johnson, & Hudson, 2012).

Simple random sampling: as implied by its name, a simple random sample is a sample chosen on a random basis, where a set of n objects in a population of N objects is selected with all possible samples equally likely to happen (Hibberts, Johnson, & Hudson, 2012).

Convenience sampling: it is a non-probability sampling method where the researcher choose to recruit participants who are easy to reach and readily available (Hibberts, Johnson, & Hudson, 2012).

3.5.4. Sample Size

Cochran's formula is used in this research to determine the appropriate sample size required to achieve statistically valid results as follows.

$$n = N*X / (X + N - 1),$$

where,

$X = Z_{\alpha/2}^2 \text{-} * p * (1\text{-}p) / D^2$,

and,

n is the sample size

N is the population size. In this case, the population size is of a large but unknown value. Therefore, it is recommended to use a value of 100,000, as the sample size becomes less sensitive for population changes larger than 100,000.

Z is the confidence level and it is expressed in percentage. Confidence level is the percentage of the population who would select an answer that lies the confidence interval. In this case, $Z_{\alpha/2}$ is the critical value of the normal distribution at $\alpha/2$ and is equal to 1.64, which corresponds to a 90% confidence level.

p is the percentage of the sample who would select the same answer. In this case, p is equal to 0.5 which represents the worst case scenario.

D is the margin of error that can be accepted. It is expressed in percentage and it represents the width of the confidence interval. The lower the margin of error the larger the required sample size in order to achieve results within the confidence level. In this case, d is equal to 0.15 for the sample size needed.

By plugging the above values into Cochran's formula, the calculated minimum sample size is around 31 respondents.

3.5.5. Survey Administration

There are various methods to administer a questionnaire such as the one subject of this research (explained in subsection 3.5.2), depending on the medium through which the questionnaire is to be circulated to respondents. Feasible media include telephones, mails, emails, face to face, and sharable links on the internet. Selection of the appropriate medium is essential as it has a considerable effect on the format, structure, and content of the survey. For example, questionnaires conducted over phone calls have to short and simple to avoid confusion, while questionnaires conducted through mails or emails can be longer and more complex.

In this research, the questionnaire was created using Google Forms, where sharable links were sent out to respondents through emails, LinkedIn and other social media platforms. Also, hardcopies of the questionnaire were printed out and filled by hand when applicable.

3.5.6. Survey Pretesting

After defining the survey questions and their response scales, its sampling and administration methodologies, as well as the designated sample size, a draft of the created questionnaire was sent to the research advisors for their review. The questionnaire was filled out by two advisors in a mock trail to pretest its effectiveness in addressing the survey objectives and to ensure that it comprehensively inquire for the required data in a clear and concise manner.

Following pretesting the questionnaire, the advisors provided feedback that was taken into consideration and the questionnaire was revised as per the advisors' comments.

3.5.7. Survey Execution

For this survey, a total of 90 questionnaires were sent out to professionals at different positions and different roles as per the defined target population using the selected sampling techniques that were mentioned in sub-section 3.5.3. A total of 35 responses pertaining to 57 projects were received. Appendix B provides details regarding the survey participants and demography.

Of the 35 responses, 3 responses were incomplete and therefore discarded. The remaining 32 responses were complete and thus viable to be considered in the study, surpassing the acceptable sample size mandated by Cochran's sample size formula and appropriate formula parameters detailed in this section. The 32 complete responses cover a total number of 53 projects. Data provided by the respondents is collected and detailed in the following chapter.

3.6. Phase Five: Modeling Framework

Based on the identified risk path elements and conducted survey, the research proceeds with developing a simulation model in the methodology's fifth and final phase. The model is constructed to emulate the life cycle of any given risk through a project as per the established risk path. The purpose of the model is to gain a better understanding of the relations amongst the identified risk path elements as well as their impact on cost overruns. Further, it aims to investigate the combinations of risk path elements with the greatest impact on project cost overruns.

3.6.1. Model Database and Scenarios

In order for the model to provide accurate simulations, a sufficient database is required. A sufficient database in this case should cover different risk scenarios in addition to corresponding project characteristics such as project type, project size, delivery method, contract type, and most importantly project cost overruns.

The database for this model was developed based on project-based data collected from the survey responses mentioned in the previous section. This database is considered comprehensive since it is based on 32 survey responses, covering a total of 53 projects. Figure 18 is an extract from the database, where the columns are the identified risk elements and vulnerability factors corresponding to each of the risk path elements while the rows demonstrate the responses of the survey participants.

As can be seen in Figure 18, data is sorted in the database such that each row contains information relative to a specific project, detailing that project's risk scenario as well as characteristics such as project type and delivery method . For each risk scenario, ratings of the risk path elements (risk elements and vulnerability factors) provided by respondents characterize the project's risk path. These ratings are assumed to be the magnitudes of the risk elements and vulnerability factors, while the probability of occurrence of all risk path elements are assumed to be a hundred percent given that the surveyed projects are completed or in progress and therefore the risk scenarios in question have already taken place and their consequences were witnessed. As for the impact, the ratings decide the impact of each of the risk path elements on the subsequent element as well as the elements with the greatest impact on cost overruns after running the model.

It is important to note that this database does not cover all possible risk scenarios, but rather only those experienced by the survey respondents and collected as part of the survey results. In other words, it is possible that there exist other common risk scenarios. However, they are not included in the database because none of the survey respondents encountered them. In conclusion, the database contains 53 risk scenarios, where all scenarios are independent of one another and may be pertaining different projects.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	Project No.	[Instability of economic conditions]	[Instability of government]	[instability of international relations]	[change in laws, policies, or regulations]	[Instability of social conditions]	[Immaturity of legal system]	[Restrictions for foreign companies]	[Lack of enforcement of legal judgment]	[Incomplete design]	[Complexity of design]	[Errors in Design/Design Drawings]	[Low constructability]	[Complexity of construction method]	[Poor accessibility of site]	[Unknown site physical conditions.]	[inadequate geotechnical investigation]	[inadequate climate conditions]	[strict quality management requirements]	[strict environmental management requirements]	[strict safety management requirements]	[strict project management requirements]	[vagueness in contract clauses]	[Errors in Contractual agreement]	[Incomplete contract terms]	[technical incompetency of project team]
2	1	3	1	1	2	1	1	2	1	3	3	3	2	2	1	3	2	1	3	3	2	2	3	3	3	4
3	2	4	3	2	4	3	4	3	3	4	4	4	2	3	3	3	2	2	3	3	3	3	3	4	4	3
4	3	5	3	3	5	4	4	3	4	4	5	4	5	4	4	3	3	3	2	2	4	4	5	5	5	3
5	4	4	4	1	4	3	2	2	2	4	3	4	3	3	1	2	3	1	5	3	5	5	2	2	2	3
6	5	4	4	4	3	3	3	4	3	3	4	4	4	4	4	4	3	3	4	3	3	4	4	5	5	5
7	6	3	3	2	4	2	4	1	3	3	3	3	4	4	1	2	2	2	3	2	4	3	3	3	3	4
8	7	3	3	2	2	2	3	2	2	4	3	4	4	3	2	1	3	4	4	3	3	4	3	5	4	3
9	8	5	2	2	5	1	1	2	2	4	2	5	2	4	2	5	4	1	1	1	1	2	5	5	4	3
10	9	3	3	2	4	3	3	3	4	5	5	5	4	4	4	3	4	3	3	3	4	4	4	4	3	5
11	10	4	2	3	3	3	4	3	4	2	2	2	2	2	2	3	3	2	2	2	2	2	3	4	4	3
12	11	5	4	3	5	3	3	3	5	5	4	5	4	5	4	4	4	3	4	4	5	5	5	5	5	4
13	12	5	5	5	5	4	4	3	4	3	4	4	4	4	1	5	3	1	3	1	2	2	5	4	5	3
14	13	4	4	2	2	2	2	1	1	3	4	2	3	3	3	2	1	1	2	1	1	3	2	1	2	5
15	14	4	4	3	4	3	4	3	4	4	4	3	4	4	3	4	5	4	4	3	4	3	4	4	4	4
16	15	1	5	5	1	2	1	5	1	5	2	2	1	4	5	1	1	1	1	1	1	1	3	2	2	1
17	16	3	3	3	3	3	3	3	3	4	4	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3
18	17	3	4	2	4	2	5	1	5	4	3	2	1	2	3	4	5	4	3	2	1	2	3	4	5	1
19	18	1	3	2	5	4	5	5	4	3	4	5	4	3	4	5	4	3	4	5	4	3	4	5	3	1
20	19	5	5	5	5	4	5	5	5	4	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
21	20	4	5	3	4	4	4	5	4	3	4	5	4	4	4	4	5	3	4	4	4	3	5	5	5	5
22	21	4	4	4	5	3	3	3	4	4	3	3	4	3	3	4	5	4	3	3	3	2	4	5	4	3
23	22	3	3	3	4	2	4	4	4	4	3	3	4	3	3	4	5	4	3	3	3	2	4	4	4	3
24	23	5	2	2	4	2	1	3	1	5	5	5	5	5	5	5	5	1	4	3	3	3	5	5	5	4

Figure 18: An extract from the database

3.6.2. Model Development

After setting the model's database, the model is developed. In this study, the model is composed of a chain of three sub models that together simulate the relations between the risk path elements as prescribed in the risk path (Figure 6). Two of the sub models are optimization models, while the third is an Artificial Neural Network (ANN) model.

The first optimization model simulates the impact of the magnitudes of the Robustness factors on the magnitudes of the Risk sources. It is a mathematical programming model with pre-defined object functions and constraints developed using Microsoft Excel in addition to Microsoft Excel solve add-in optimization tool.

While the second optimization model simulates the impact of the magnitudes of both Resilience factors and Risk sources on Risk events. Similarly, it is a mathematical programming model with pre-defined object functions and constraints developed using Microsoft Excel in addition to Microsoft Excel solve add-in optimization tool.

As for the third and only ANN model, it simulates the impact of the magnitudes of both Sensitivity factors and Risk events on Risk consequences, which in this case is cost overruns. It is developed using Microsoft Excel in addition to Palisades' Neuraltools DecisionTools Suite (Palisade, 2019).

The proposed modeling framework is as illustrated in the flowchart in Figure 19. As can be seen in the flowchart, model development is divided into three modules: Input, Processing, and Output.

