ANALYSIS OF CONSTRUCTION AND STAKEHOLDER RISKS FOR PUBLIC PRIVATE PARTNERSHIP PROJECTS IN DEVELOPING COUNTRIES

A comparative analysis using Artificial Neural Networks to determine the effect of poor stakeholder management and construction risks on the project's schedule

(PPP vs. traditional projects)

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A thesis submitted in Fulfilment of the Requirements of the Degree of Doctor of Philosophy

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March 2020

Abstract

There has been a continuously increasing demand for public services and infrastructure all over the world especially in developing countries in order to respond to the rapidly growing population and the targeted economic growth in these countries. Accordingly resorting to the PPP scheme is a way for the governmental authorities to achieve the objectives of better services to the end user in energy, educational, water and wastewater, and transportation projects with the help and expertise of the private sector. While PPP was proven to be successful in several instances, there are also several failure stories where the PPP scheme was used.

In order to avoid such problems and due to the complex nature of PPP projects and their extended life span, an adequate risk management technique should be performed for PPP projects to ensure their success. One of the crucial steps linked to risk management is stakeholder management.

This research primarily aims to develop a mathematical model that analyzes the expected total effect of risks associated with poor stakeholder management during the construction phase on PPP projects' schedule based on historical details of previous PPP projects in a comparative study with traditional construction projects using Artificial Neural Networks.

In order to develop "the risks checklist" that will be inserted in the model, an extensive literature review of 30 sources was thoroughly studied in order to develop the list of the risks affecting PPP projects. To properly develop a comprehensive list of risks, the journal papers, research and publications that were studied covered the time span between 1998 until 2018. Furthermore, the literature review performed for the sake of developing the risk factors was covering different countries such as: the United Kingdom, Hong Kong, Scotland, China, Australia, India, Indonesia, Singapore, Iran, Malaysia, Thailand, Portugal and South Africa. These countries were chosen to encompass different levels of PPP experience. Accordingly, a comprehensive list of 118 risks was developed.

In addition to the ranking and classification of risks into various risks categories, each one of the identified risks was mapped to its corresponding country. The purpose of this step is to determine the critical risks that the literature identified for each country in order to establish a cross-country comparison. From this mapping, it is found that most of the risks affecting PPP projects around the world are political, legal, stakeholder and construction risks. The inadequate PPP experience, lack of support from government, force majeure and permits delays are affecting PPP projects in all the countries included in this research. It is also noticed that risks affecting developed countries such as Hong Kong, China and UK are of similar nature to the risks affecting developing countries.

The model was developed using Neural Designer ® Software. This software was used in particular as it is a powerful user-friendly interface able to make complex operations and build predictive models in an intuitive way with a graphical user interface.

To build the model, the input variables were the 44 risk factors related to consttruction and stakehoders while the schedule Growth (or total project delay) was used as the target variable.

The dataset contains 12 instances (or 12 projects) and was divided into three sets:

a. Training comprising 66.7% of the projects (8 traditional projects)
b. Selection (testing) comprising 16.7% of the projects (2 traditional projects)
c. Validation comprising 16.7 of the projects (2 PPP projects)

Once all the dataset information has been set, some analytics were performed in order to check the quality of the data.

Model performance was detected using Mean Squared Error (MSE) and Normalized Squared Error (NSE) over the training, testing and validation datasets.

Ten trials of the ANN model were performed using different training and testing strategies in order to be able choose the optimum model that has the best learning capabilities and delivering the least possible errors during the training and testing.

Based on the different trials output, it is concluded that Model 4 delivers the smallest range of error (MSE and NSE) for training and testing. The architecture of this particular model is: 18 input nodes, three hidden neurons on two layers and one output. It was trained using a logistic function.

It is noticed that having the hidden perceptron on two layers improved the model's performance significantly and decreased errors for both training and testing. After performing training and testing of all models, and in all trials, it was noticed that the error decreased considerably by decreasing the number of input nodes.

In order to validate the model's performance, sensitivity analysis was performed to determine the cause and effect relationship between inputs and outputs of the ANN model. The most significant risk factor is "the lack of coordination" as it is the most important contributor to the model´s ability to predict total project´s delay. On the other hand, the least significant risk factor in this case is the "constructability" and the "protection of geological and historical objects". Comparing the results of this sensitivity analysis to the risk mapping to different countries, it is noticed that the lack of coordination risk is not present in other countries such as Australia, Hong Kong and the UK.

Based on the model´s outcomes, correlations between all input and target variables ranked in descending order based on the best model out of the ten models were calculated. The maximum correlation (0.803336) is yield between the input variable "Delay in resolving contractual dispute" and the target variable "Schedule growth". 37 risk factors out of the 44 have a high correlation factor (more than 0.1) with the total project´s delay.

Furthermore, a comparison was established between this new ranking and the ranking previously obtained from the literature review based on content analysis and on the ranking obtained from the sensitivity analysis. The following observations were drawn:

- Based on the literature review, the material availability risk occupies the first position in terms of the most critical risks. This ranking is similar to a great extent to its ranking based on the correlation calculations according to which this risk occupies the third position.

- The "Delay in resolving contractual dispute" occupies the highest rank in terms of correlation with the total project delay based on the ANN model's outputs. This ranking is also similar to the results of the sensitivity analysis where it occupies the second position in terms of the risks having the highest contribution to the total project's delay. On the other hand, the same risk is ranked 31st based on the results of the analysis of the literature review. Since the ANN model was based on real case projects, it makes more sense that this particular risk can be of detrimental effect to the project's completion time. The same goes for the risk "Inadequate negotiation period prior to initiation". This risk, based on the model's deliverables, is ranking 11th and 17th in sensitivity analysis and correlation to the total project's delay while, based on the literature review, is ranking 42nd out of 44.

- The "Public opposition" risk is one of the most severe risks facing PPP projects based on the literature review as it occupies the second position based on the various sources taken into account. Nevertheless, based on the sensitivity analysis and on the correlation analysis, this risk occupies the 35th and 44th positions respectively. This difference in ranking can be caused by the relatively small sample size of PPP projects studied in this research. The dataset studied was not encompassing such risk as it was not faced in the projects that were analyzed. However, this does not mean that this risk is not significant especially for PPP projects.

- For other risks such as "Constructability", "staff crisis" and "subjective evaluation", the literature review and the model deliverables produced very close results.

- Based on the literature review, the material availability risk occupies the first position in terms of the most critical risks. This ranking is similar to a great extent to its ranking based on the correlation calculations according to which this risk occupies the third position. On the other hand, the ranking of this same risk is 31 based on the sensitivity analysis in terms of its effect and contribution to the total project delay. The "Delay in resolving contractual dispute" occupies the highest rank in terms of correlation with the total project delay based on the ANN model's outputs. This ranking is also similar to the results of the sensitivity analysis where it occupies the second position in terms of the risks having the highest contribution to the total project's delay. The "Public opposition" risk is one of the most severe risks facing PPP projects based on the literature review as it occupies the second position based on the various sources taken into account. Nevertheless, based on the sensitivity analysis and on the correlation analysis, this risk occupies the 35th and 44th positions respectively.

A future destination for this study is to provide, in addition to the ANN model determining the contribution of the risks to the overall project delay, a tool assisting the public sector to choose and determine whether the PPP scheme in a particular project is the optimum scheme to use or not.

Declaration

I, Yosr Badran, declare that the work contained in this thesis has not been submitted for any other degree or professional qualification. It represents my own work, except where duly referenced, carried out under the supervision of Dr. Anthony Higham and Dr. A. Samer Ezeldin between September 2016 and March 2020.

Yosr

21 March 2020

Dedication

To the closest persons to my heart

To my late grandmother who is living forever in my heart and soul. I really wish you were physically here but the warmth of your happiness hugs me and that smile on your angelic face illuminates my life.

To my late grandfather who, instinctively, guided my professional and academic lives.

I must thank you for bringing to this world my sunshine:
My lovely mother who fills me with life and perseverance. May God bless you, protect you and always grant you health, happiness and serenity as you always generously provided them to me. I owe you every success I realize in my life and I promise to always make you proud.

Acknowledgment

I cannot find words to describe my happiness while writing the very last page of my research. In fact, this happiness is mixed with a feeling of gratitude towards many special people who are sent by God to help me along the way.

I would like to thank my mother for her endless love, help and support.

I am really grateful for the support, supervision, guidance of my dear supervisors Dr. Anthony Higham and Dr. Samer Ezeldin.

Dr. Samer Ezeldin, my local advisor, who has always been more than supportive with his wisdom, encouragement, precious advice, deep knowledge and optimism. I am proud for being your student since my undergraduate studies in 2006.

Dr. Anthony Higham, it has been a real pleasure working under your supervision. Thank you for every valuable comment and each piece of advice you provided along the way to guide and help me. I have learned a lot a lot from you.

I also would like to express my deepest gratitude and thanks to each and every person who generously helped me along the way to collect the data, accomplish my research especially every person who took the time to respond to interview questions and test the model. Without your help and support, the thesis would have never been completed in its current form.

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List of abbreviations

(ANN): Artificial Neural Networks

(BOO): Build Own Operate

(BOOT): Build-Own-Operate-Transfer

(BOT): Build-Operate-Transfer

(BP): Backpropagation

(CRG): Critical Risk Groups

(CSF): Critical Success Factors

(DB): Design-Build

(DBFMO): Design-Build-Finance-Maintain-Operate

(DBFO): Design-Build-Finance-Operate

(DFBMT): Design, Finance, Build, Maintain and Transfer

(DSS): Decision Support System

(GDP): Gross Domestic Product

(GWI): Global Water Intelligence

(ECA): Europe and Central Asia

(EAP): East Asia and Pacific

(ERSAR): Water and Waste Services Regulatory Authority

(EU): European Union

(EWRA): Water Sector Regulator

(IFC): International Finance Corporation

(IRAR): Institute for the Regulation of Water and Waste

(LAC): Latin America and Carribean

(MENA): Middle East and North Africa

(MHUUD): Ministry of Housing

(MLR): Multiple Linear Regression

(MoF): Ministry of Finance

(MoI): Ministry of Investment

(MRG): The Minimum Revenue Guarantee

(MSE): Mean Square Error

(NIE): New Institutional Economics theory

(NUCA): New Urban Communities Authority

(NCRE): Non-Conventional Renewable Energy

(O & M): Operation and Maintenance Contracts

(PFI): Private Finance Initiative

(PPI): Private Participation in Infrastructure

(PPIAF): Public-Private Infrastructure Advisory Facility

(PPP (P3 or P^3)): Public Private Partnership

(PRC): People's Republic of China

(PTB): Partnership Technical Bureau

(RDSS-PPP): Risk Decision Support System for Public Private Partnership Projects

(RM): Relationship Management

(RMS): Root Mean Square Error

(ROT): Rehabilitate-Operate-Transfer

(SAR): South Asia Region

(SI): Stakeholder Involvement

(SM): Stakeholder Management

(SPV): Special Purpose Vehicle

(SSA): Sub-Saharan Africa

(TRC): Toll Revenue Cap

(VFM): Value for Money

Chapter 1 – Introduction

1.1 Chapter Introduction

Over the past years, there has been a continuously increasing demand for public services and infrastructure all over the world. In 2014, the World Bank Group announced the increase of their financed infrastructure projects by 45%. Such increase mainly occurred in developing countries (World Bank 2014). There has been a need to strengthen the infrastructure in the rapidly growing population countries with the intention of sustaining the economic growth. In order to meet such need, governments all over the world invest billions of dollars into infrastructure projects (World Finance 2015). In developing countries, and with the tremendous population increase, the need for projects in various domains: infrastructure (such as roads, water, wastewater, etc.), health, educational and residential is becoming inevitable to improve the living conditions. However, with the current economic circumstances prevailing in the developing countries, the public sector is sometimes unable to deliver such services and projects efficiently and effectively. The private sector, on the other hand, has the financial capability and skills to improve the delivery of public services and projects.