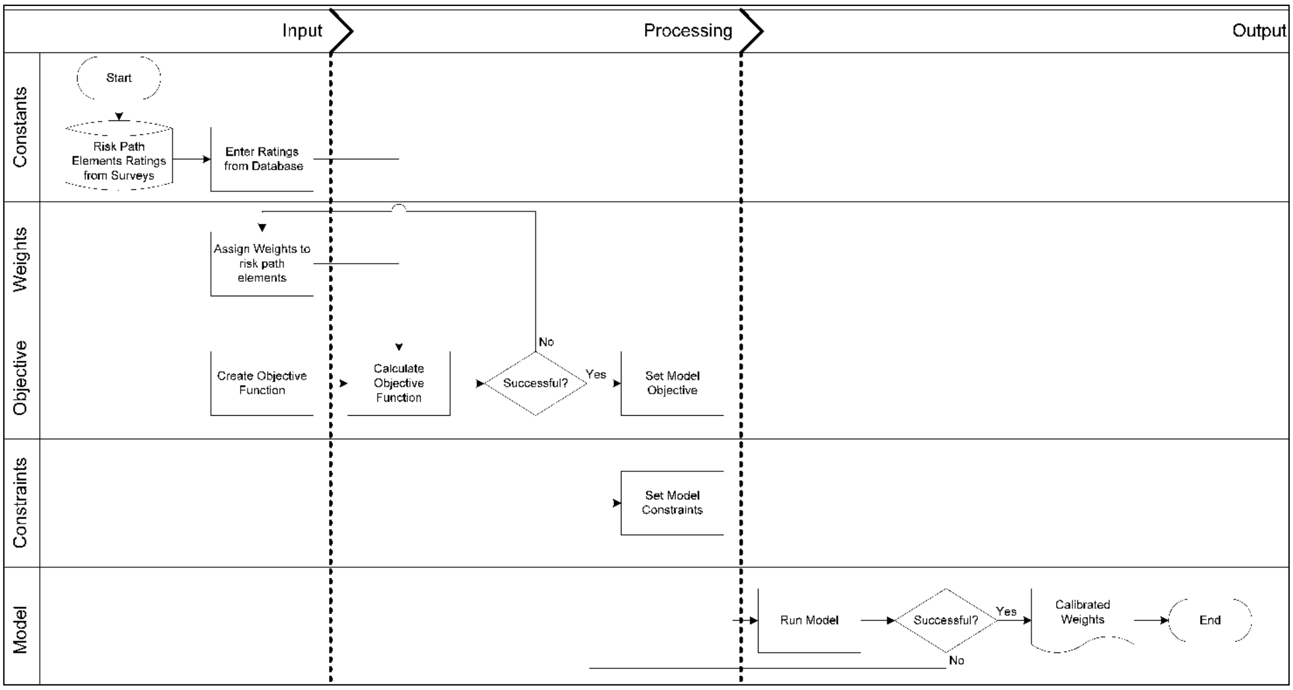

Figure 19: ANN Model Flowchart

3.6.3. Input Module

In this module, the database is imported to a Microsoft excel sheet, where the three models are to be created. The models' dataset covers 52 of the 53 database scenarios, as one scenario was found to be a data anomaly and therefore was discarded.

As mentioned earlier, the first model is an optimization model that simulates the impact of the magnitudes of the Robustness factors on the magnitudes of the Risk sources. For this model, the first input is the robustness factors' ratings imported from the database. The second input is the Robustness factors weights. Each of the robustness factors is assigned an arbitrary value, the value "1" in this case. These values are considered the weights of the robustness factors when forming the model's objective function, and are subject to change when running the model. The Robustness factors weights are used to calculate the weighted average of the robustness factors' ratings. For each of the database scenarios, the weighted average of all Robustness factors is calculated based on the weights assigned to each of the factors and the corresponding ratings provided in the database as per Equation 1.

Equation 1: Robustness factors weighted average

$$Robustness\ Factors\ weighted\ average = \sum_{i=1}^{44} \frac{Robustness\ Factors\ Ratings_i}{Robustness\ Factors\ Weights_i}$$

The third input is the objective function, which is the sum of the squares of the difference between the weighted average of the robustness factors' ratings (independent variables) and sum of the risk sources ratings (dependent variables) for each of the database scenarios as per Equation 2. As for the model constraints, they are determined in the Processing Module.

Equation 2: 1st model's objective function

$$Error = \sum_{i=1}^{52}(Robustness\ Factors\ weighted\ average_i - \ Risk\ Sources\ ratings\ sum_i)^2$$

The second model is an optimization model that simulates the impact of the magnitudes of both Resilience factors and Risk sources on Risk events. The second model follows the same logic established in the first model, where the first input is the Resilience factors and Risk sources' ratings imported from the database. The second input is the Resilience factors and Risk sources weights. Each of the Resilience factors and Risk sources is assigned an arbitrary value, the value "1" in this case. These values are considered the weights of the Resilience factors and Risk sources when forming the model's objective function, and are subject to change when running the model. The Resilience factors and Risk sources weights are used to calculate the weighted average of their ratings. For each of the database scenarios, the weighted averages of Resilience factors and Risk sources is calculated based on the weights assigned to each of the factors and the corresponding ratings provided in the database as per Equations 3 and 4.

Equation 3: Resilience factors weighted average

$$Resilience\ Factors\ weighted\ average = \sum_{i=1}^{19}\frac{Resilience\ Factors\ Ratings_i}{Resilience\ Factors\ Weights_i}$$

Equation 4: Risk sources weighted average

$$Risk\ Sources\ weighted\ average = \sum_{i=1}^{58}\frac{Risk\ Sources\ Ratings_i}{Risk\ Sources\ Weights_i}$$

The third input is the objective function. Similar to the first model, the objective function is the sum of the squares of the difference between the weighted averages of the Resilience factors and Risk sources' ratings (independent variables), and sum of the risk events ratings (dependent variables) for each of the database scenarios as per Equation 5. As for the model constraints, they are determined in the Processing Module.

$$Er$$

Equation 5: 2nd model's objective function

$$ror = \sum_{i=1}^{52} (Resilience\ Factors\ weighted\ average_i -\ Risk\ Events\ ratings\ sum_i)^2$$

$$Error = \sum_{i=1}^{52} (Risk\ Sources\ weighted\ average_i -\ Risk\ Events\ ratings\ sum_i)^2$$

As for the third model, it is an ANN model that simulates the impact of the magnitudes of both Sensitivity factors and Risk events on Risk consequences (cost overruns). The model inputs, named input neurons in this model, are the Sensitivity factors and Risk events' ratings imported from the database. Sensitivity factors ratings are independent category variables except for project budget, which is an independent numerical variable, and Risk events ratings are independent numerical variables. The model weights and objective function are created automatically and the model weights are adjusted iteratively in accordance with the error value in order to minimize the error. The model contains one hidden layer that consists of 5 hidden nodes. The model follows a supervised learning algorithm, since the values of the outputs are known and the function of the model is to map a training net based on provided input-output pairs.

3.6.4. Processing Module

After setting the models inputs, processing module commences by simulating the models using two Microsoft excel add in optimization tools: solver add-in and neuraltools add-in. Using solver add-in, the objectives, variables, and constraints of the first model's objective function are assigned. The objective is to minimize the model's error, which is the difference between the weighted average of the robustness factors' ratings and sum of the risk sources ratings. The variables are the weights assigned to the robustness factors, while the constraint is that none of the weights shall be equal to Zero.

Similarly, the objectives, variables, and constraints of the second model's objective function are assigned. The objective is to minimize the model's error, which is the difference between the weighted averages of the Resilience factors and Risk sources' ratings (independent variables), and sum of the risk events ratings. The variables are the weights assigned to the Resilience factors and Risk sources, while the constraint is that none of the weights shall be equal to Zero.

In other words, the first two models run such that the solver finds the smallest possible value for the sum of the squares of the differences between the weighted averages of the independent elements' rankings and the sum of the dependent elements' rankings for each of the database scenarios. This objective is realized by calibrating the independent elements weights given that none of them can be equal to zero.

As for the third model, the ANN model is trained using the neuraltools add-in. Through the add-in's interface, the model's dataset and variables are assigned. The variables are divided into independent and dependent variables. The independent variables are the Sensitivity factors and Risk events' ratings, while the dependent variable is the cost overruns. The model is a MLFN Numeric Predictor. It consists of 18 input nodes (independent variables), one output node (dependent variable), and one hidden layer that consists of five nodes. 80 percent of the dataset's scenarios is used in training the model. By running the model, the model's net data is developed and a variables impact analysis is calculated.

3.6.5. Output Module

After processing the models, models outputs are generated. The optimization models outputs are calibrated weights, while the ANN model outputs are variable impact percentages. These outputs represent the true weights of the risk path elements on subsequent elements and ultimately on cost overruns as per the relations established in this study's risk path. For the first optimization model, the model outputs consist of calibrated weights that were assigned as arbitrary values to each of the robustness factors in the input module stage. These weights represent the impact of robustness factors on risk sources. Similarly for the second optimization model, the model outputs consist of calibrated weights as well that represent the impact of resilience factors and risk sources on risk events. As for the ANN model, the Neuraltools add-in generates a variable impact analysis report showing the percentage of impact each of the independent variables had when forming the model's objective equation. These percentages are used as an indication of the weights each of the sensitivity factors and risk events have on cost overruns.

In total, outputs generated by the three models comprise of five sets of weights, one set corresponding to each of the risk path elements. The first set is generated by the first optimization model and it consists of Robustness factors weights. These weights determine the effect of each of the robustness factors on risk sources. The second set is generated by the second optimization model and it consists of Resilience factors weights. These weights determine the effect of each of the Resilience factors on Risk events. Similarly, the third set is generated by the second optimization model as well and it consists of Risk sources weights, which determine the effect of each of the Risk sources on Risk events as well. As for the fourth set, it is generated by the third and only ANN model. It consists of Sensitivity factors weights, which determine the effect of each of the Sensitivity factors on cost overruns. Lastly, the fifth set is generated by the ANN model as well and it consists of Risk events weights, which determine the effect of each of the Risk events on cost overruns. Table 13 summarizes the three models used in this study and the calibrated weights generated by each of them.

Table 13: Summary of the risk path models and their outputs

Model No.	**Model Type**	**Relations Simulated by Model**	**Generated Output**
Model 1	Optimization model	Robustness Factors on Risk Sources	Robustness Factors weights
Model 2	Optimization model	Resilience Factors on Risk Events	Resilience Factors weights
		Risk Sources on Risk Events	Risk Sources weights
Model 3	ANN model	Sensitivity Factors on Cost Overruns	Sensitivity Factors weights
		Risk Events on Cost Overruns	Risk Events weights

All models outputs are generated and collected for further analysis and investigation as discussed in the next chapter.

Chapter 4: Results and Analysis

4.1. Introduction

This chapter presents the models outputs as well as the analysis and investigations conducted to comprehend them. First, it highlights the data collected by the survey. Following, it provides a detailed account of the outputs generated by the models and the findings constructed based on these outputs. Second, it presents and discusses a case study used to show case these weights. Lastly, it describes the model verification and validations procedures adopted in this research.

4.2. Survey Results

As discussed earlier, data provided by the survey respondents consists mainly of ratings for each of the components of the risk path elements. Table 14 is a summary of the collected ratings, highlighting the count of each of the scale five ratings from 1 to 5.

Table 14: Summary of ratings collected by the survey

Risk	**Survey Ratings**				
	1	**2**	**3**	**4**	**5**
Risk Sources					
Change in financial situation of owner	6	3	11	12	20
Change in financial situation of contractor	2	6	17	14	13
Change in currency exchange rates	3	5	8	16	20
Change in inflation rates	4	6	11	16	15
Change in interest rates	4	6	18	15	9
Change in tax rates	5	5	16	16	10
Low credibility of Owner	5	8	13	20	6
Low credibility of Contractor	2	11	13	20	6
Low credibility of Subcontractor	3	8	16	21	4
Difficult convertibility of Local Currency	3	9	12	17	11
Breach of contracts by Owner	3	9	11	18	11
Breach of contracts by Contractor	4	8	19	13	8
Disputes between project parties	4	3	16	22	7
Uncertainty and unfairness of court justice	4	9	16	15	8
Change in relations with government	4	7	19	14	8

Change in level of bureaucracy	5	11	18	10	8
Change in level of bribery and Corruption	7	7	16	12	10
Change in public reaction	8	10	16	8	10
Hazards of environmental regulations	7	16	10	13	6
Change in relation between parties	5	10	19	15	3
Change in communication between parties	4	7	21	12	8
Problems associated with culture difference	8	18	14	9	3
Change in geological conditions	8	12	12	12	8
Competition from other similar projects.	10	11	17	10	4
Fall short of expected income from project use	5	10	16	15	6
Inadequate forecast about market demand.	6	9	15	17	5
Change in availability of labor	5	5	17	14	11
Change in availability of material	3	3	21	15	10
Change in availability of equipment	5	1	19	19	8
Change in availability of subcontractor	1	6	24	17	4
Change in availability of accessory facilities	3	12	22	12	3
Improper project feasibility study	3	10	17	13	9
Improper project planning and budgeting	2	8	14	12	16
Improper selection of project location	7	4	14	19	8
Improper selection of project type.	8	7	13	17	7
Inadequate project organization structure	8	8	16	15	5
Increase in project overheads.	3	8	19	11	11
Change in project scope	3	7	12	17	13
Change in project design	1	6	10	20	15
Change in performance of Owner	4	8	15	15	10
Change in performance of designer	4	4	21	17	6
Change in performance of engineer	3	9	19	16	5
Change in performance of contractor	2	2	16	20	12
Unfairness in tendering	9	6	10	16	11
Difference in practices amongst project participants	5	11	19	13	4
Accidents on site	3	9	20	15	5
Obsoleteness/failure of Equipment	5	5	21	16	5

Incompetence of transportation facilities	7	12	18	12	3
Increase in site overheads	3	3	23	16	7
Poor quality of procured accessory facilities	4	13	20	10	5
Poor quality of procured materials.	3	10	14	18	7
Shortage in supply of water, gas, and electricity	5	10	18	13	6
Change in weather conditions	12	13	17	6	4
Change in site organization	5	17	16	10	4
Change in work quality	3	10	19	12	8
Change in site conditions	5	9	17	12	9
Change in construction method/technology	3	6	17	17	9
Change in original schedule	5	5	8	20	14
Risk Events					
Decrease in productivity	4	4	19	14	11
Increase in quantity of work	3	7	14	18	10
Decrease in quality of work	3	7	17	18	7
Increase in labor costs.	2	3	13	22	12
Increase in materials prices	4	0	15	17	16
Increase in accessory facilities prices	3	4	17	21	7
Increase in project overheads costs	2	5	20	16	9
Increase in site overheads costs	3	5	18	15	11
Increase in resettlement costs	6	6	17	17	6
Delays due to client bureaucracy	5	9	12	15	11
Delays due to government bureaucracy	4	6	13	21	8
Delay in work progress	1	3	19	19	10
Delay in project logistics	2	7	20	17	6
Delay in client payments	3	1	13	19	16
Robustness Factors					
Instability of economic conditions	3	6	14	14	15
Instability of government	4	10	15	13	10
Instability of international relations	5	18	14	8	7
Change in laws, policies, or regulations	3	7	14	17	11
Instability of social conditions	5	16	15	13	3
Immaturity of legal system	5	12	14	17	4

Restrictions for foreign companies	3	14	16	10	9
Lack of enforcement of legal judgment	6	13	10	16	7
Incomplete design	6	3	15	18	10
Complexity of design	2	7	19	15	9
Errors in Design/Design Drawings	3	6	15	18	10
Low constructability	4	6	17	21	4
Complexity of construction method	1	6	22	18	5
Poor accessibility of site	9	10	12	15	6
Unknown site physical conditions.	6	10	12	15	9
Inadequate geotechnical investigation	5	10	15	11	11
Inadequate climate conditions	13	9	20	8	2
Strict quality management requirements	3	9	19	16	5
Strict environmental management requirements	6	13	19	10	4
Strict safety management requirements	5	9	16	13	9
Strict project management requirements	2	12	17	12	9
Vagueness in contract clauses	0	4	16	22	10
Errors in Contractual agreement	4	8	7	18	15
Incomplete contract terms	2	7	12	19	12
Unclarity of Owner's objectives	9	3	17	17	6
Lack of financial resources	3	5	19	17	8
Technical incompetency of project team	5	10	8	20	9
Change in Owner top management	6	7	12	21	6
Change in project team	5	5	18	13	11
Change in company organizational structure	6	7	15	17	7
Level of bureaucracy of Owner	2	5	21	15	9
Managerial incompetency of project team	8	4	11	19	10
Negative attitude of Owner	3	8	19	16	6
Technical incompetency of project team	5	5	22	17	3
Managerial incompetency of project team	5	9	18	17	3
Lack of financial resources	3	3	17	14	15
Lack of technical resources	2	7	14	20	9
Change in project team	4	4	19	17	8

Technical incompetency of project team	3	4	11	21	13
Managerial incompetency of project team	3	4	19	16	10
Lack of financial resources	2	5	17	15	13
Lack of technical resources	8	7	14	12	11
Change in project team	6	4	22	12	8
Lack of Engineer staff	6	9	18	9	10
Resilience Factors					
Lack of experience in similar projects	6	4	10	17	15
Lack of experience in country	7	4	13	18	10
Lack of experience in delivery system	5	5	15	19	8
Lack of experience with Owner	8	7	20	12	5
Lack of experience with other project parties	6	9	17	14	6
Lack of financial resources	1	5	13	17	16
Lack of technical resources	3	2	14	21	12
Lack of contractor staff	5	6	15	16	10
Change in project team	2	9	15	17	9
Technical incompetency of project team	3	3	15	18	13
Managerial incompetency of project team	0	4	17	19	12
Change in company organizational structure	7	11	17	10	7
Lack of project scope management	5	3	16	16	12
Lack of project time management	0	4	14	21	13
Lack of project human resources management	3	3	23	12	11
Lack of project cost management	2	5	13	20	12
Lack of project communication management	2	5	16	20	9
Lack of project risk management	2	5	15	22	8
Lack of project procurement management	2	2	18	17	13

4.3. Model Findings

As discussed earlier, outputs generated by the three models are comprised of five sets of weights: Robustness factors, Resilience factors, Risk sources, Sensitivity factors, and Risk events. Each set represents the effect of one risk path element on a subsequent element. Collectively, the five sets quantitatively demonstrate the relations connecting the risk path elements. A series of examinations is carried out in order to gain an initial understanding as to what these weights indicate.

The first of these examinations is elements ranking. Risk path elements are ranked according to their corresponding weights as generated by the models. Elements are sorted in descending order from highest to lowest in terms of their impact on subsequent elements.

Tables 15 to 17 show risk path elements identified in this research sorted as per their calibrated weights. The following five subsections, each corresponding to one of the risk path elements, describe the realized model outputs and present the elements rankings. Furthermore, they highlight some trends established based on those outputs.

4.3.1. Robustness factors

Out of the 44 identified Robustness factors, Lack of enforcement of legal judgment, Low constructability of design, and Managerial incompetency of Owner's project team are the top three factors in terms of their effect on the magnitude of Risk sources. On the other hand, Unclarity of Owner's objectives, Incomplete contract terms, and Complexity of construction method are among amongst the lowest.

As can be seen in Table 15, 35 percent of the top 20 factors are related to project design whether they are Project Design Conditions such as Low Constructability or Errors in Design/Design Drawings, or Designer Conditions such as Technical incompetency of Designer's project team or Change in Designer's project team. Conversely, Project Conditions factors with the exception of Project Design Conditions rank amongst the lowest Robustness factors especially Project Management conditions such as Strict quality management requirements and Strict project management requirements.

4.3.2. Resilience factors

Out of the 19 Resilience factors included in this study, Lack of Contractor's experience in project delivery system, Change in Contractor's company organizational structure, and Contractor's lack of project procurement management are the top three factors in terms of their effect on the magnitude of Risk events. While Technical incompetency of Contractor's project team, Lack of Contractor's experience in country, and Managerial incompetency of Contractor's project team are at the bottom of the list.

Unlike Robustness factors, Resilience factors do not follow any clear patterns or recognizable trends. Table 15 shows the resilience factors ranked according to their calibrated weights. However, it is worthy to note that, generally, contractor’s financial related factors such as Contractor's lack of project cost management and Lack of Contractor's financial resources do not rank amongst the top five factors. Also the Lack of contractor’s technical resources rank higher than the Lack of contractor’s financial resources in terms of their effect on Risk events.

Table 15: Sorted Robustness Factors and Resilience Factors

Robustness factors	Resilience factors
Lack of enforcement of legal judgment	Lack of Contractor's experience in delivery system
Low constructability	Change in Contractor's company organizational structure
Managerial incompetency of Owner's project team	Contractor's lack of project procurement management
Technical incompetency of Designer's project team	Contractor's lack of project communication management
Instability of economic conditions	Contractor's lack of project scope management
Change in Designer's project team	Contractor's lack of project cost management
Errors in Design/Design Drawings	Lack of Contractor's technical resources
Instability of government	Lack of contractor staff
Instability of international relations	Lack of Contractor's experience in similar projects
Change in Engineer's project team	Lack of Contractor's experience with Owner
Lack of Designer's technical resources	Change in Contractor's project team
Lack of Engineer's financial resources	Contractor's lack of project time management
Inadequate geotechnical investigation	Lack of Contractor's financial resources
Lack of Engineer's technical resources	Lack of Contractor's experience with other project parties
Managerial incompetency of Designer's project team	Contractor's lack of project risk management
Complexity of design	Contractor's lack of project human resources management
Technical incompetency of Engineer's project team	Technical incompetency of Contractor's project team
Incomplete design	Lack of Contractor's experience in country
Immaturity of legal system	Managerial incompetency of Contractor's project team
Restrictions for foreign companies	
Managerial incompetency of Engineer's project team	
Errors in Contractual agreement	
Lack of Designer's financial resources	
Lack of Owner's financial resources	
Level of bureaucracy of Owner	
Change in laws, policies, or regulations	
Change in Owner's company organizational structure	
Technical incompetency of Owner's project team	
Strict environmental management requirements	
Vagueness in contract clauses	
Poor accessibility of site	
Instability of social conditions	

Unknown site physical conditions.	
Negative attitude of Owner	
Strict safety management requirements	
Change in Owner's top management	
Strict quality management requirements	
Strict project management requirements	
Change in Owner's project team	
Lack of Engineer's staff	
Incomplete contract terms	
Unclarity of Owner's objectives	
Inadequate climate conditions	
Complexity of construction method	

4.3.3. Risk Sources

Out of the 58 identified Risk sources, Change in availability of labor, Change in site conditions, and Change in project design are the top three factors in terms of their effect on the magnitude of Risk events. While Change in project scope, Change in relations with government, Change in work quality are of the bottom five sources according to the same measure.

It is important to note that Change in the financial situation of owner is amongst the sources with the lowest influence on Risk events. As for the contractor, even though the Lack of Contractor's financial resources has a low rank amongst the rest of the resilience factors, a Change in financial situation of contractor is amongst the top 25 percent of Risk sources with the greatest effect on Risk events as highlighted in Table 16. Further, the low creditability of the owner is found to have a higher impact on Risk Events compared to that of either the contractor or subcontractor.