According to the World Bank (2008), the collaboration between business, civil society and government can only produce a win-win situation for all parties as it provides long-term benefits to the business sector while meeting the social objectives of civil society and the state by helping create stable social and financial environments. Consequently, Public Private Partnership (PPP) has been, and continues to be used in various sectors all over the world especially in the infrastructure sector as it is considered as a "catalyst for economic growth" (Babatunde 2012). The PPP scheme is believed to be able to deliver better value for money especially for infrastructure projects (Hwang, *et al.,* 2012).

It has been noticed that there is an increasing attention towards the PPP scheme especially in the developing countries as PPP is a way for the public authorities to improve their infrastructure, provide better services to the end user through educational, water and wastewater, transportation projects with the help and expertise of the private sector (Ke, *et al.,* 2009). PPPs came into existence as a result of continuous challenges facing the public sector in its attempts to improve its services, facilities and infrastructure which is, in many cases, demanding challenging economic resources. Hwang *et al.* (2012) mentioned that in general, if an infrastructure project is expected to have a value in excess of $50 million, then, the involvement of the private sector should be considered. Also, sometimes, the need for the private partner comes as a solution to some problems caused by the deficiencies present at the public partner's side.

Based on the annual report on private participation in infrastructure published by the World Bank in 2017, the investment in PPP infrastructure projects by the private sector reached $93.3 billion US dollars across 304 projects around the world, with an increase of 37 percent from 2016's levels. 20 projects among the 304 projects are mega-projects with an average size of $2.4 billion US dollars accounting for 51 percent of the total private participation in infrastructure in 2017 compared to only thirteen projects accounting for 40 percent of the total private participation in infrastructure in 2016. Figures 1 and 2 show the amount of investments in PPP infrastructure projects in US dollars (billions) from 1991 to 2015 and from 2008 to 2017 respectively across the world. Figure 1 shows the investments in PPP infrastructure projects as a percentage of GDP as well between 1991 and 2015.

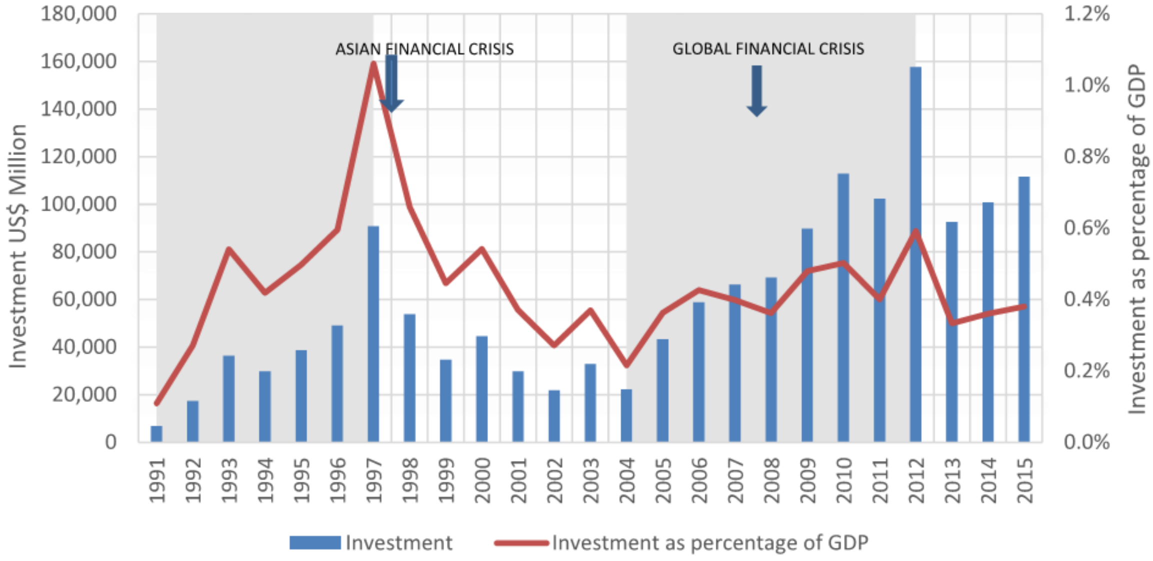


***Figure 1*. Investment in PPP infrastructure projects in US dollars (millions) between 1991 and 2015 across the world (World Bank, 2016, p.8)**

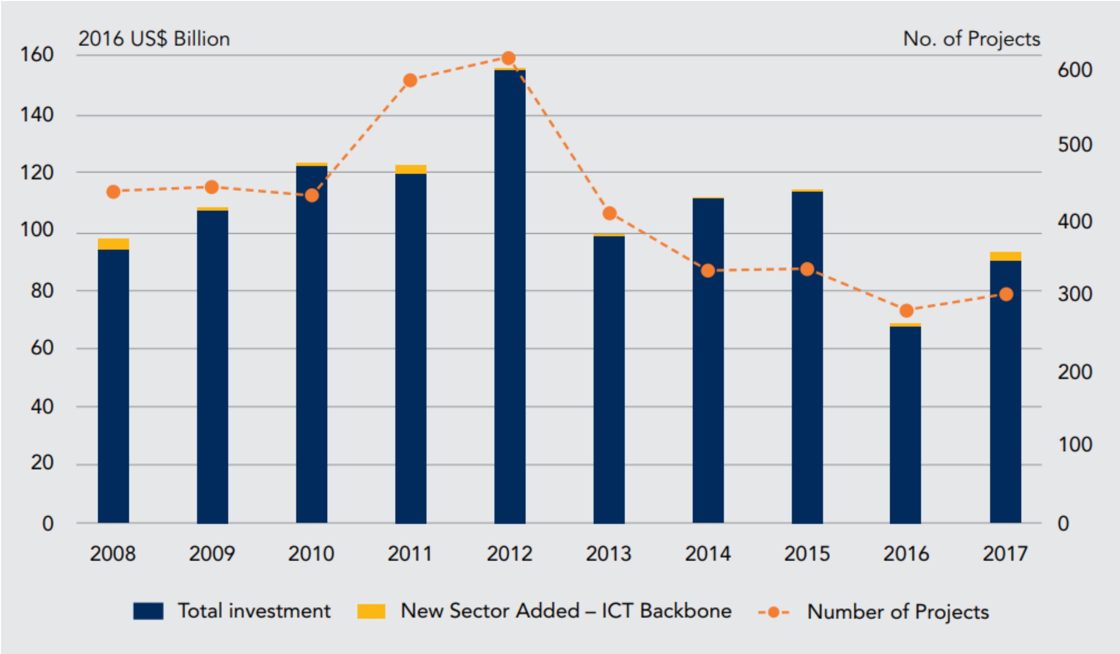


***Figure 2*. Investment in PPP infrastructure projects in US dollars (billions) between 2008 and 2017 across the world (World Bank, 2017, p.4)**

From the charts, it is clear that the number of projects increased from 280 projects in 2016 to 304 in 2017 (by approximately nine percent.). It is however noticed that despite the increase of the private sector participation in 2017 compared to 2016, the total investment in 2017 is still 15 percent lower than the average during the last five years (starting from 2012). Table 1 shows the frequency distribution of project sizes in US Dollars (million) over the past five-year period and 2017.

***Table 1*. The frequency distribution of project sizes in US Dollars (million) over the past five-year period and 2017 (World Bank, 2017, p.5)**

TABLE 1: FREQUENCY DISTRIBUTION OF PROJECT SIZES IN US$ MILLION OVER THE PAST FIVE-YEAR PERIOD AND 2017

Year	No. of Projects	Mean	Median	Maximum
2012	614	289	94	15,471
2013	410	253	101	3,720
2014	338	348	87	10,653
2015	341	341	87	36,035
2016	280	261	95	5,190
2017	304	310	103	6,882

Source: World Bank, 2017, p.5

On a country level, the five countries with the highest levels of investment in PPP infrastructure projects in 2017 were: China, with $17.5 billion US dollars across 73 projects; Indonesia, with $15.4 billion US dollars across 11 projects; Mexico, with 8.6 billion US dollars across 20 projects; Brazil, with $7.3 billion US dollars across 24 projects; and Pakistan, with $5.9 billion US dollars across four projects. In 2017, in total, these five countries attracted $54.7 billion US dollars, and captured 58 percent of global investment (World Bank 2017). This is illustrated in Figure 3.

Figure 3. **Investment in infrastructure projects with private participation by region and country (World Bank, 2017, p. 8)**

To have a broad and more general view, the participation of the private sector in infrastructure projects by region, between 2008 and 2017 is illustrated in Figure 4.

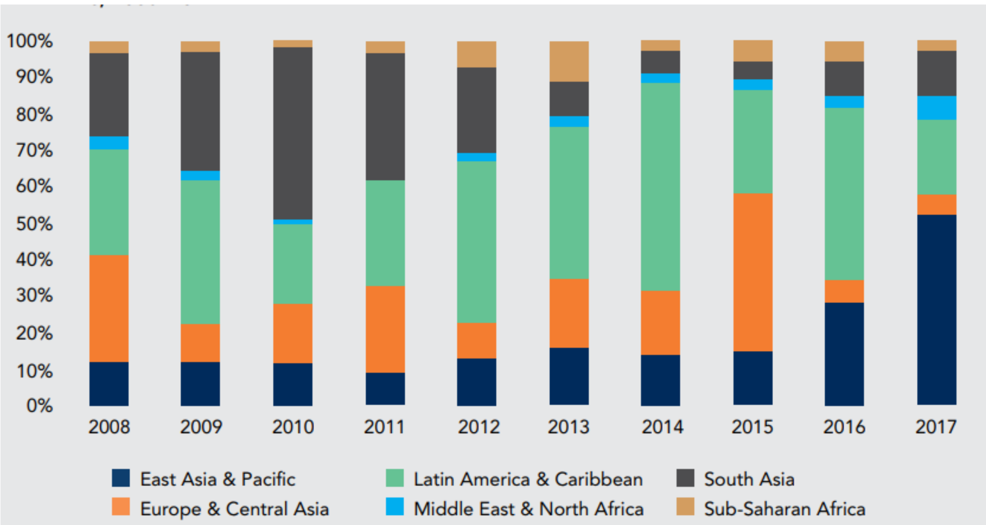


Figure 4. **Participation of the private sector in infrastructure projects by region, between 2008 and 2017 (World Bank, 2017, p. 7)**

As the above figure shows, private sector investment for all the regions except Latin America and Caribbean and Sub-Saharan Africa were higher in 2017 than in 2016. In these two regions, private sector participation declined by 40 percent and 44 percent, respectively.