Table 16: Sorted Risk Sources and Risk Events

Risk Sources	Risk Events
Change in availability of labor	Delay in Owner payments
Change in site conditions	Increase in quantity of work
Change in project design	Decrease in productivity
Poor quality of procured accessory facilities	Increase of labor costs
Increase in site overheads	Increase of accessory facilities prices
Change in performance of designer	Increase of materials prices
Low credibility of Owner	Increase in project overheads costs
Change in availability of subcontractor	Decrease in quality of work
Change in construction method/technology	Delay in work progress
Problems associated with culture difference	Increase in site overheads costs
Breach of contracts by Owner	Increase of resettlement costs

Change in level of bribery and Corruption	Delays due to government bureaucracy
Incompetence of transportation facilities	Delay in project logistics
Change in performance of engineer	Delays due to Owner bureaucracy
Change in financial situation of contractor	
Change in currency exchange rates	
Improper selection of project location	
Inadequate forecast about market demand.	
Increase in project overheads.	
Change in original schedule	
Obsoleteness/failure of Equipment	
Low credibility of Contractor	
Low credibility of Subcontractor	
Change in availability of material	
Uncertainty and unfairness of court justice	
Accidents on site	
Breach of contracts by Contractor	
Change in inflation rates	
Change in availability of accessory facilities	
Change in level of bureaucracy	
Change in weather conditions	
Hazards of environmental regulations	
Improper selection of project type.	
Change in relation between parties	
Difficult convertibility of Local Currency	
Disputes between project parties	
Inadequate project organization structure	
Improper project planning and budgeting	
Change in tax rates	
Change in interest rates	
Competition from other similar projects.	
Improper project feasibility study	
Change in availability of equipment	
Fall short of expected income from project use	
Poor quality of procured materials.	
Change in performance of Owner	
Change in geological conditions	
Difference in practices amongst project participants	
Change in communication between parties	
Change in performance of contractor	
Change in public reaction	
Unfairness in tendering	
Shortage in supply of water, gas, and electricity	
Change in site organization	
Change in project scope	
Change in financial situation of owner	
Change in relations with government	

Change in work quality	

4.3.4. Sensitivity factors

Out of the five Sensitivity factors identified in this study, only four were included in the ANN model. The Project contract from factor was discarded due to insufficient information as a number of survey respondents refrained from answering this question.

As can be seen in Table 17, the Project type has the most impact on a project cost overrun, followed by the Project delivery method. The Project size, represented by Project budget, ranks third amongst the Sensitivity factors in terms of its effect on cost overruns, while the Project contract from has the least impact on cost overruns.

Table 17: Sorted Sensitivity Factors

Sensitivity factors
Project type
Project delivery method
Project budget
Project contract type

4.3.5. Risk Events

Out of the 14 risk events identified, Delay in owner interim payments, Increase in quantity of work, and Decrease in productivity are the three greatest risk events in terms of their impact on the magnitude of risk consequences (cost overruns). As can be noticed, none of the three top risk events are factors related to a project's cost. Nonetheless, they are directly followed by events related to project cost such as Increase in labor costs, Increase of materials prices, and Increase in project overheads costs as can be seen in Table 16. Delays due to bureaucracy whether from the owner or the government's side rank at the bottom of the list.

4.4. Weights Normalization

While weights ranking discussed in the previous section provide an understanding of the relative effect of the components of risk path elements on subsequent elements in the risk path and on cost overruns, ranking alone as an indication is not sufficient. Another form of analysis is needed to provide insight into the true influence each of the components of the risk path elements have on subsequent elements and on cost overruns. This type of analysis is important because for example two resilience factors can have successive rankings in terms of their influence on risk events. However, the weight of the latter factor can be much smaller compared to that of the former one, rendering any assumptions or deductions based on this comparison as misleading. This is why in addition to the weights ranking presented earlier, scales that show the degree of influence of all risk path elements in a true and absolute way are also needed to attain a better understanding of the model outputs. This can be achieved through weights normalization.

Normalization is the process of bringing values measured against different scales to a unified single scale, thus allowing comparison of corresponding normalized values for different datasets in a way that eliminates the effects of certain gross influences (Novak, 2004). In this study, ratio normalization is performed. Model weights are normalized by dividing the weights of all components of a certain risk path element by the value corresponding to the component with the highest rank (component with the largest weight). Figures 20 to 24 demonstrate the scales generated based on normalized weights of the components of the risk path elements.

As can be seen in Figures 20 to 24, not all of the risk path elements components have significant weights when compared to their counterparts in the same category. This is shown in risk path elements such as Resilience factors, Robustness factors, and Risk sources.

For example in Figure 20, the Robustness factors normalized weights scale chart can be divided into two segments. The first segment consists of factors with varying values of weights ranging from 1 to 0.33. This indicates that these factors have varying degrees of considerable impact on the magnitude of risk sources. As can be seen in the figure, the factors in this segment has a smooth descending gradient characterizing their degree of variance. Alternatively, the second segment has factors with values approaching zero. These weights are considered insignificant and suggest that their corresponding factors have minimal impact on risk sources.

According to the normalized weights summarized in Figure 20, 32 percent of the robustness factors identified in this study have insignificant weights and are therefore negligible. These factors include Owner conditions such as Negative attitude of Owner and Unclarity of Owner’s objectives as well as Project construction conditions such as Complexity of construction method, Unknown site physical conditions, and Inadequate climate conditions.

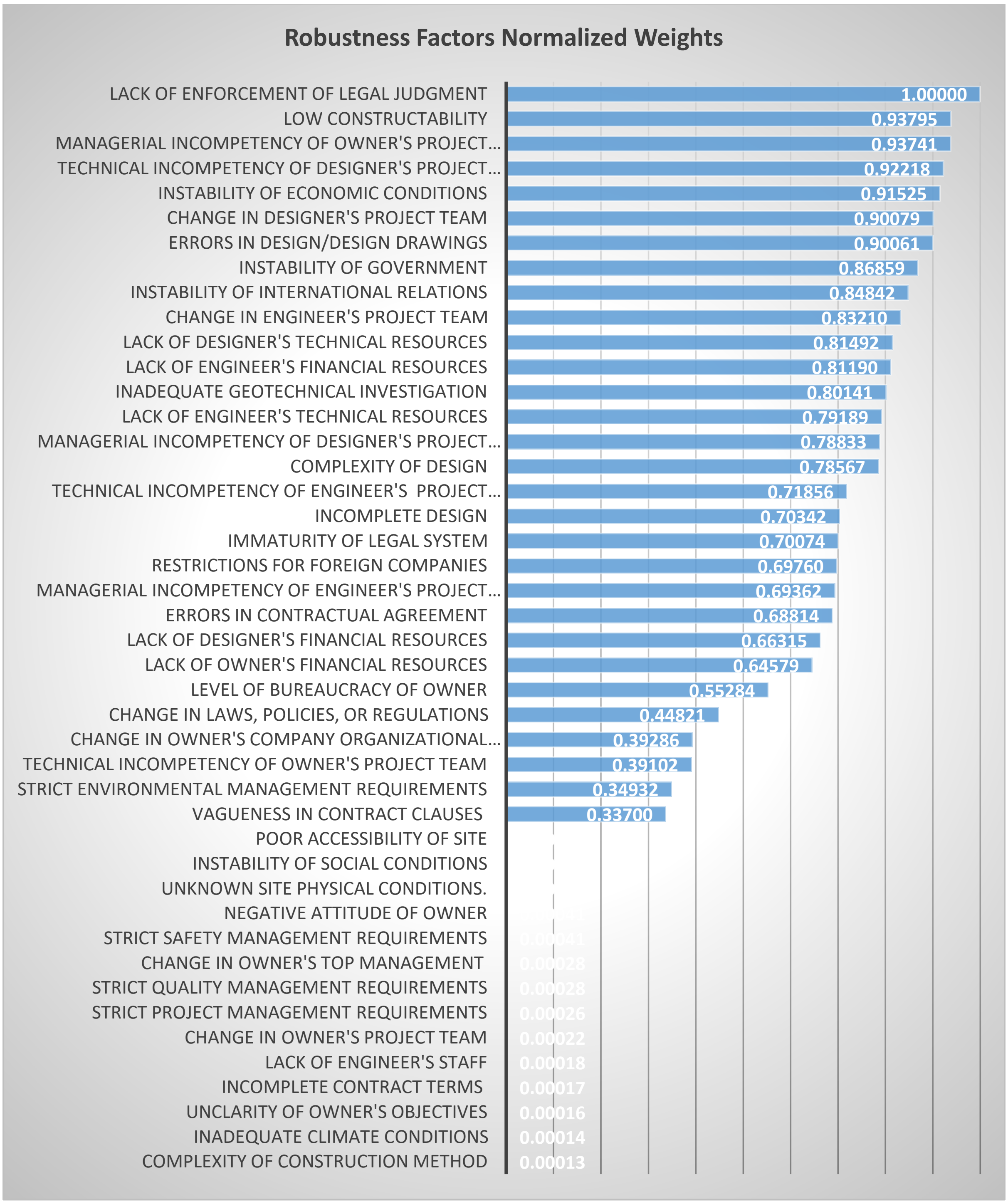

Figure 20: Robustness Factors Normalized Weights

Similar to robustness factors, resilience factors normalized weights project the same pattern of significant versus insignificant weights described above. According to the normalized weights summarized in Figure 21, 42 percent of the resilience factors identified in this study have normalized weights of almost zero. In other words, almost half of the resilience factors included in this study have minimal impact on risk events and are therefore negligible. Thus, Contractor managerial ability factors such as Lack of project time management, Lack of project risk management, and Lack of project human resources management are inconsiderable. Further, Contractor experience conditions such as Lack of experience in country and Lack of experience with other project parties are also inconsiderable.

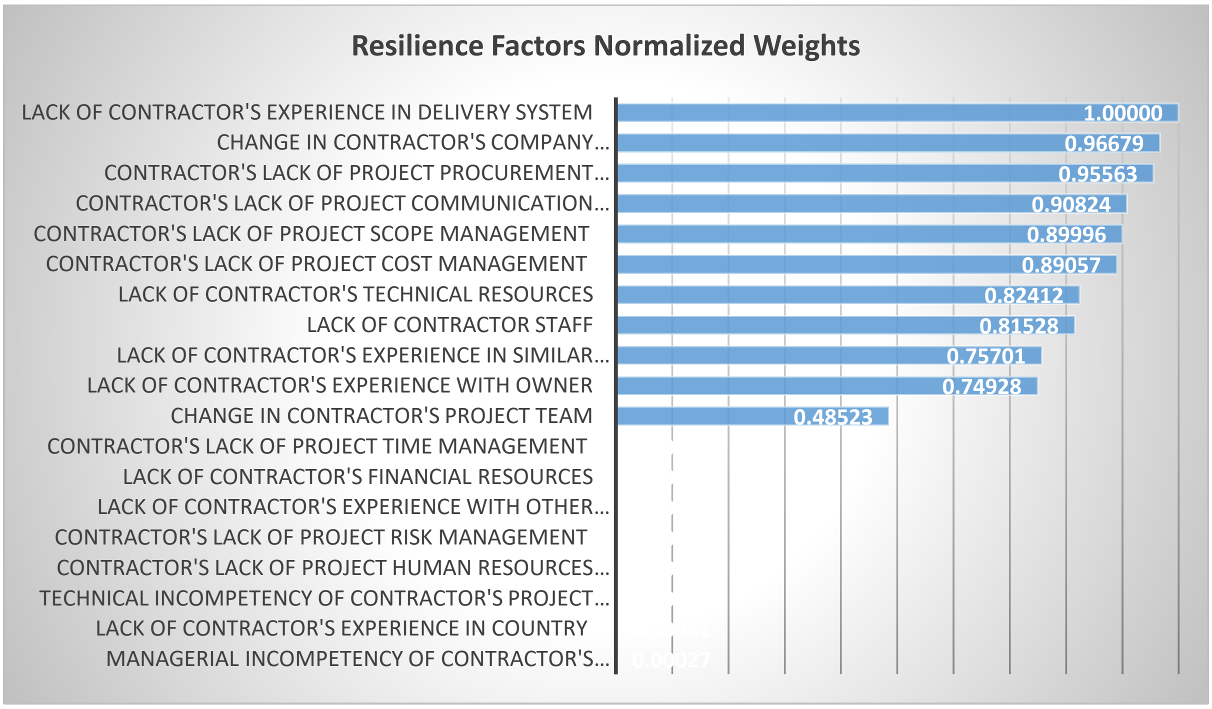

Figure 21: Resilience Factors Normalized Weights

Risk sources follow the same trend as well. However, only 9 percent of risk sources identified in this study are negligible as shown in Figure 22. These risk sources include Construction risks such as Change in site organization and Change in work quality.

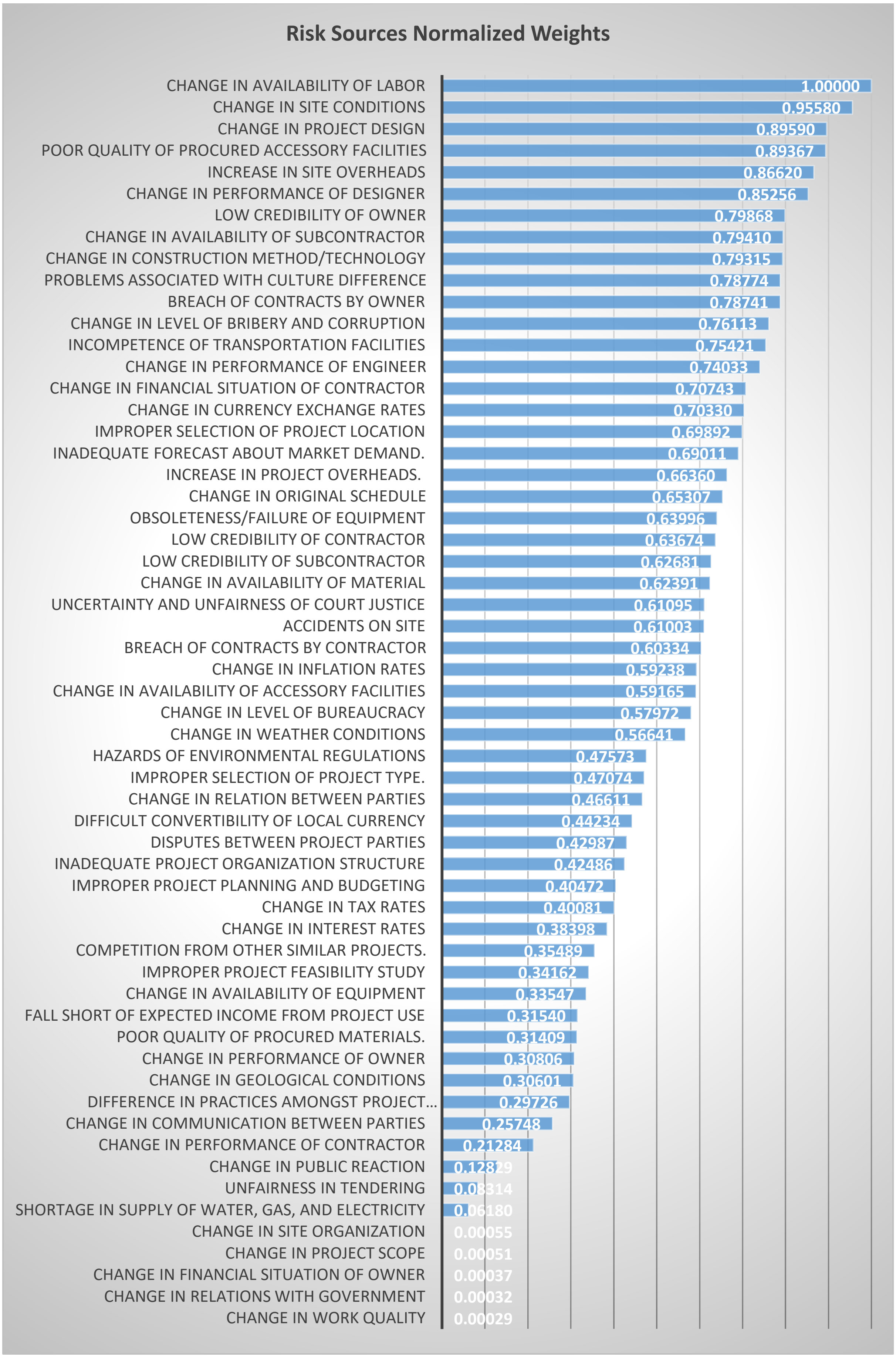

Figure 22: Risk Sources Normalized Weights

In contrast, all risk events and Sensitivity factors identified in this study have significant weights. Hence, all risk events and sensitivity factors included in Figures 23 and 24 have substantial effect on cost overruns.

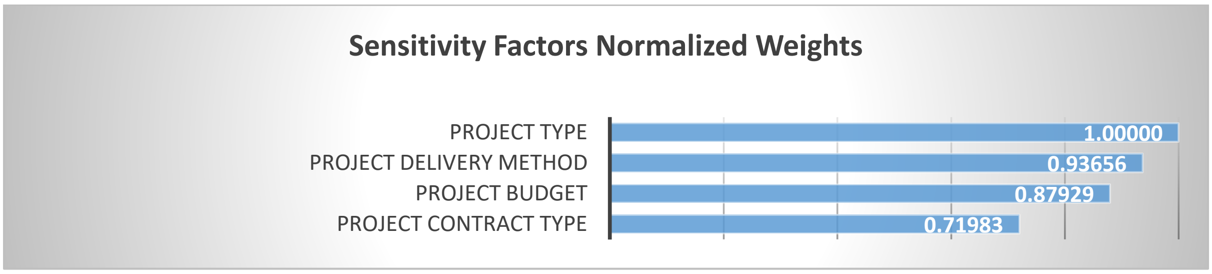

Figure 23: Sensitivity Factors Normalized Weights

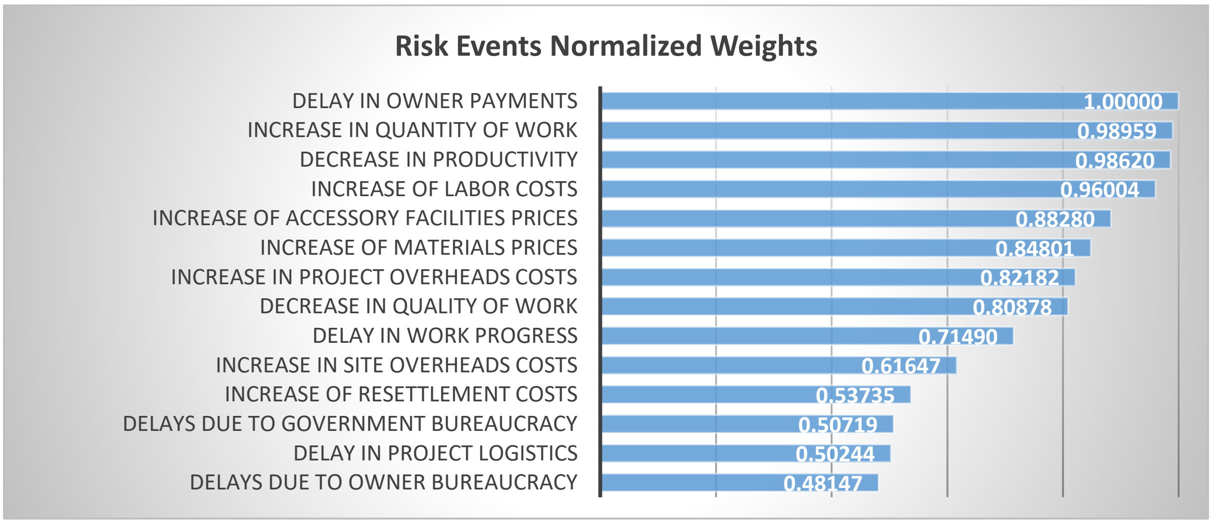

Figure 24: Risk Events Normalized Weights

4.5. Emerging Themes

As can be seen from the patterns of significant versus insignificant weights discussed in the previous section, different components across the risk path elements have varying degrees of impact on cost overruns. These variations in weights give rise to certain risk components and diminish others. Through closer inspection of these variations, an assembly of emerging themes of risk path components that share common attributes or characteristics can be established. While risk components of a certain theme may not be strictly connected to one another in a single risk path or scenario. Still, they are linked to one another by two mutual trails. First, they address a common project property or trait. Second, they were found to have significant weights on cost overruns according to the findings of the models developed in this research. The following sub-sections discuss a number of these themes.

4.5.1. Project Properties

Defined in this research as sensitivity factors, project characteristics such as size, type, and contract type determine how sensitive a project is to risk events that take place as well as the degree of significance those risk events have in terms of their impact on cost overruns. Four sensitivity factors were studied in this research, and as demonstrated in Figure 23, they were all found to have weights of substantial values. These weights prove that sensitivity factors have considerable impact on cost overruns. Nonetheless, the importance of project properties exceeds that portrayed by the weights of the sensitivity factors, as these properties are represented by other risk path elements that are spread out across the risk path.

For example, Project delivery method is represented by Lack of Contractor's experience in delivery system (Resilience factor) where this factor is ranked the first in terms on its impact on risk events. Also, Project type is represented by Improper selection of project type (Risk source) and its weight has a considerable value that ranks in the mid-range of risk sources. Further, project budget is represented by Improper project planning and budgeting (Risk sources). Table 18 highlight risk components from across all the risk path elements that were found to represent project properties.

Table 18: Project properties risk components

Project Properties
Improper selection of project location
Improper selection of project type
Improper project planning and budgeting
Competition from other similar projects.
Lack of Contractor's experience in delivery system
Lack of Contractor's experience in similar projects
Project type
Project delivery method
Project budget
Project contract type
Increase in quantity of work

Robustness Factors
Risk Sources
Resilience Factors
Risk Events
Sensitivity Factors

4.5.2. Design/Designer Properties

Design and Designer properties is another theme. Based on the risk path elements' weights that were provided by the models, all components related to either the project design or designer were found to have significant impact on cost overruns. These weights show that having a qualified project designer with sound technical and financial resources can demise the magnitude and probability of associated risk sources and events. Such components can be found across the entire risk path as presented in Table 19.

For example, design properties are represented by Low constructability and Error in design/ design drawings in the Robustness factors and by change in project design in Risk sources. As for designer properties, they are represented by Technical incompetency of Designer's project team and Lack of Designer's financial resources in Robustness factors and Change in performance of designer in Risk sources.

Table 19: Design/Designer properties risk components

DESIGN/DESIGNER PROPERTIES
Low constructability
Technical incompetency of Designer's project team
Change in Designer's project team
Errors in Design/Design Drawings
Lack of Designer's technical resources
Managerial incompetency of Designer's project team
Complexity of design
Incomplete design
Lack of Designer's financial resources
Change in project design
Change in performance of designer
Lack of Contractor's technical resources

(light blue)	Robustness Factors
(yellow)	Risk Sources
(orange)	Resilience Factors
(purple)	Risk Events
(green)	Sensitivity Factors

4.5.3. Economic and Financial Conditions

Lastly, economic and financial properties of the project were also found to be highly influential in terms of their impact on cost overruns. This is proved by both the magnitudes of the weights of the related risk path components and their count. Components of this theme are concerned with the economic conditions of the country and the financial standings of all project parties including the owner, contractor, and designer. Table 20 highlight risk components from across all the risk path elements that were found to represent economic and financial properties.