It is also noticed that the private sector investment share for East Asia and Pacific has been increasing and reached its peak in 2017, accounting for over half of global investment. Although the private sector investment has always been higher in Latin America and Caribbean, reaching its peak of 68 percent in 2016; in 2017, it dropped significantly to 21 percent. Meanwhile, private sector investment in South Asia Region continues to increase after its lowest level in 2015. In the Middle East and North Africa, the private sector participation has remained consistent over the years, at around two percent. Nevertheless, in 2017, it tripled to six percent (World Bank 2017).

From the aforementioned statistics, it can be concluded that recent years have witnessed an increased cooperation between the private and the public sector especially in the infrastructure sector all over the world as it is believed that PPP can deliver a better Value for Money (VFM) for facilities, projects and services. Accordingly, the public sector resorted to the partnership with the private sector in order to deliver projects or public services by benefiting from the private sector's experience, financial ability, management and technical skills. Based on the General Regional Policy guidelines for successful Public Private Partnerships published by the European Commission Directorate (2003), the Private sector has four major roles within the PPP model which are to provide the following:

- Supplementary capital;
- Alternative management techniques and a good use of skills;
- Value added to the consumer and the public at large;
- Better identification and response to the public needs through the optimum use of available resources.

Nevertheless, while the PPP model appears attractive, it should be considered that it is not miracle solution: for each project, it is indispensable to perform the necessary study assessing whether the PPP scheme will be an added value to this project compared with other options such as the traditional model (Abdel Wahab 2009). In fact, due to the lack of the adequate study of the feasibility of certain PPP projects, Valipour *et al.,*(2016) argues that several PPP projects failed to be on budget and on schedule. Furthermore, many projects were not delivered to the required quality. According to the statistics published by the World Bank in 2015, from 1990 and until 2012 there were 327 unsuccessful PPP projects: 135 projects in Latin America, 86 projects in East Asia and Pacific, 50 projects in Sub-Saharan Africa, 13 projects in South Asia, 36 projects in Europe and Central Asia and 7 projects in Middle East and North Africa.

Accordingly, for each project, it is necessary to perform the necessary study in order to know whether implementing PPP will be beneficial or not. Furthermore, there are various degrees of success of PPP projects across the countries which differ based on the place and time where PPP is applied. Henjewele *et al.,*(2013) argues that PPPs are not just a normal partnership between the public and private parties. PPPs have a very complex nature as they consists of bringing together two entirely different organizations, having different goals (Starr 1988) into one single project (Collin 1998). Moreover, Kumaraswamy *et al.,* (2015) points out that the PPP scheme consists of combined and critical relationships, not just “contractual relationships” as it involves people, from different backgrounds, working in a long-term relationship to achieve common goals.

Due to the long term nature of PPP contracts, the key concepts present in the relationship between the public partner and the private partner such as the management of risks, stakeholders, quality of service required, value for money, how to handle disputes and how to deal with changes that may occur during the project's lifetime should be identified. There are several success factors that contribute to the success of any PPP project such as the effective procurement, project implementability, government guarantee, favorable economic and political conditions and available financial market (Marques and Berg 2011). Moreover, Zou *et al.,* (2013) argues that "Relationship Management" is also crucial in PPP projects as it establishes the partnering strategies with project counterparties and project stakeholders in order to create sustainable relationships for the benefit of the project. Accordingly, a good and sound management of stakeholders is crucial for the success of the PPP project and this should be applied at the start of the project (Schepper, *et al.,* 2014).

On the other hand, there are two major causes of PPP failure which are the contractual incompleteness in addition to the imperfect allocation of risks to the appropriate parties/stakeholders. According to the Guidelines for Successful PPP Projects in Egypt published by the PPP Central unit (2013), "Risk allocation is at the heart of how PPPs are structured". Also, El-Gohary, *et al.,* (2006) and Rwelamila, *et al.,* (2014) argues that such underestimation of the stakeholders' effect and impact on the success of the project led to the failure of several previous PPP projects.

It is against this backdrop that this research seeks to analyze the risks associated with PPP projects with a special emphasis on the risks emerging from construction and poor stakeholder management in order to determine the effects of such risks on future PPP projects in an attempt to provide some solutions for dealing with such risks.

1.2 Problem Statement

PPP has often been viewed as an optimal solution especially in developing countries as it is a way for the public authorities to improve their infrastructure, provide better services to the end user for infrastructure, educational, water and wastewater, transportation projects with the help and expertise of the private sector. In some cases, because of certain budget constraints and due to the government's unwillingness to raise the taxes despite the need for the project, the PPP model can be the only way the project can be built (Reuters 2013). The PPP model is based on the concept of bringing the strengths of both parties (public and private sectors) together. The private sector has the financial capability and skills to improve the delivery of public services and projects while the public sector shall perform its usual and normal duties which consist of planning, regulation and policy making.

Nevertheless, not all PPP projects that have been performed were successful. The PPP scheme is different than the conventional project delivery methods and is characterized by its complexity and by its long terms relationships. Moreover, in any country (especially the developing countries), the needs, agendas and priorities can differ from time to time (Akintola, *et al.,* 2016).

Furthermore, PPP projects involve two entirely different entities, naturally having different objectives, to work together, for an extended duration, towards a common goal which is not an easy target to achieve especially in light of the complexity of the relationships being both contractual and non-contractual (involving people dealing together). Based on previous projects, PPP history showed that the major cause of PPP failure is the inadequate risk management and the underestimation of the stakeholder management's importance. Unfortunately, the failure of PPP projects not only affects the public sector and the private sector but also will be affecting the end users of the projects and taxpayers who will bear several consequences especially economic ones. Moreover, poor risk and stakeholder management will lead to project delays and subsequently cost overruns and poor Value for Money.

According to the PMBOK (2009), the current risk management techniques are significantly inadequate in managing risks associated with several issues such as the selection of the appropriate procurement types, contractual arrangements, management of stakeholders, organizational complexity and operational performance and de-investment decisions. Henjewele *et al.* (2013) points out that both the private and public partners took stakeholders and stakeholders management from a narrow perspective. El-Gohary *et al.* (2006) and Rwelamila *et al.* (2014) argue that such underestimation of the stakeholders' effect and impact on the success of the project led to the failure of several previous PPP projects. Accordingly, it is not difficult to appreciate the need for the early implementation of risk management for the PPP project ensuring it takes into account the concept of "Stakeholder Involvement" (SI). Stakeholders do not only include the private and public entities but must also include the "general public" and the "end users". According to Doloi (2012), due to the involvement of various stakeholders in the PPP project, the risks associated with PPP projects are "multifaceted". Consequently, proper risk management in PPP projects necessitates a clear understanding of the PPP process and a proper identification of all the risks associated with all stakeholders over the PPP lifecycle, specially the construction phase.

1.3 Research aim

This doctoral study seeks to resolve the existing gap in knowledge in the context of the relationship between poor stakeholder management and the arising of additional risks to the PPP project affecting the PPP project's completion time and subsequently leading to additional costs especially in developing countries. Accordingly, establishing a good stakeholder management technique will eliminate many risks facing PPP projects and will make the parties involved in the PPP project focus on the actual uncertainties facing the project.

The research primarily aims to develop a mathematical approach modelling the expected total effect of risks associated with poor stakeholder management during the construction phase on PPP projects' schedule based on historical details of previous PPP projects in a comparative study with traditional construction projects using Artificial Neural Networks. This mathematical approach shall primarily assist the Private Sector in choosing the optimum contractual relationship for any given project and to decide whether (or not) the PPP scheme will be the optimum solution.

1.4 Research objectives

In order to achieve the aforementioned aim, the objectives are stated as follows:

1. Provide a better conceptual understanding of the PPP scheme and different types of PPP.
2. In light of the PPP history, study, evaluate previous failure and success stories in different countries that used PPP delivery method and critically appraise existing international literatures relating to PPP to identify the common key success factors and major causes of failure of PPP projects.
3. Provide a better conceptual understanding of "Risk Management" and "Stakeholder Management" and ascertain, through a critical review of the literature, how both concepts are related.
4. Develop from existing literature a comprehensive list including all the risks affecting PPP projects and determine to which risk group each individual risk is associated (For instance: economic, political, etc.), map each identified risk to its root cause and establish a cross-country comparison between different risks.
5. Develop a ranking for the identified risks based on the literature review with a special emphasis on risks related to construction and poor stakeholder management.
6. Using data collected from real case projects, design the Neural Network approach modelling the effect of construction risks and poor stakeholder management risks (previously identified in step (4)) on the project's schedule and time for completion. The data will be collected for both traditional and PPP projects.
7. Determine, based on the model's outputs, a new ranking for the risks affecting the project's time for the completion.
8. Compare the risk ranking generated through the Neural Network model to the risk ranking previously developed though the literature review in step (7).
9. Critically evaluate the mathematical model's performance based on:
    a. The percentage error the model will deliver;
    b. The discrepancies in the risk ranking between the model and the literature review.

1.5 Research Questions

A preliminary review of the literature on PPP projects led to the following research questions that will guide the research in order to achieve the previously stated research aim and objectives:

- *What is the phase characterized by the highest number and impact of risks that is really worth being studied in a PPP project's lifetime?*

Any PPP project has different phases throughout its lifecycle, expanding over a long time span, sometimes reaching up to 40 years. There are several ways to describe the different stages any PPP projects goes through. Li and Zou (2012) identified the stages of PPP differently; into six main stages:

- Feasibility
- Financing stage
- Design stage
- Construction stage
- Operation stage
- Transfer stage

As Chapter two and three will demonstrate, each phase in the PPP project lifecycle is characterized by its own risks. There are also some risks with an extended effect all over the project's lifetime. Accordingly, in any PPP project, the risk picture will vary throughout the different stages. However, a primary review of the literature sources point out to the fact that the majority of the risks occur during the construction phase. Then, the number and magnitude of risks start to decrease gradually until reaching the end of the PPP project's lifecycle. Accordingly, the construction period of the PPP project can be considered as a representative period for studying the risks affecting PPP projects as it is characterized by being a critical period in the PPP project's lifetime where most of the risks occur.

- *What are the major distinctions between the PPP scheme and other conventional procurement techniques?*

The literature review confirms that the PPP scheme is not just a collaboration between the public and private sectors. It is a unique concept resulting in a boundary zone where both the public and the private sectors' characteristics are still present and identifiable (Collin 1998). PPP projects are mainly characterized by the long-term nature and by the complexity of relationship among stakeholders. In PPP projects, the private partner bears more risks and responsibilities related to design, construction, operation and maintenance depending on the PPP type.

On the other hand, in traditional procurement model, the public partner finances the design and construction of the facility. Once the construction phase is complete, the government will be responsible for the operation and maintenance of the facility. Nevertheless, a primary review of several literature sources demonstrates that the construction phase in particular, in PPP projects, is similar in its characteristics to traditional projects especially when it comes to the major risks impacting it. The major difference lies in the allocation of the risk (who bears the risk). Accordingly, comparing the impact of risks on traditional projects versus their effect on PPP projects can be a valid initiative.