For example, economic properties is represented by Instability of economic conditions in Robustness factors, Change in currency exchange and interest rates in Risk sources, and Increase of labor costs and material prices in Risk events. As for the financial properties of the project parties, they are represented by Lack of Owner's financial resources in Robustness factors, Change in financial situation of contractor in Risk sources, and Delay in Owner payments and Increase in project overheads costs in Risk events.

Table 20: Economic and financial properties risk components

ECONOMIC AND FINANCIAL PROPERTIES	
Instability of economic conditions	Lack of Owner's financial resources
Increase in site overheads	Change in inflation rates
Change in financial situation of contractor	Difficult convertibility of Local Currency
Change in currency exchange rates	Change in interest rates
Increase in project overheads.	
Contractor's lack of project cost management	Lack of Contractor's financial resources
Delay in Owner payments	Increase in project overheads costs
Increase of labor costs	Increase in site overheads costs
Increase of accessory facilities prices	Increase of resettlement costs
Increase of materials prices	

Robustness Factors
Risk Sources
Resilience Factors
Risk Events
Sensitivity Factors

4.6. Case Study

A case study project in Dubai, United Arab Emirates is used to show case the weights generated by the modeling framework developed in this research. The case study project is an infrastructure project whose information was procured from Fidan et al. (2011)'s work. Information regarding the events and risks that took place during the project life was recorded and provided to Fidan et al.'s team through interviews conducted with personnel involved in the project. The events narrative inscribed in Fidan et al.'s work was studied and converted into corresponding vulnerability factors and risk elements components from those identified in this research. Figure 25 shows the identified risk elements and vulnerability factors as per the project's narrative as well as their corresponding weights. There are two types of weights included in the figure. The first type is weights on node, which are the weights of the components as produced by the models. While the second type is weights on arrow, which are the resultant of the weights of the preceding components in a specific risk path.

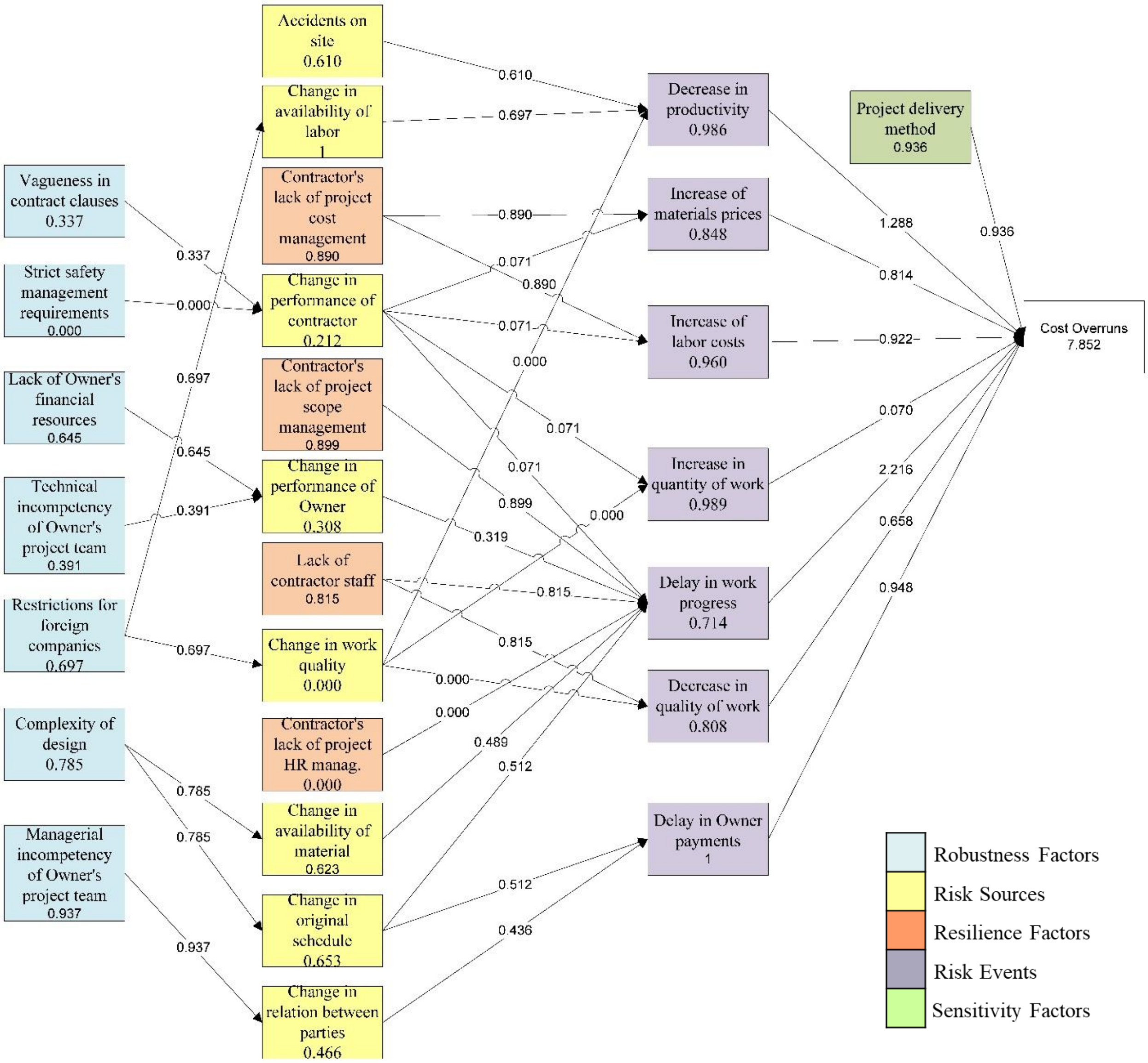

Figure 25: Case study risk path

As illustrated in Figure 25, while Delay in owner payments has the greatest weight (value of 1), its effect on cost overruns ranks third (with a value of 0.948) to Delay in work progress (with a value of 2.215) and Decrease in productivity (with a value of 1.288). This can be contributed to the fact that Delay in work progress and Decrease in productivity were impacted by a large number of risk sources and resilience factors compared to Delay in owner payments.

4.7. Analysis and Discussion

After analyzing the findings and information presented in this Chapter, a number of observations are noted in this section for further discussion. These observations are:

First, Elements addressing bureaucracy in construction projects across the entire risk path generally rank in the mid and low ranges of their respective categories. For example, Level of bureaucracy of Owner ranks in the bottom third of the Robustness factors with significant weights, while Change in level of the government's bureaucracy ranks in the mid-range of risk sources. As for the Risk events, delays due to both government and owner bureaucracy rank at the bottom of the list. These observations indicate that while bureaucracy has a considerable impact on cost overruns, this impact can be rated as low, which suggests that contractors are becoming increasingly aware of the effect of both owner and government bureaucracy on project duration and costs. Accordingly, contractors are progressively able to take the consequences of bureaucracy into consideration in their project schedules and contingency plans.

Second, the managerial abilities of contractors do not have a significant effect on risk events. As mentioned before almost half of the resilience factors identified in this study have insignificant weights. Half of those factors were found to be related to the managerial ability of the contractor's team, which include Contractor resources such as Managerial incompetency of the project team, and Contractor managerial abilities such as Lack of project time management and Lack of project risk management. These findings suggest that even though some crucial project management tasks might not be competently handled by contractors, this incompetency from the contractors' side still have minimal impact on the magnitudes of the risk events. This suggests the involvement of another party that carries out essential project management tasks competently so that they won't have grave effect on risk events and consequently on cost overruns. This supports the notion that the Project Manager as a project party is relied upon to execute project management tasks in an effective and efficient manner and has become growingly more in control of projects' proceedings in the Egyptian construction industry.

Lastly, vulnerability factors (robustness, resilience, and sensitivity factors) are defined in this research as project system characteristics that describe project conditions established either before or at project initiation. Further, Risk sources are defined as observable risks that may lead to one or more risk events. To that end, it can be understood that by definition both vulnerability factors and risk sources are foreseeable elements that can be observed and monitored along a project's duration. Risk sources form around 41 percent of the risk elements included in this study with only 9 percent of the risk sources identified as negligible. While Vulnerabiluty factors constitute 80 percent of all risk path elements. With risk sources and vulnerability factors added together, it can be concluded that 89 percent of the risk path elements discussed in this research are observable and can be identified at project initiation which encourages effective and efficient risk management practices. Further, after project commencement and during the project life watching for observable risk sources can help reduce the magnitude of a risk event and alleviate the impact of a risk scenario on project outcomes.

While vulnerability factors pertain project characteristics that cannot be changed once a project commences, the findings realized in this research can be used as a tool to help decision makers make cost conscience decisions when considering these project characteristics before project initiation. Also, they render contractors aware of the consequences of given project characteristics on cost overruns so they are adequately prepared when bidding for a project. Moreover, risk sources can be observed, monitored and controlled along a project duration, which enables contractors to predict the risk events that may take place as well as their magnitudes and measure their impact on cost overruns.

4.8. Model Verification and Validation

As previously mentioned, the purpose of the model is to provide calibrated weights corresponding to each of the identified risk path elements. The model calculates these weights based on simulating the relations between the various risk path elements and cost overruns given the magnitude values provided by the survey data. Accordingly, the purpose of verifying the model is to test whether it can provide reliable weights that are a true representation of the effect of all risk path elements on cost overruns. In this study, model verification and validation are conducted mathematically by testing a sample of the database scenarios.

Using Neuraltools add-in, the model's net data (objective function and relations) developed in subsection 0 to train the model is used here again to test the model. The remaining 20 percent of the model dataset's scenarios is selected for testing with a thirty percent tolerance interval for bad predictions. Figure 26 is a screenshot extract from the testing summary report generated by Neuraltools.

Testing	
Number of Cases	11
% Bad Predictions (30% Tolerance)	9.0909%
Root Mean Square Error	0.03028
Mean Absolute Error	0.01739
Std. Deviation of Abs. Error	0.02478
Data Set	
Name	Optimization and ANN
Number of Rows	11
Manual Case Tags	NO
Variable Matching	Automatic
Indep. Category Variables Used	Names from training
Indep. Numeric Variables Used	Names from training
Dependent Variable	Numeric Var. (Cost overrun percentage)

Figure 26: Testing summary report generated by Neuraltools

As can be seen in Figure 26, around 9 percent of all tested cases are bad predictions. Moreover, the values of the Root mean square error, Mean absolute error, and Std. deviation of abs. error are within acceptable ranges. Thus, it can be concluded that the model together with its net data (objective function and relations) are an accurate representation of risk path elements relations. As a result, the corresponding weights calculated by the model are reliable and can be considered an indication of the relative effect of each of the risk path elements on projects cost overruns.

Chapter 5: Conclusion and Recommendations

5.1. Research Overview

The construction industry's sensitivity towards events that may take place either inside or outside project boundaries render it a highly dynamic environment. This is why contractors are always faced with a new challenge each time they are estimating a project's price. Furthermore, contractors often encounter situations where they are forced to submit the lowest bid possible due to a number of reasons ranging from economic conditions of the country to bidding conditions of the project. As a result, contractors may choose to minimize their mark-up margins in order to maximize their chances of winning a bid, resorting sometimes to extreme measures such as submitting bids at zero percent profit and/or zero percent contingency.

Such drastic bidding conditions render contractors sensitive towards all types of potential risks associated with executing a project. This is why it is important for contractors to always learn new risk management techniques and apply them effectively and efficiently in their projects. However, the process of effective risk management proves to be challenging for a number of reasons. First, lack of comprehensive understanding of the interrelated relations between projects risks, which may lead to inaccurate risk identification and assessment. Second, lack of project based data, due to the difficulties most researchers face when collecting comprehensive project based information. Thus, a large number of studies focusing on the construction industry in Egypt are based primarily on data collected through surveys.

The main objective of this research is to identify the risk elements with the greatest impact on projects' costs in the Egyptian construction industry. This objective is fulfilled by developing a risk path model that represents project risk elements, their interdependencies, and their effect on cost overruns in order to be able to simulate the various project risk scenarios and estimate their corresponding cost overruns.

In phase one of this research, a literature review is conducted to identify construction project's most significant risks, explore relevant categorization methods, as well as explore common risk mapping approaches. Then in phase two, a project risk path is developed as well as the main elements forming it. The risk path developed for this research include risk elements as well as project vulnerability factors. It portrays the pattern through which risks propagate throughout the project life starting from its realization at project initiation to its materialization as a risk event and subsequently a risk consequence, which is cost overruns.

In phase three, an ontology model is created based on the risk path developed in phase two. The purpose of the ontology model is to create and preserve an information domain that is easy to share and modify for future research. Following in phase four, industry professionals are surveyed to collect information regarding patterns of dependencies amongst the identified risk elements as well as the degree of significance of these dependencies in terms of their effect on projects' cost. Lastly in phase five, a series of models is constructed to simulate risk path elements in order to investigate their dependencies with the purpose of identifying the elements that have the greatest impact on cost overruns.

The model's outputs showed the following:

- Out of the 44 identified Robustness factors, Lack of enforcement of legal judgment, Low constructability of design, and Managerial incompetency of Owner's project team are the top three factors in terms of their effect on the magnitude of Risk sources. On the other hand, Incomplete contract terms and Complexity of construction method are among the lowest. It can also be noticed that 35 percent of the top 20 factors are related to project design.

- Out of the 19 Resilience factors, Lack of Contractor's experience in delivery system, and Contractor's lack of project procurement management are of the top factors in terms of their effect on the magnitude of Risk events. While Technical incompetency of Contractor's project team, Lack of Contractor's experience in country, and Managerial incompetency of Contractor's project team are at the bottom of the list. Contractor's financial matters such as Contractor's lack of project cost management and Lack of Contractor's financial resources do not rank amongst the top five factors. Further, Lack of contractor's technical resources rank higher than that of contractor's financial resources in terms of their effect on Risk events.

- As for the Sensitivity Factors, Project type has the most impact on project cost overrun, followed by Project delivery method.

- Out of the 58 identified Risk sources, Change in availability of labor, Change in site conditions, and Change in project design are the top three factors in terms of their effect on the magnitude of Risk events. While Change in project scope, Change in relations with government, Change in work quality, and Change in the financial situation of owner are amongst the sources with the lowest influence on Risk events.

- Of the 14 risk events identified, Delay in owner interim payments, Increase in quantity of work, and Decrease in productivity are the three greatest risk events in terms of their impact on the magnitude of risk consequences (cost overruns). None of the three top risk events are factors related to a project's cost. Delays due to bureaucracy whether from the owner or the government's side rank at the bottom of the list.

5.2. Research Contribution

This research made several contributions to the risk management field through its adopted methodology and attained results. These contributions are:

1. A developed risk path as well as its main elements to describe the pattern through which risks propagate throughout the project life starting from its realization at project initiation to its materialization a risk consequence (cost overrun).
2. A library of risk elements and vulnerability factors of over 130 component, categorized according to their role in the risk path into their corresponding risk path elements.
3. A risk path modeling approach used to simulate the relations amongst the identified risk path elements as well as their impact on cost overruns.
4. A database of project-based data which covers different risk scenarios as well as corresponding project characteristics including project type, size, delivery method, contract type, and cost overruns. This database can be built upon or be used as the base upon which other research methodologies can be applied.
5. An ontology model that defines and represents the developed risk path elements, components, relations, and properties. The ontology model is developed on a flexible platform to allow for easy transfer, modification, and addition of knowledge.
6. The realized model outputs and findings, which consist of 5 sets of weights that represent the effect of risk path elements on subsequent elements and ultimately on cost overruns as per the relations established in the developed risk path.

5.3. Recommendations for Future Research

The following are a set of recommendations to be considered in future research.

- Add more risk scenarios to the model's database by extending the surveying process duration. The more cases the model can represent, the more accurate and relevant its outputs are to real life conditions. Further, given that a number of sufficient cases are acquired per type of project delivery model, the model framework developed in this study can be implemented several times, one for each delivery method type. This way each model can render sets of weights that are more tuned to the nature of projects with a certain delivery method.

- Build on results attained from this research by identifying and developing contract conditions that effectively address the identified risk elements with the greatest impact on projects' costs in the Egyptian construction industry.

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APPENDIX A: Sample Questionnaire

An Ontology Framework for Addressing Cost Overrun Through Risk Modeling: A Risk Path Approach

The purpose of this survey is to identify and rank risk elements with the greatest effect on projects' costs. Your feedback will help develop a model that simulate construction risk dynamics in a project and their impact on its costs/cost overruns. Therefore, answers based on real projects are much appreciated. Responses are anonymous and collected data will be used solely in relation to this research.

Thank you for your time!

* Required

1. **Educational background**

   Mark only one oval.

   - Bachelor's degree
   - Master's degree
   - Doctoral degree
   - Other: ____________________

2. **Profession**

   Mark only one oval.

   - Architect
   - Mechanical engineer
   - Electrical engineer
   - Civil engineer
   - Construction engineer
   - Project manager
   - Other: ____________________

3. **Years of work experience** *

   Mark only one oval.

   - Less than 5 years
   - 5 - 10 years
   - 10 - 15 years
   - 15 - 20 years
   - More than 20 years

4. **Current role** *

Mark only one oval.

- ⬭ Developer/Client/Client representative
- ⬭ Designer
- ⬭ Project manager
- ⬭ Engineer (site supervision)
- ⬭ Contractor
- ⬭ Subcontractor
- ⬭ Other: ____________________

5. **Current position** *

Mark only one oval.

- ⬭ Executive
- ⬭ Manager
- ⬭ Department head
- ⬭ Senior Architect/Engineer
- ⬭ Architect/Engineer

Project 1

Based on your experience in a given project, please answer the following questions relative to this project.

Rank the below Vulnerability Factors with respect to their relevance to the project's conditions

(1= Not relevant; 2= Slightly relevant; 3= Relevant; 4= Very relevant; 5= Extremely relevant)

6. **Country conditions** *

Mark only one oval per row.

	1	2	3	4	5
Instability of economic conditions	⬭	⬭	⬭	⬭	⬭
Instability of government	⬭	⬭	⬭	⬭	⬭
instability of international relations	⬭	⬭	⬭	⬭	⬭
change in laws, policies, or regulations	⬭	⬭	⬭	⬭	⬭
Instability of social conditions	⬭	⬭	⬭	⬭	⬭
Immaturity of legal system	⬭	⬭	⬭	⬭	⬭
Restrictions for foreign companies	⬭	⬭	⬭	⬭	⬭
Lack of enforcement of legal judgment	⬭	⬭	⬭	⬭	⬭

7. **Project Conditions** *
Mark only one oval per row.

	1	2	3	4	5
Incomplete design					
Complexity of design					
Errors in Design/Design Drawings					
Low constructability					
Complexity of construction method					
Poor accessibility of site					
Unknown site physical conditions.					
inadequate geotechnical investigation					
inadequate climate conditions					
strict quality management requirements					
strict environmental management requirements					
strict safety management requirements					
strict project management requirements					
vagueness in contract clauses					
Errors in Contractual agreement					
Incomplete contract terms					

8. **Designer conditions** *
Mark only one oval per row.

	1	2	3	4	5
technical incompetency of project team					
managerial incompetency of project team					
lack of financial resources					
lack of technical resources					
change in project team					

9. **Engineer conditions** *
Mark only one oval per row.

	1	2	3	4	5
technical incompetency of project team					
managerial incompetency of project team					
lack of financial resources					
lack of technical resources					
change in project team					
lack of consultant staff					

10. **Client conditions** *

Mark only one oval per row.

	1	2	3	4	5
unclarity of client's objectives	◯	◯	◯	◯	◯
level of bureaucracy of client	◯	◯	◯	◯	◯
nagative attitude of client	◯	◯	◯	◯	◯
lack of financial resources	◯	◯	◯	◯	◯
technical incompetency of project team	◯	◯	◯	◯	◯
managerial incompetency of project team	◯	◯	◯	◯	◯
change in client top management	◯	◯	◯	◯	◯
change in project team	◯	◯	◯	◯	◯
change in company organizational structure	◯	◯	◯	◯	◯

11. **Contractor conditions** *

Mark only one oval per row.

	1	2	3	4	5
lack of experience in similar projects	◯	◯	◯	◯	◯
lack of experience in country	◯	◯	◯	◯	◯
lack of experience in deliver system	◯	◯	◯	◯	◯
lack of experience with client	◯	◯	◯	◯	◯
lack of expertience with other project parties	◯	◯	◯	◯	◯
lack of financial resources	◯	◯	◯	◯	◯
lack of technical resources	◯	◯	◯	◯	◯
lack of contractor staff	◯	◯	◯	◯	◯
change in project team	◯	◯	◯	◯	◯
technical incompetency of project team	◯	◯	◯	◯	◯
managerial incompetency of project team	◯	◯	◯	◯	◯
change in company organizational structure	◯	◯	◯	◯	◯
lack of project scope management	◯	◯	◯	◯	◯
lack of project time management	◯	◯	◯	◯	◯
lack of project human resources management	◯	◯	◯	◯	◯
lack of project cost management	◯	◯	◯	◯	◯
lack of project communication management	◯	◯	◯	◯	◯
lack of project risk management	◯	◯	◯	◯	◯
lack of project procurement management	◯	◯	◯	◯	◯

Rank the below Risk Elements with respect to their effect on the project's cost overruns

(1= Not significant; 2= Slightly significant; 3= Significant; 4= Very significant; 5= Extremely significant)

12. **Risk sources** *

Mark only one oval per row.

	1	2	3	4	5
Change in financial situation of owner					
change in financial situation of contractor					
change in currency exchange rates					
change in inflation rates					
change in interest rate					
change in tax rates					
Low credibility of Owner					
Low credibility of Contractor					
Low credibility of Subcontractor					
Difficult convertibility of Local Currency					
Breach of contracts by Owner					
Breach of contracts by Contractor					
Disputes between project parties					
Uncertainty and unfairness of court justice					
change in relations with government					
change in level of bereaucracy					
change in level of bribery and Corruption					
change in public reaction					
Hazards of environmental regulations.					
change in relation between parties					
change in communication between parties					
Problems associated with culture difference.					
change in geological conditions					
Competition from other similar projects.					
Fall short of expected income from project use.					
Inadequate forecast about market demand.					
change in availability of labor					
change in availability of material					
change in availability of equipment					
change in availability of subcontractor					
change in availability of accessory facilities					
Improper project feasibility study.					
Improper project planning and budgeting.					
Improper selection of project location.					
Improper selection of project type.					
Inadequate project organization structure.					