- *Has PPP always been a successful solution in order to provide better Value for Money and in order to ensure the public needs are met?*

The literature review shows that while PPP has been widely implemented and while it aims to bringing the strengths of both the public and private parties together, PPP is not a miraculous solution for any project: while PPP was proven to be successful in several instances, there are also several failure stories where the PPP scheme was used. There were projects that suffered from cost overruns, others were negotiated and others were abandoned. Based on the literature review, failure of PPP projects can be attributable to several reasons such as: poor risk management, inadequate risk allocation, poor stakeholder management and underestimation of the role of the general public and end user for the success of PPP projects.

- *How are "Risk Management" and "Stakeholder Management" related especially in PPP projects?*

The literature review has proven that Risk Management and Stakeholder Management are closely related. Zou *et al.* (2013) argues that due to the fact that PPP projects have a long lifetime, there will be a higher chance of problems/changes arising. Accordingly, a good risk allocation between PPP parties is crucial to ensure a successful PPP project. Nevertheless, many of the changes happening during the lifetime of the PPP project will be unanticipated for as potential risks and therefore, will not be accounted for in the PPP contract. Therefore, relying on the established relationships is crucial in order to maintain and protect the contractual bond. The quality of the relationship between public and private sector on one side and the end users on the other side has been shown to be a key contributor to the success of a PPP project. Furthermore, many of the risks affecting PPP projects arise due to poor management of stakeholders. Therefore, minimizing the risks caused by inadequate management of stakeholders is a way of mitigation of a significant number of risks affecting PPP projects which is step towards better Risk Management for PPP projects.

- *What advantages can Artificial Neural Networks offer to this research over linear regression model?*

This research aims to develop a mathematical model (Artificial Neural Network approach) modelling the impact of stakeholder risks on PPP projects during the construction phase. This is a complex problem involving several attributes linked by non-linear relationships. Based on an initial review of the literature, Artificial Neural Networks (ANNs) were proven to deliver better outcomes in this kind of problems. Furthermore, ANNs have analogies with the human brain especially when it comes to their ability to learn, to adapt and to generate results. This conforms to the aim and objectives of the research.

1.6 Overview of research approach

This research mainly adopts a quantitative approach with some elements of qualitative approach.

After the aims and objectives were defined, a thorough and extensive review of the literature was done on the PPP concept, types of PPP, failure and success stories of PPP, risk management and stakeholder management in PPP projects. The literature review played a crucial role in developing the list of risks (checklist) affecting PPP projects and mapping each risk to its root cause. Also, the literature review was essential in performing the cross-country comparison for the different risks in addition to establishing the risk ranking. A list including the risks caused by poor stakeholder management is obtained.

An experimental approach was then designed based on data collected from actual projects in order to develop the mathematical model for both traditional and PPP projects in light of the risks related to construction and poor stakeholder management and their impact on the project's schedule and completion time. The research approach and methodology will be discussed thoroughly in Chapter Three.

1.7 Contribution to knowledge

According to Ke *et al.* (2009), in the period from 1998 to 2003, the papers published and tackling PPP scheme were initially studying three major aspects in PPP which are the risks associated with PPPs, Procurement method in PPP and financial issues in PPP. Among these three major points of interest, papers published about risk management for PPPs account for approximately 21 percent of the total number of papers published and concerning PPPs. Table 2 identifies the major points of interest of PPP papers from 1998 to 2008.

Table 2. **Areas of concern in PPP papers from 1998 to 2003**

Topic	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Total	%
Risk management	2	2	5	0	2	5	1	4	5	2	7	35	20.6
Integration research	4	3	0	0	6	1	2	5	6	4	3	34	20.0
Governance issue	0	1	1	3	0	7	1	1	6	4	7	31	18.2
Investment environment	0	1	2	2	0	5	2	1	4	2	2	21	12.4
Procurement	2	1	0	1	2	0	3	2	2	5	1	19	11.2
Economics viability	0	3	1	0	2	1	2	3	3	2	2	19	11.2
Financial package	1	0	0	2	0	4	0	1	2	1	0	11	6.5

Source: Ke *et al.* 2009

Moreover, Figure 5 shows the number of papers published worldwide about PPP from 2005 and until 2014 showing the increased attention towards studying PPP projects and their related aspects (Zhang, *et al.,* 2016).

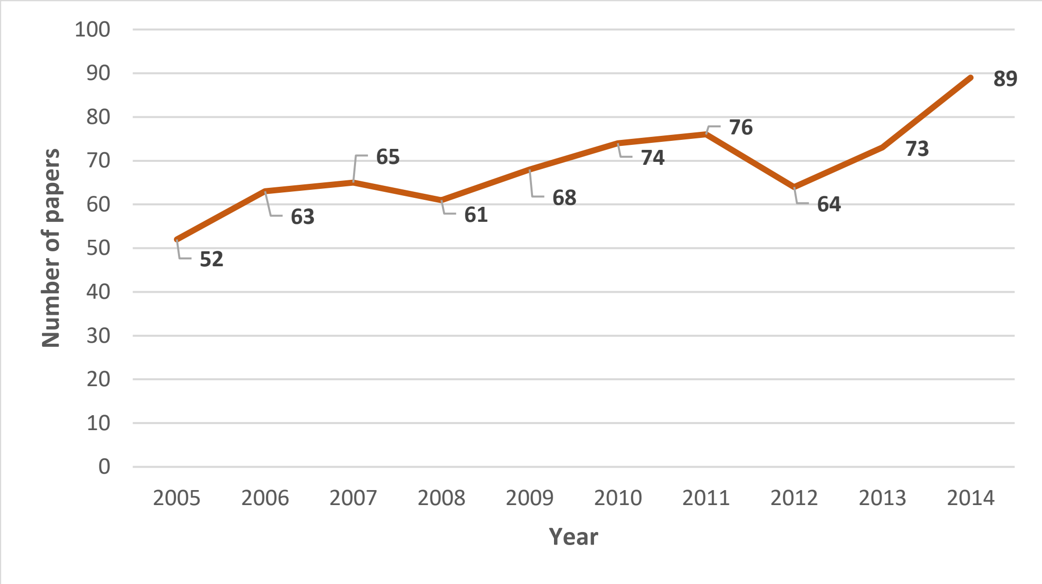


Figure 5. **Number of papers published about PPP from 2005 till 2014 worldwide (Zhang *et al. 2016)***

Figure 6 shows the total number of papers published worldwide about PPP projects from 2005 until 2014 categorized by research topic.

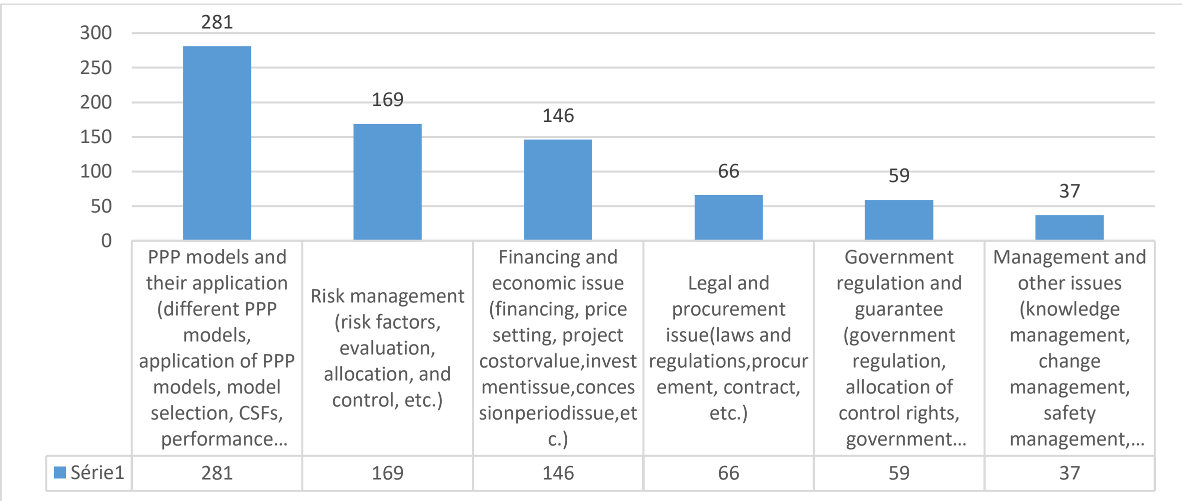


Figure 6. **Total number of papers published worldwide about PPP projects from 2005 until 2014 categorized by research topic (Zhang *et al. 2016)***

Accordingly, it is noticed that the top two research topics in the domain of PPP projects are:

- PPP models and their applications
- Risk management

Accordingly, this proves that these two topics are considered as areas of concern among the various topics and issues related to PPP.

One of the most important barriers to a sound and proper risk management is the poor stakeholder management causing issues in collaboration, trust, negotiation and teamwork. Accordingly, analyzing the effect of risks associated with poor stakeholder management on the PPP project is a crucial step towards better risk management.

Among the published papers on PPP projects, different research methods are adopted. Figure 7 illustrates the research methods adopted by PPP research papers from 2005 until 2014. It is worth mentioning that some papers combine different methods into one research. This chart shows that the case study method is adopted in most of the papers (331 papers), modelling occupies the third place in terms of the number of papers adopting it (203 papers). On the other hand, from 2005 till 2014, only 80 papers adopted the comparison method.

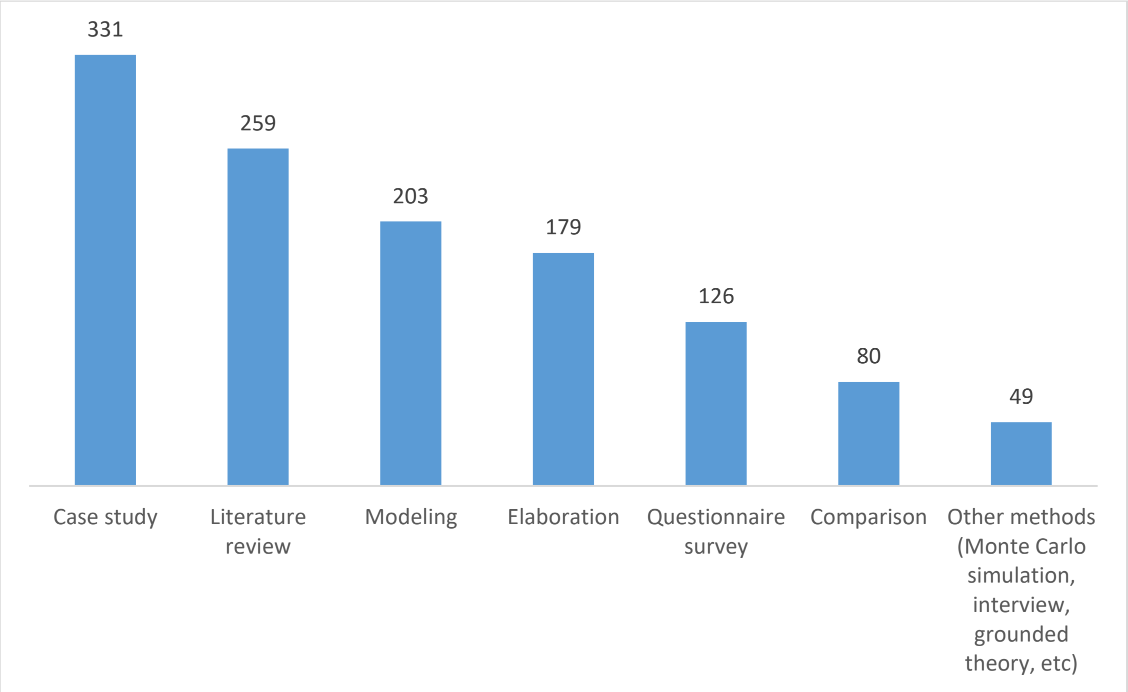


Figure 7. **The research methods adopted by PPP research papers from 2005 until 2014 (Zhang *et al.* 2016)**

Based on the above, the contributions of this research to the field of construction project management and especially to the domain of PPP projects are in line with the research aims and objectives described previously. The major contributions are summarized as follows:

Primary contribution:

- **A mathematical Artificial Neural Network approach modelling the contribution of construction and stakeholders related risks to the project's delay based on a comparative analysis between traditional projects and PPP projects in developing nations**

There was one research conducted in 2010 about modelling optimal risk allocation in PPP projects using artificial neural networks by Jin and Zhang (2010) and though the adoption of neural networks models developed by: Odeyinka *et al* (2002), Maria-Sanchez (2004) and Lhee *et al.,* (2014) studying respectively the impact of construction risks on total project cost, the impact of environmental risks on construction projects and predicting the optimal contingency for transportation projects. The contribution here is developing a mathematical model determining the impact of poor stakeholder management risks and construction risks in PPP projects for developing nations based on a comparative analysis with traditional projects. The Artificial Neural Network approach is modelling the impact of those risks on the project's time for completion.