	1	2	3	4	5
Increase in project overheads.					
Change in project scope					
Change in project design					
change in performance of Owner					
change in performance of designer					
change in performance of engineer					
change in performance of contractor					
Unfairness in tendering.					
Difference in practices amongst project participants					
Accidents on site.					
Obseletness/failure of Equipment					
Incompetence of transportation facilities.					
Increase in site overheads.					
Poor quality of procured accessory facilities.					
Poor quality of procured materials.					
Shortage in supply of water, gas, and electricity.					
change in weather conditions					
change in site organization					
change in work quality					
change in site conditions					
change in contruction method/technology					
change in original schedule					

13. **Risk Events** *

Mark only one oval per row.

	1	2	3	4	5
Decrease in productivity					
Increase in quantity of work					
Decrease in quality of work					
Increase of labor costs.					
Increase of materials prices					
Increase of accessory facilities prices					
Increase in project overheads costs					
Increase in site overheads costs					
Increase of resettlement costs					
Delays due to client bureaucracy					
Delays due to government bureaucracy					
Delay in work progress					
Delay in project logistics					
Delay in client payments					

Please provide the following project information

14. **Project type** *

Mark only one oval.

- Residential
- Commercial
- Mixed use
- Industrial
- Infrastructure
- Other: ____________________

15. **Project contract type** *

Mark only one oval.

- Lump Sum
- Unit Price
- Cost Plus Fixed Fee
- Cost Plus Percentage of Cost Fee
- Cost Plus Award Fee
- Other: ____________________

16. **Project delivery method** *

Mark only one oval.

- Traditional
- Turnkey
- Build Operate Transfer (BOT)
- Integrated Project Delivery
- Other: ____________________

17. **Project contract form** *

Mark only one oval.

- FIDIC
- AIA
- JCT
- AGC
- Custom
- Other: ____________________

18. **Please provide an estimate for the project budget** *

____

19. **Please provide an estimate for the cost overrun percentage** *

Project 2

Based on your experience in a given project, please answer the following questions relative to this project.

Rank the below Vulnerability Factors with respect to their relevance to the project's conditions

(1= Not relevant; 2= Slightly relevant; 3= Relevant; 4= Very relevant; 5= Extremely relevant)

20. **Country conditions**

Mark only one oval per row.

	1	2	3	4	5
Instability of economic conditions					
Instability of government					
instability of international relations					
change in laws, policies, or regulations					
Instability of social conditions					
Immaturity of legal system					
Restrictions for foreign companies					
Lack of enforcement of legal judgment					

21. **Project Conditions**

Mark only one oval per row.

	1	2	3	4	5
Incomplete design					
Complexity of design					
Errors in Design/Design Drawings					
Low constructability					
Complexity of construction method					
Poor accessibility of site					
Unknown site physical conditions.					
inadequate geotechnical investigation					
inadequate climate conditions					
strict quality management requirements					
strict environmental management requirements					
strict safety management requirements					
strict project management requirements					
vagueness in contract clauses					
Errors in Contractual agreement					
Incomplete contract terms					

22. **Designer conditions**

Mark only one oval per row.

	1	2	3	4	5
technical incompetency of project team					
managerial incompetency of project team					
lack of financial resources					
lack of technical resources					
change in project team					

23. **Engineer conditions**

Mark only one oval per row.

	1	2	3	4	5
technical incompetency of project team					
managerial incompetency of project team					
lack of financial resources					
lack of technical resources					
change in project team					
lack of consultant staff					

24. **Client conditions**

Mark only one oval per row.

	1	2	3	4	5
unclarity of client's objectives					
level of bureaucracy of client					
nagative attitude of client					
lack of financial resources					
technical incompetency of project team					
managerial incompetency of project team					
change in client top management					
change in project team					
change in company organizational structure					

25. **Contractor conditions**

Mark only one oval per row.

	1	2	3	4	5
lack of experience in similar projects					
lack of experience in country					
lack of experience in deliver system					
lack of experience with client					
lack of expertience with other project parties					
lack of financial resources					
lack of technical resources					
lack of contractor staff					
change in project team					
technical incompetency of project team					
managerial incompetency of project team					
change in company organizational structure					
lack of project scope management					
lack of project time management					
lack of project human resources management					
lack of project cost management					
lack of project communication management					
lack of project risk management					
lack of project procurement management					

Rank the below Risk Elements with respect to their effect on the project's cost overruns

(1= Not significant; 2= Slightly significant; 3= Significant; 4= Very significant; 5= Extremely significant)

26. **Risk sources**

Mark only one oval per row.

	1	2	3	4	5
Change in financial situation of owner					
change in financial situation of contractor					
change in currency exchange rates					
change in inflation rates					
change in interest rate					
change in tax rates					
Low credibility of Owner					
Low credibility of Contractor					
Low credibility of Subcontractor					
Difficult convertibility of Local Currency					
Breach of contracts by Owner					
Breach of contracts by Contractor					
Disputes between project parties					
Uncertainty and unfairness of court justice					
change in relations with government					
change in level of bereaucracy					
change in level of bribery and Corruption					
change in public reaction					
Hazards of environmental regulations.					
change in relation between parties					
change in communication between parties					
Problems associated with culture difference.					
change in geological conditions					
Competition from other similar projects.					
Fall short of expected income from project use.					
Inadequate forecast about market demand.					
change in availability of labor					
change in availability of material					
change in availability of equipment					
change in availability of subcontractor					
change in availability of accessory facilities					
Improper project feasibility study.					
Improper project planning and budgeting.					
Improper selection of project location.					
Improper selection of project type.					
Inadequate project organization structure.					

	1	2	3	4	5
Increase in project overheads.					
Change in project scope					
Change in project design					
change in performance of Owner					
change in performance of designer					
change in performance of engineer					
change in performance of contractor					
Unfairness in tendering.					
Difference in practices amongst project participants					
Accidents on site.					
Obseletness/failure of Equipment					
Incompetence of transportation facilities.					
Increase in site overheads.					
Poor quality of procured accessory facilities.					
Poor quality of procured materials.					
Shortage in supply of water, gas, and electricity.					
change in weather conditions					
change in site organization					
change in work quality					
change in site conditions					
change in contruction method/technology					
change in original schedule					

27. **Risk Events**

Mark only one oval per row.

	1	2	3	4	5
Decrease in productivity					
Increase in quantity of work					
Decrease in quality of work					
Increase of labor costs.					
Increase of materials prices					
Increase of accessory facilities prices					
Increase in project overheads costs					
Increase in site overheads costs					
Increase of resettlement costs					
Delays due to client bureaucracy					
Delays due to government bureaucracy					
Delay in work progress					
Delay in project logistics					
Delay in client payments					

Please provide the following project information

28. **Project type**
Mark only one oval.

- ◯ Residential
- ◯ Commercial
- ◯ Mixed use
- ◯ Industrial
- ◯ Infrastructure
- ◯ Other: ____________________

29. **Project contract type**
Mark only one oval.

- ◯ Lump Sum
- ◯ Unit Price
- ◯ Cost Plus Fixed Fee
- ◯ Cost Plus Percentage of Cost Fee
- ◯ Cost Plus Award Fee
- ◯ Other: ____________________

30. **Project delivery method**
Mark only one oval.

- ◯ Traditional
- ◯ Turnkey
- ◯ Build Operate Transfer (BOT)
- ◯ Integrated Project Delivery
- ◯ Other: ____________________

31. **Project contract form**
Mark only one oval.

- ◯ FIDIC
- ◯ AIA
- ◯ JCT
- ◯ AGC
- ◯ Custom
- ◯ Other: ____________________

32. **Please provide an estimate for the project budget**

____

33. **Please provide an estimate for the cost overrun percentage**

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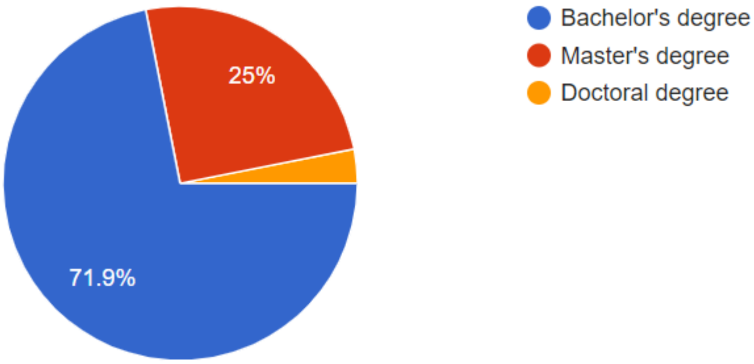
APPENDIX B: Survey Demography

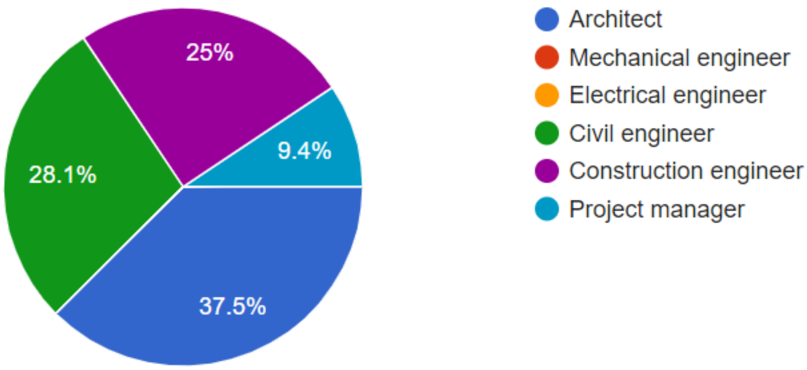
Educational background

32 responses



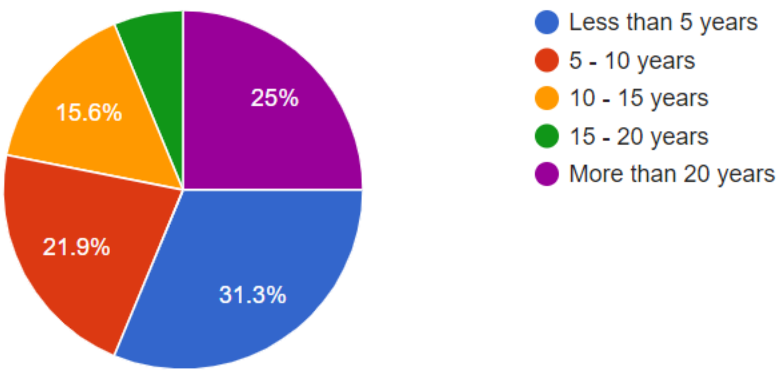
Profession

32 responses



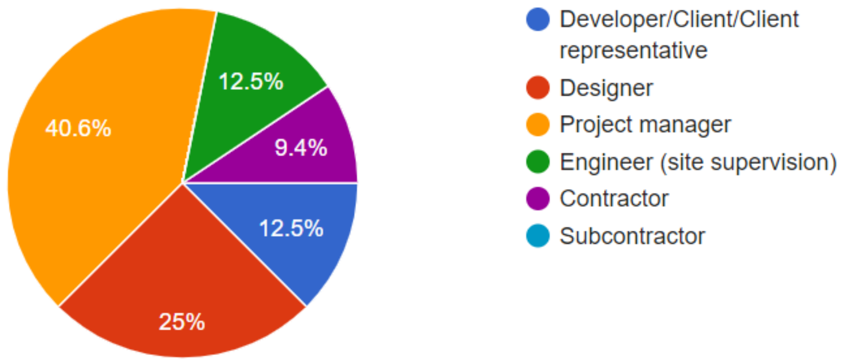
Years of work experience

32 responses



Current role

32 responses



Current position

32 responses