Furthermore, the data used to develop the model is based on real case projects not on questionnaires results. Accordingly, the results delivered by the model are closer to real life and not subject to bias as it may happen in case of depending on respondents' opinions. Also, the research is adopting a combination between different research methods and techniques such as: literature review, modelling, comparison and case studies which is enriching the research and enabling the problems studied to be treated from different perspectives.

It is not expected for the developed model to be ready for immediate use but the construction industry is active and research is continuously done. This research here makes an original contribution to it.

Secondary contributions:

- **A comprehensive definition of Stakeholder Management and Stakeholder Involvement (including the importance of the "People" (general public/end users) as a major PPP project stakeholder)**

According to Schepper *et al.* (2014), proper stakeholder management along with the identification and classification of all stakeholders are indispensable to ensure the PPP project's success especially in the early set-up phase. Nevertheless and despite the importance of stakeholder analysis and stakeholder engagement, there exist various limitations and gaps in the literature regarding these concepts (Missonier and Loufrani-Fedida 2014;, Jepsen & Eskerod, 2009, Littau *et al.,* 2010, Pacheco and Garcia, 2012, Yang, *et al.,* 2009). Achterkamp and Vos (2008) argue that research examining the importance of stakeholder management and involvement in traditional construction projects is generally limited and even less so for PPP projects.

The contribution here is a thorough study and examination of previous research conducted on Stakeholder Management in PPP projects in addition to a set of failure and success stories highlighting the importance of performing adequate stakeholder management technique involving the "general public" as an essential project party.

- **Understanding of the relationship between Risk Management and Stakeholder Management**

According to Henjewele *et al.* (2013), both the private and public partners took stakeholders and stakeholders management from a narrow perspective. El-Gohary *et al.* (2006) and Rwelamila *et al.* (2014) argue that such underestimation of the stakeholders' effect and impact on the success of the project led to the failure of several previous PPP projects. The contribution here is to provide a clear relationship between Stakeholder Management and Risk Management and to provide clear Stakeholder Management recommendations and guidelines that can deliver better Risk Management for PPP projects in the future.

1.8 Thesis structure

Figure 8 shows the various chapters that the research consists of:

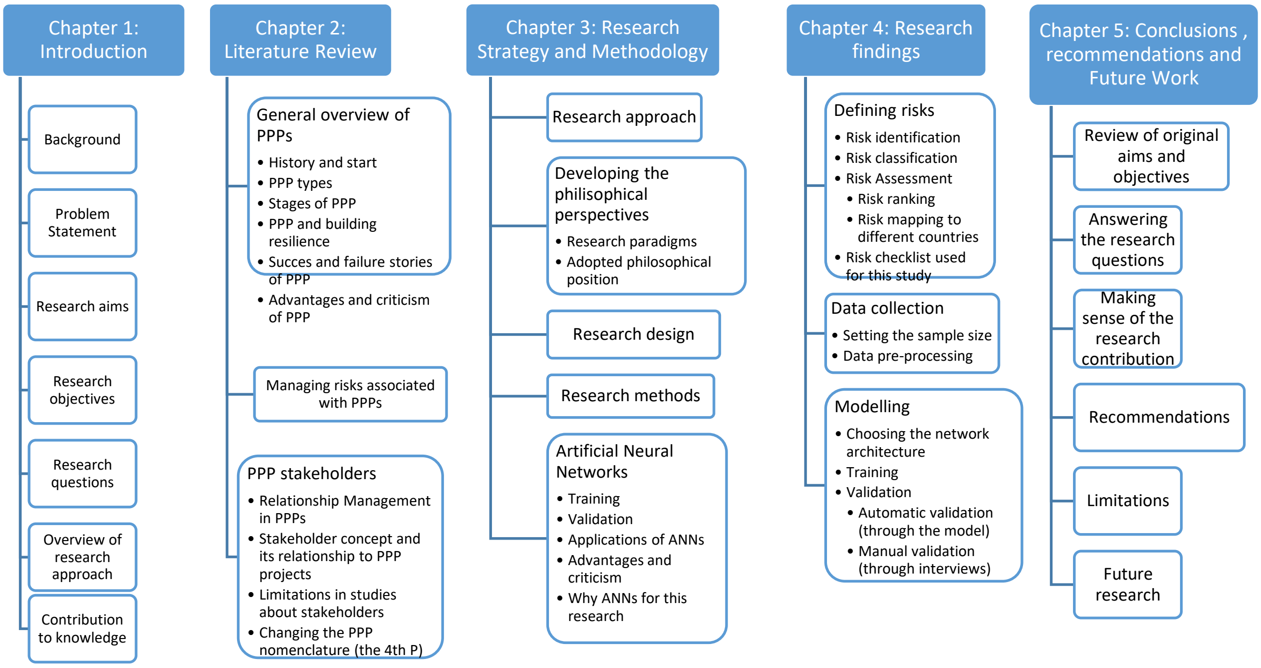


***Figure 8.* Thesis Structure**

1.8.1 Chapter One- Introduction

This chapter includes the background and context of the research, specifying the problem statement along with the aims and objectives of the research. An overview of the research approach is presented. The research questions are also stated in this chapter.

1.8.2 Chapter Two- Literature Review

This chapter forms the critical spine of the research. It analyzes and shows the explicit gaps in the literature. The literature review is divided into three major sections.

- The first section is a general overview of PPP projects including a description of the history of PPP projects, PPP structure among other procurement options, stages of PPP. A subsection is describing the complex nature of PPP projects. In this subsection, a concept is explained which is: “building resilience in PPP projects”. Another subsection is dedicated to success and failure stories of PPP projects around the world with failure and success stories. Finally, a subsection is describing the advantages and criticism of PPP projects.

- The second section is concerning the management of risks associated with PPP projects. In this section, the impact of various risks on PPP projects delays (and associated cost overruns) is also discussed.
- The third section is about PPP stakeholders. In this section, the following topics are discussed: Relationship Management in PPP projects, stakeholder concepts (power, legitimacy and urgency) and their relationship to PPP projects, limitations in studies about stakeholders in PPP projects and changing the PPP nomenclature (introducing the 4th P to the PPP). In the section discussing the introduction of the 4th P to the PPP, real case PPP projects showing the power of the general public are presented and the importance of stakeholder involvement in PPP projects is discussed. Finally, an important section summarizing the literature review by stating the relationship between Risk Management and Stakeholder Management is included.

1.8.3 Chapter Three- Research Strategy and methodology

This section includes the research approach and the framework that will guide the rest of the research. It provides a critical appraisal and justification of the research methodology adopted. It includes the steps performed and that will be followed and further explained in Chapter Four. Furthermore, the background, components and applications of Artificial Neural Networks in civil engineering are also evaluated in this chapter. The advantages and criticism to Artificial Neural Networks are discussed in addition to the reasons for which this technique was used in this research in particular.

1.8.4 Chapter Four- Research findings

This is the experimental chapter of the research. The chapter starts by developing a risk checklist based on the literature review, a categorization of the identified risks, cross-country comparison and ranking. Then, the specific risks studied in this research are listed. Then, all the data collected for both traditional and PPP project will be "put to work" to develop the ANN model. The steps of the data collection are explained, a justification for the sample size for both traditional and PPP projects is discussed. The datasets are then subject to extensive pre-processing steps consisting of cleaning, integration, transformation and partitioning in order to be inserted into the ANN model. The different details associated with the model development are thoroughly explained starting by choosing the network architecture, the training and testing strategies. The model is trained numerous times until reaching the “optimum” model delivering “acceptable” results. Then, validation is performed in order to test the model’s performance and ability to generate “new data”.

Furthermore, sensitivity analysis is used in order to get a new ranking of the different risks previously identified through the literature review. This new ranking is also compared to the first ranking that was obtained from the literature review. The aim of this whole chapter is straightforward: to make data “learn” and “work” by extracting embedded useful information in order to predict the contribution of major stakeholder and construction risks to the total project’s delay in a comparative study between traditional and PPP projects. The data analysis and the results achieved have intentionally been integrated into the same chapter in order to strengthen the link between the analysis and the results which shall improve the clarity and readability of the research.

1.8.5 Chapter Five- Conclusions, recommendations and future work

In the closing chapter, conclusions will be drawn based on the findings from the literature review in addition to the data modelling chapter. The aims and objectives presented in Chapter One will be revisited and a judgement shall be made on whether such objectives were achieved, and to which extent. Furthermore, the novelty and contributions of the research will be summarized, detailing the implications of such contribution on future work and projects. Moreover, limitations to the current research and challenges that were faced are discussed. Finally, an overview of the future work that can become a new destination for this research is presented.

1.9 Chapter Summary

There has been an increasing demand for public services and infrastructure all over the world especially in developing countries. With the population increase in developing countries, the need for projects in various domains such as roads and wastewater projects is becoming inevitable. Nevertheless, with the current economic circumstances, the public sector is sometimes unable to deliver such services and projects efficiently and effectively; this is why the need for the private sector's capability and skills became essential. Consequently, PPP is used around the world and can be of special importance to developing countries as "catalyst for economic growth". The PPP model emerged as a way to bring the strengths of both the public and private sectors together. Nevertheless, due to the complexity and the long-term relationships involved in the PPP scheme, not all PPP projects that have been performed were successful. Consequently, proper risk management in PPP projects is of utmost importance to ensure the success of PPP projects. This doctoral study seeks to resolve the existing gap in knowledge in the context of the relationship between poor stakeholder management and the arising of additional risks to the PPP project affecting the PPP project's completion time and subsequently leading to additional costs especially in developing countries. The following chapters will explain in details how this aim is achieved by developing a mathematical approach modelling the expected total effect of risks associated with poor stakeholder management during the construction phase on PPP projects' schedule based on historical details of previous PPP projects in a comparative study with traditional construction projects using Artificial Neural Networks.

Chapter 2 – Literature Review

2.1 Chapter Introduction

Public Private partnership (PPP, also referred to as P3 or P^3) is described as a venture between the government from one side and one or more private companies from the other side in which responsibilities, risks and rewards are shared between the public and the private parties for the aim of delivering a clearly defined and agreed upon activity which is collectively needed such as public services. PPP is an output-oriented long-term relationship between the public and the private party (Marques 2012). Being focused on outputs rather than on inputs is a distinctive characteristic of a PPP project (Guidelines for Successful PPP Projects in Egypt 2013). “PPP is best described as an arrangement between the private and public sectors to deliver cost effective and high quality services to the public sector over an extended period of time” (Quick 2006, p.3).

Van Ham and Koppenjan (2001, p.598) define PPP as “a cooperation of some sort of durability between public and private sectors in which they jointly develop products and services and share risks, costs and resources which are connected with these products”.
Accordingly, PPP is characterized by the following:

- It is a long term relationship
- The major role of the Public partner is to define the end result, or in other words, the goals that need to be attained in terms of the public demand in addition to the type and quality of services. This means that the public partner plays the role of the policy maker.
- In general, the aim of such partnership is to transfer the major risks facing the public sector in the project’s implementation. However, this does not mean that the private party shall bear all the risks. A proper risk allocation technique shall be done in order to ensure each risk is borne by the party that is able to manage it (Abdel Wahab 2009).

Kumaraswamy *et al.* (2015) stated that despite the fact that PPPs have been defined in somewhat different ways, they all encompass the private sector playing roles that were traditionally played by the government in the provision of public infrastructure. According to Smith *et al.* (2018, p.103) PPPs are defined as “a cross-sectoral collaboration wherein the following features are present to different degrees: joint determination of goals, collaborative and consensus-based decision-making, nonhierarchical and horizontal structures and processes, trust-based and informal as well as formalized relationships, synergistic interactions among partners, and shared accountability for outcomes and results” (Birkerhoff and Birkerhoff 2011). According to Henjewele *et al.* (2013), the partnership between the public and private partner helps in providing supplementary capital, skills and motivation which can be of great benefit to developing countries to help them enhance their infrastructure. Chowdhury, Chen and Tiong (2011) points out that the reason countries adopt PPP differ: for some countries, PPP is a way to provide solutions to supply and demand gaps, fiscal deficit, budgetary pressure and inadequate infrastructure. On the other hand, other countries use PPP to benefit from the private sector’s innovative solution, experience and managerial skills.

2.2 Background of PPP projects

2.2.1 History and start

The idea of PPP is not recent. In fact, it was initiated before World War I when various projects such as: railways, roads, ports and power plants were undertaken by private entrepreneurs, who were willing to take risks in return for high rewards. El-Gohary *et al.* (2006) stated that the first PPP project in modern history was the construction and operation of the Suez Canal in 1854. Tang, *et al.,* (2009) specifies that the public sector in Europe has started collaborating with private companies for infrastructure projects since the 18th century. The most important contract where, in that time, the public sector entered into a partnership with the private sector was the supply of drinking water to Paris. Later in the 19th century, there were other projects that were implemented not only in Europe but also in the United States, China and Japan where infrastructure projects such as canals and railroads were undertaken. Moreover, the Suez Canal and the trans-Siberian railway were two huge projects where a collaboration between the public and the private sectors was implemented.

After World War I, the governments started financing different projects (especially infrastructure ones) out of general taxation (Abdel Wahab 2009). In the 1980s and the 1990s, neoliberalism and the funding requirements of capital projects for essential infrastructures made several countries choose the privatization which was a better option for energy and telecommunications projects while PPPs were preferred for the water sector and transportation projects (Marques 2010). According to Almarri and Abuhijleh (2017), engaging the private sector in projects in the United Kingdom was considered among the “Private Finance Initiative” (PFI) projects. Meanwhile, the first time the term “Private Public Partnership” or “PPP” was introduced and used was in the United Kingdom in 1997.

2.2.2 PPP structure among project procurement options

There is no standardized nomenclature used for describing the different PPP categories as each case has to be studied and understood separately. However, since the instruction of the nomenclature of PPP projects in the UK in 1997, four major forms of PPP appeared which are: Build-Operate- Transfer (BOT), Build-Own-Operate (BOO), Build-Own-Operate-Transfer (BOOT) and Design-Build-Finance-Operate (DBFO). BOT is considered as the most widely used method (Almarri & Abuhijleh 2017).

There is a scale for Public-Private Partnerships which is defined by the degree of the Private sector involvement which ranges from the Design Build (DB) where the private sector only designs and builds the project up to the privatization (Private Divestiture) by giving the private sector not only full control over the investment, operation and maintenance but also a permanent ownership of the facility's assets. In other words, PPP can fall somewhere between the full control of the public sector over a certain project and privatization. In the "Finance Only" model which is located at the start of PPP spectrum, the private partner provides financial services to the projects through lease payments which transfer the commercial risks to the private entity. This type of agreement can last for a period ranging from five to fifteen years. The involvement of the private entity can take place in another type of PPP called "Operation and Maintenance Contracts" (O & M) also known as "Operation and Management Contracts". In this type of contractual agreement, the ownership stays public while the private partner operates and maintains the facility for a short period of time (which can be extended though). This type of PPP is useful for communities with recent PPP history or for a private partner who wants a little risk exposure. Also, this type of agreement ensures a smooth transition from public ownership. Another type of PPP is called "Build-Finance" in which the private partner is responsible for building the project or facility as well as financing it during the construction period only (Canadian Council for Private-Public Partnerships 2009). In the lease or affermage contracts, the assets of the project are owned by the Public Partner who is also responsible for the investment costs. However, the end users (the consumers) in this case deal with the Private Partner and not with the Public Partner. In a lease contracts, a portion of the payments by the end users goes to the Public Sector as owner of the assets in the form of a lease fee and the remainder is given to the operator (The Private Partner). In this case, the Public Partner bears less risk as it is guaranteeing a fixed payment irrespective of the revenues. In the case of an affermage, the Private sector retains its fees and the additional fees (that are charged to customers) are paid to the Public sector. In this case, the Private Sector is the party that is guaranteeing receiving its fees (World Bank 2014).

When it comes to the categorization of PPP schemes, existing literature seems to conflate different categorization principles. For instance, according to the European Union, PPPs can be divided into two major types: *Contractual PPPs* and *Institutionalized PPPs.* The differences highlighted by the literature sources between both terms will be explained in this section.

Contractual PPP:

In the case of a "Contractual Public Private Partnership", the exact relationship between the private and the public partner as well as the rights and responsibilities of each party relative to the other are clearly specified in the contractual terms. One of the best models to describe this relationship is the "concession model" in which the private sector concessionaire is in direct contact with the final user (the customer) by undertaking the investment, constructing, operating and maintaining the service or the facility for a certain period of time, charging customers for such service and afterwards, the ownership goes back to the public partner. The concession contracts are characterized by being long term relationships (usually between 20 and 35 years or even longer) between the private and the public partner. They can be used in various sectors especially in water and transportation (such as highways). Design-Build-Finance-Operate (DBFO) or Design-Build-Finance-Maintain-Operate (DBFMO) is another type of PPP which is similar to the concession model except for the fact that in this type of PPP (DBFO) or (DBFMO), the project or facility recovers its costs not through charging the users for the service but mainly through public subvention. The DBFO and the DBFMO differ in the fact that in the latter, the private partner carries also the responsibility of the maintenance of the facility or project (Marques 2010). One of the most well-known forms of PPP is the "Build-Operate-Transfer" (BOT) system in which the private partner builds and operates the project or facility, transferring it to the public partner at the end of the contractual period. In this case, the ownership of the facility remains, during the whole contractual period, in the hands of the public sector. According to Ke *et al.* (2009), BOT system is considered as the most popular type of PPP used and adopted. However, the whole idea in this type of PPP consists in transferring the construction and operation risks to the private partner. The Private party in BOT projects is generally referred to as “the concessionaire”. In the Build-Own-Operate-Transfer (BOOT) form, the facility's ownership becomes also private during the whole contractual period. According to the Guidelines for Successful PPP Projects in Egypt published by the PPP Central unit, there are other versions of PPP such as Rehabilitate-Operate and Transfer (ROT) or the Build-Own-Operate (BOO). Each type of the aforementioned PPP types has its own strengths, weaknesses and risks which have to be individually taken into consideration for each project (Ke *et al.* 2009).

The major types of contractual PPP that the existing literature explored are summarized in table 3:

Table 3. **Summary of major types of contractual PPPs**

Name	Meaning	Role of private sector
DB	Design and Build	Designs and Builds
OM	Operation and Management Contracts	Operates and maintains the facility

Name	Meaning	Role of private sector
Concession		Undertakes the investment, constructs, operates and maintains the project
BOT	Build Operate Transfer	Builds, operates and transfers the project at the end of the contractual period.
BOOT	Build Own Operate Transfer	Builds, owns operates and transfers the project at the end of the contractual period.
DBFO	Design Build Finance Operate	Designs, builds, finances and operates the facility
DBFMO	Design Build Finance Maintain Operate	Designs, builds, finances, maintains and operates§ the facility
ROT	Rehabilitate, Operate and Transfer	Does the necessary repairs for the facility, operates and transfers.

There are various spectrums explaining the different kinds of PPP and explained in the literature and which all draw on the same concept. According to the Canadian Council for PPP (2009), Figure 9 depicts the categorization of PPPs based on the degree of the public and private sector involvement and based on the extent of risk allocation between different parties (Ke *et al.* 2009).

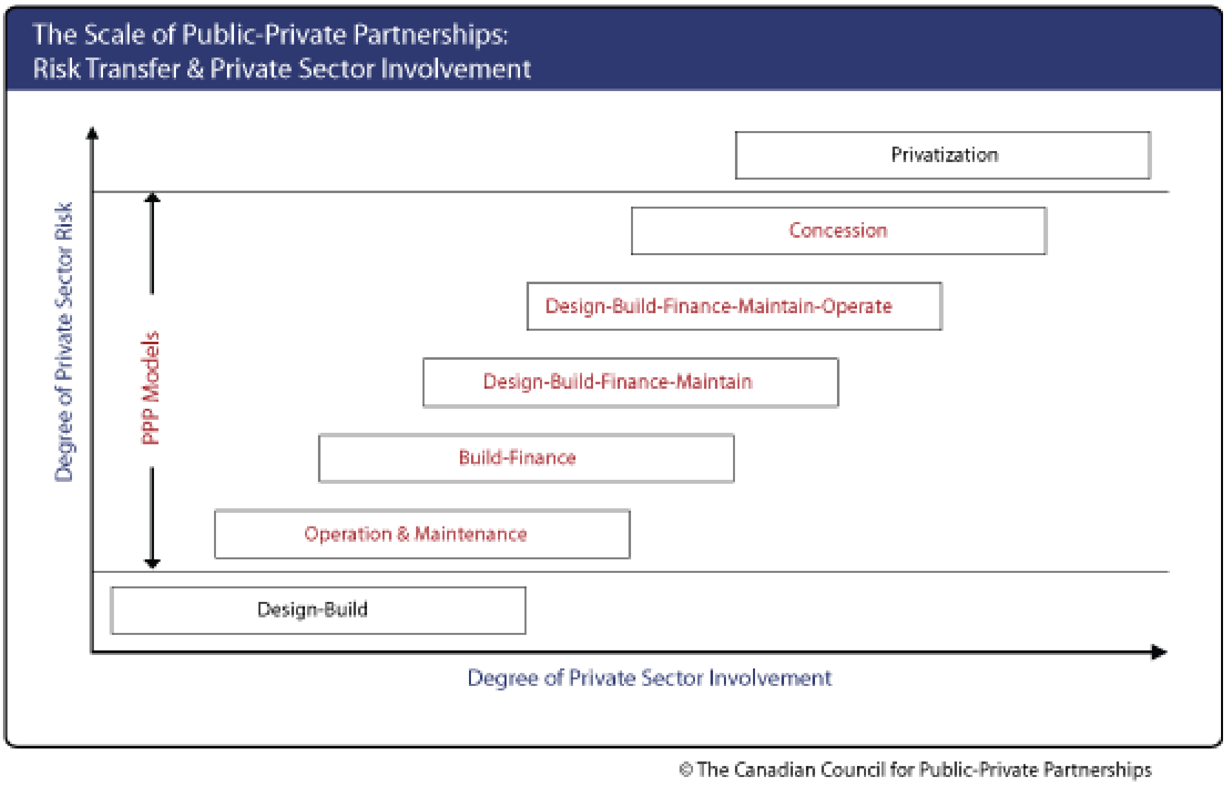


Figure 9. **The Scale of Public Private Partnership according to the PPP council (Canadian Council for PPP, 2009)**

Similarly, the World Bank (2011), offers a slightly different view of this spectrum, shown in figure 10, which captures the varying degree of private enterprise involvement in the different PPP arrangements. Both perspectives are just complementing sides of the same coin. The difference lies in the nomenclature of the PPP type.

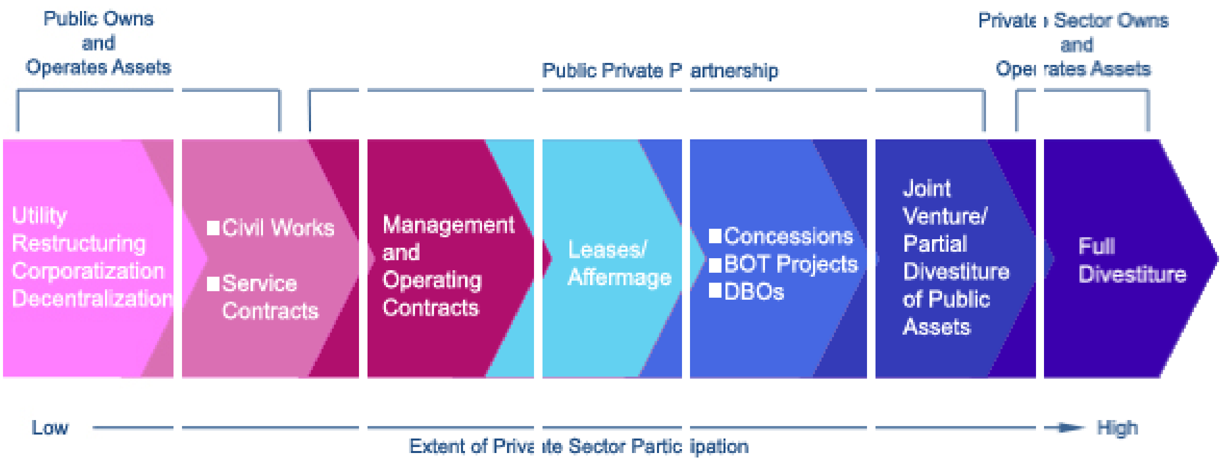


Figure 10. **The Scale of Public Private Partnership according to the World Bank (World Bank, 2011)**

The aforementioned perspectives are also in line to the one stated in the Guidelines for Successful PPP Projects in Egypt published by the PPP Central unit in 2013. Figure 11 describes the different degrees of private sector participation in projects ranging from the Works and Services Contracts up to the Concessions Contracts and finally the Privatization.

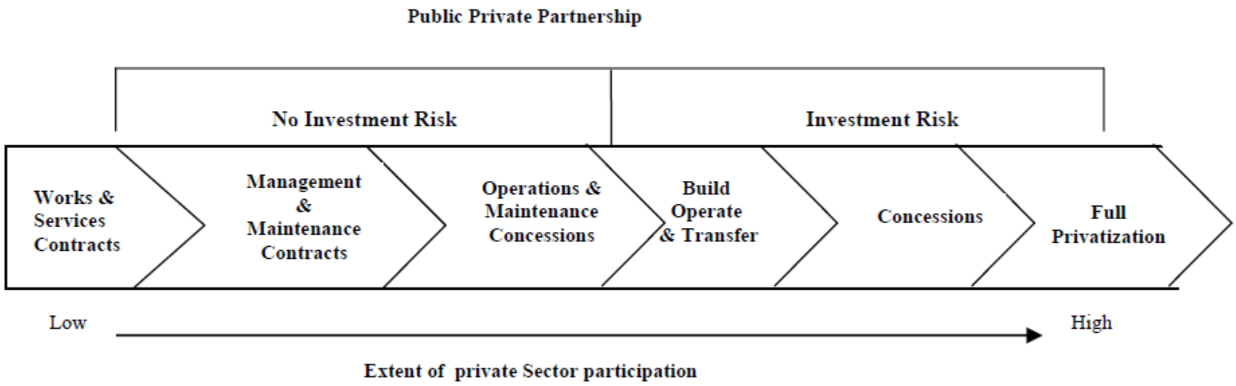


Figure 11. **Degree of Private Sector Participation in PPP projects according to the PPP Central Unit in Egypt (Guidelines for Successful PPP projects in Egypt)**

Institutionalized PPP:

Concerning "Institutionalized PPP", it means creating a joint entity or more precisely a third company formed by the public and the private sectors in order to ensure delivering the necessary benefit to the public. This can be achieved as well through selling a part of the assets of the public sector to the private sector. Usually, the third party or company that is designed to bear the risks is called a "Special Purpose Vehicle" (SPV). In this case, the public sector remains in control though remaining as a shareholder or through some special rights while the private sector is responsible for the technical management and operations. This type of relationships can be very beneficial as it gives the public sector the power and authority over the project while the public sector will benefit from the private sector's experience. In fact, Quick (2003) discussed the fact that the private sector is more suitable to directly provide the service to the end user in exchange for a fee in the case of economic infrastructure such as toll roads and concessions are the optimum solution in the cases where the private sector provides the service to the public sector in other projects such as hospitals, prisons, schools, courts and police stations.

Nevertheless, Marques and Berg (2011) tried to show a different facet to PPP projects by highlighting that problems and conflicts may arise between both the public and the private sectors which can have negative implications on the end customers through higher service rates. The relationship between the PPP project parties will be critically discussed in the next sections of the Literature Review.

This categorization of PPPs into "contractual" and "institutionalized" goes in tandem with the study done by Marques and Berg in 2011.

2.2.3 Stages of PPP

There are different ways to describe the stages that any PPP project goes through. Osborne and Murray (2000) identified five PPP stages which are: pre-contract, preliminary contact, negotiation, implementation and evaluation. On the other hand, Smith, *et al.,* (2018) proposed a more global identification for the stages that a PPP consists of. They defined four stages for any PPP project which are:

- Initial feasibility: During this stage, the public partner weighs the potential advantages and disadvantages for the project and does a study for the stakeholders. According to Keong *et al*. (1997), this step is crucial to determine the success or failure of any project. Nevertheless, and despite its importance, Ng, Wong and Wong (2012) argues that this step is usually not studied enough and not well covered in research conducted regarding PPP projects.
- Procurement: During this stage, the contractual negotiations between the private and public partner occur. Carrillo, *et al.,* (2008) argues that this stage is of utmost importance to the private partner as it shows the risks associated with unclear contractual requirements, financing, etc.
- Operation: This is the phase of the actual project execution where all the construction is undertaken (Smith *et al.* 2018).
- Conclusion: This is the phase where the PPP results are evaluated (Smith *et al*. 2018).

On the other hand, Li and Zou (2012) identified the stages of PPP differently into a more detailed classification; into six main stages as follows:

- Feasibility: This period is considered as the phase in which the project is studied. This stage is described in a similar way to its description in the study performed by Smith *et al.* (2018).
- Financing stage: which is equivalent (in Smith *et al*. study) to the procurement stage.
- Design stage
- Construction stage
- Operation stage
- Transfer stage

As it appears from the above classification, Li and Zou (2012) divided "the operation stage" (as named by Smith *et al.* (2018)) into three sub-stages: design, construction and operation. In light of the nature of PPP projects, the classification provided by Li and Zou (2012) provides a clearer understanding of the phases and stages of PPP projects especially that the operation period is a distinct characteristic in any PPP project.

2.2.4 The complex nature of PPP and building resilience

Chou and Pramudawardhani (2015) argues that the public private partnership is not just a normal collaboration between the public and private sectors as the PPP is a much more unique concept. In fact, a long time before Chou and Pramudawardhani's study was performed, Collin (1998) described PPP as bringing together two institutionally different milieus to operate in a single project organization. The resultant is a boundary zone where both the public and the private sectors' characteristics are still present and identifiable. In an earlier study, Starr (1988) provided an interesting observation explaining that the extreme challenge facing PPP project is the paradox between the concepts of "public" and "private". In his research, Starr (1988) points out that the goal of the public sector is to act for the general public being concerned about the community as a whole. This is exactly the opposite of the private sector's aims as the private sector is more concerned about the Value for Money, the profit and the market competitiveness. Chou and

Pramudawardhani (2015) draws on this concept by discussing the fact that in order to bring together those two different entities, the major aim of a PPP project is to "outsource" risks to the private partner in order to enable the public partner to perform its usual and normal duties which consist of planning, regulation and policy making. Kumaraswamy *et al.* (2015) discusses the fact that in PPPs the public partner (the government) does not just sign a contract with a private consortium as it may occur in conventional project. In a project under the PPP scheme, both the government and the private partner are expected to work closely as "partners". Such partnership is very significant as it usually goes beyond the "contractual partnership", or "structured relationship" which is already defined in the contract terms and conditions. Such relationship depends on the coexisting social and cultural norms that are less explicit and less visible. Consequently, in their research, Kumaraswamy *et al.* (2015, p.121) confirms that "this combined or dyadic relationship is more critical than "rule-based" relationship alone, because PPPs involve people working in long-term teams that include societal elements and deliver outputs aimed at meeting societal needs".

In their research roadmap for Public Private Partnerships, Akintoye and Kumaraswamy (2016) discusses a different side of PPP by arguing that PPP are not flawless solutions that ensure the success of any project. There are projects that were abandoned, renegotiated, taken over by governments, etc. as they became impossible to manage. This is due to the fact that PPP projects usually have greater scales, more sophisticated and complex nature and their duration is extended over a long-time span; increasing variables, unknowns and therefore risks. Moreover, according to Kumaraswamy *et al.* (2015), the large number of stakeholders involved in a PPP project causes it to be more complex than a conventional project. Kumaraswamy *et al.* (2015) provides a holistic assessment of the types of relationships in PPP projects by defining two types of relationships:

- 'Hard' relationships

This type of relationships is built on the contract, it can be also called the 'formal' relationships. The contract is the tool providing the framework defining each party's right, roles and responsibilities. Despite the fact that contracts can only provide solutions and remedies for foreseen problems, it can just provide processes for some of the unforeseen ones. Even a very well prepared and structured contract cannot contain all necessary safeguards for any problem or risk that may arise. Kumaraswamy *et al.*(2015) argues that even this 'hard' type of relationships is influenced by "socially embedded relationships, such as trust and commitment" which can appear for instance in 'grace periods' for completing tasks and/or making payments which can often go beyond deadlines based on only "trust and commitment" concepts.

- 'Soft' relationships

This type of relationships is built on social concepts such as trust, confidence, commitment, flexibility, solidarity, information exchange, etc. These 'informal' concepts "lubricate the cooperative arrangements for smoother operations" (Kumaraswamy *et al.* 2015, p.122). Soft relationships are crucial to establish during the PPP project's lifetime especially in order to solve any unforeseen problem that may arise because it will be impossible for the parties to revert back to the contract terms and conditions to rewrite/modify them each time a problem arises. Moreover, in light of the long life cycle of any PPP project (which can be ranging from 10 to 40 years), such relationships are very beneficial to the project as they facilitate the work towards the common goal of all parties which is the project's success. Henjewele *et al.* (2013) explored a different dimension related to the success of PPP projects, in light of their complex nature. They argue that the success of a PPP project depends on two important factors:

- Meeting the project's objectives
- Acceptance of the project by the general public.

The outcomes of both studies can be combined together to reach the conclusion that both good "hard" and "soft" relationships between the PPP project parties are beneficial to the project's success taking into consideration that the general public should be involved as an important project party. Healthy hard and soft relationship result in a better PPP project "resilience". Resilience of a project is a term that emerged from Kumaraswamy *et al.*'s (2015) study and which is defined as the capability of the project to sustain, bear and adapt to the complexity, risks and changes.

2.2.5 PPP around the world: Success and failure stories

2.2.5.1 Canada

PPP projects have been widely implemented in Canada. According to Akintoye and Kumaraswamy (2016), until 2016, more than one hundred PPP projects have been completed in different domains such as: healthcare, justice, transportation, wastewater treatment, energy and recreation facilities. Furthermore, another one hundred PPP projects are still under construction. It is worth mentioning that the government in Canada is keeping its central role for the infrastructure development based on the public needs.

2.2.5.2 The Americas

In the United Stated the BOT (Build, Operate and Transfer) method is the same as the BOOT (Build, Own, Operate and Transfer) method in Canada, Australia and New Zealand. In some cases, BOT projects have not witnessed success such as in Mexico where the Mexican government had to take over 23 BOT toll road projects as well as pay $5 billion in debt to the Mexican Banks and $2.6 billion to construction companies. The failure of PPP projects is accordingly caused by improper risk allocation whether to private or public partners as well as some supply and demand related problems. In the United States, in order to solve the demand problems, two major principles are applied. The Minimum Revenue Guarantee (MRG) is a way of support provided by the government in order to solve the problem that may arise for the private company if the revenues are less than anticipated. On the other hand, the Toll Revenue Cap (TRC) is applied if the demand is higher than anticipated. This principle consists in sharing the extra revenues between the private and public sectors (Ashuri *et al.* 2011). According to Akintoye and Kumaraswamy (2016), as of 2016, 33 states and one territory gave authorization to implement PPP projects. 29 states of the 33 have at least one PPP project implemented.

2.2.5.3 Oceania

2.2.5.3.1 Australia

According to Akintoye and Kumaraswamy (2016), the need for partnership between the public and private partners arose due to the increase in population and the lack of government funding to support such demographic increase. The involvement of the private sector in the public infrastructure projects has started particularly in New South Wales (NSW) and in Victoria especially in the provision of roads. Victoria witnessed the prosperity of the partnership between the public and the private sector. This was named “Partnerships Victoria”. Partnership Victoria was focusing on a main objective which is “Value for Money.” This term is generally used to describe a commitment established in order to ensure that the money spent brings the best possible results and outcomes. It is based on the philosophy of “Gain-share, pain-share” (Quick 2003). The Australian PPP market is characterized by the lack of standardization which is widespread in the various Australian states, a lack of international contractors, some unfair tendering processes and a common trend for risk transfer. Many experts think that Australia should improve its contract documents, its ethics as well as adopt better risk management in order to improve the application of PPP concepts (Quick 2003). According to the Australian Centre for Public Infrastructure, the PPP agreement is output focused. This is the basic difference between the PPP and the traditional procurement model. The government is rather focused on the end use of the project/facility rather than on the methods or techniques that are used to achieve this end use. This makes the government play the role of the regulator or more precisely “eyes-on/hands-off” (Quick 2006).

According to Quick (2006), typical project documents for PPP projects in Australia are:

- The Concession deed (or Project Agreement)
- Output specifications
- Construction Contract
- Operation and Maintenance agreement
- Financing documents.

Starting November 2003, the Victorian State Government promoted a “National PPP Ministerial Council” in order to provide better enhancement for PPP Projects as well as to develop a new national PPP market (Quick 2006). In 2005, PPP projects accounted for approximately eight percent of the total infrastructure projects executed in Australia (Ke *et al.* 2009). Akintoye and Kumaraswamy (2016) stated that by 2012, there has been 125 PPP projects completed under the PPP scheme with a total value exceeding $59 billion Australian Dollars. Furthermore, Akintoye and Kumaraswamy (2016) specified that the Australian government gained great skills of risk assessment and risk allocation.

2.2.5.4 Europe

2.2.5.4.1 European Union

According to General Regional Policy guidelines for successful Public Private Partnerships published by the European Commission Directorate in 2012, in Europe, recent years have witnessed a great increase of PPP projects. Chou and Pramudawardhani (2015) confirms that there has been 1,400 PPP projects in the European Union between 1990 and 2009 with a total value of €260 billion. The history of Member States countries of the European Union (EU) differs from one country to the other. The European Commission that is responsible for the regional policy has shown a great attention to the implementation of PPP projects. The continuous efforts and studies implemented by the European Commission in this domain helped in having a complete view about the strengths and weaknesses of the PPP projects. It has been found that successful PPPs require an effective legislative and control framework and each partner should recognize the objectives and the needs of the other party. There are major issues that have to be ensured when applying PPPs such as time impact, choosing the most suitable PPP type for the project, ensuring that the goals and objectives of the end user are realized, conforming to the regional regulations and avoiding monopoly. According to Hwang *et al.* (2012), the PPP scheme is applied to a great extent in the water sector with different forms. For instance, in France and Spain, the private sector is mainly responsible for the operation of the whole water system. In Holland and Belgium, the private sector is only partially responsible for the operation of the water system. In England and Wales, the private sector may own the assets while the public sector is the party responsible for the water provision (Hwang *et al.* 2012). In Belgium, for instance, PPP was not widely used in infrastructure projects until 2013. Based on the number and magnitude of PPP projects, the Flemish region has more PPP projects that the Walloon region and Brussels Capital region. This is due to the fact that a national PPP policy is not yet drafted in Belgium. In Italy, there exist several gaps in the existing literature related to PPPs. Moreover, the existing studies are not tackling the various aspects of PPPs which makes PPP projects less efficient in Italy. The same occurred in Switzerland due to the lack of a clear PPP law that regulates the relationships between parties (Akintoye and Kumaraswamy 2016).

2.2.5.4.2 Portugal

A comparison was established between the two major types of PPP (Contractual and Institutionalized) in the water sector in Portugal. The major outcome of this study was that proper risk allocation is a crucial tool that ensures the success of any project under the PPP scheme. In Portugal, the private participation in governmental projects started in 1993 through purely contractual PPPs. As the government wanted to have a proper regulation and supervision over the private companies entering into PPPs, a special institute was established for that purpose called "the IRAR" (Institute for the Regulation of Water and Waste) which was replaced afterwards by "the ERSAR" (Water and Waste Services Regulatory Authority) which aimed at supervising the service quality and which had a "nonbinding" opinion concerning all the tender documents. Until that time, PPPs were only of contractual type. Starting from 1998, PPPs started to take the institutionalized type as well by creating mixed companies between the public and the private sectors. The private partner is always chosen for both cases (whether contractual PPPs or institutionalized PPPs) through an open bid. However, it has been noticed that there has been problems associated with the implementation of PPPs in Portugal whether for contractual or institutionalized PPPs. For instance, statistics were developed in December 2009 mentioning that at that time, 25 of the 30 signed PPP contracts were concessions (contractual PPPs) while the rest were institutionalized PPPs with 60% of the PPP projects that were negotiated. According to Marques and Berg (2011), the main causes of such a problem is related to an improper risk allocation between the private and public sectors which proves the importance of a good application of risk allocations and risk study before the start of the project. This conclusion is similar to that reached by Akintoye and Kumaraswamy in 2016 when confirmed in their study that several PPP renegotiations took place in Portugal due to several reasons among them is the improper risk allocation. Furthermore, Akintoye and Kumaraswamy (2016) offered another conclusion in this regard by explaining that having too many PPP projects in a short period of time, with an obvious lack of preparation from the public sector's side for such collaboration in addition to not properly using the expertise of the private sector contributed to the problems that emerged with the use of PPP projects and which resulted in some cases, in a financial burden on the public sector instead of realizing the main goal of PPP which is “better value for money”.

2.2.5.4.3 Turkey

Ozeke (2009) provided a robust study on PPP projects in Turkey. In Turkey, the concession method was rarely used under the Concessions Law of 1910. However, the Concessions Law of 1910 provided only general guidelines but not detailed procedure. Concessions contracts are reviewed by the Council of State. In 1984, the first BOT law (Law No. 3096) was established. The amendments to the aforementioned law appeared in 1994, in law No. 3996 in a new law applicable in various sectors such as energy, transportation, communication and municipal services. In Turkey, the BOT system is now used for most of the infrastructure projects especially airports while the normal concession scheme is used to give the private party the right of operations of public properties such as ports. However, the PPP scheme in Turkey has shown some proofs of deficiencies due to the absence of any entity affiliated to the government whose role is to monitor and supervise the PPP projects in hand. Consequently, in 2009, a draft law was proposed which includes amendments and improvements to the previous laws and regulations such as the following:

- Defining PPP according to the law. Accordingly, PPP is a general term under which many definitions can be extracted such as BOT, BO, etc.
- The draft PPP law encloses a standardized format that can be followed by nearly all PPP projects.
- PPP can be used in any project type such as state hospitals, prisons, water and energy projects, transportation, etc.
- Risks should be properly allocated between the private and public partners according to one criterion: the partner that is better able to manage the risk will be the one who bears it (Ozeke, 2009).

The improvements and enhancements of the PPP scheme in Turkey continued. Akintoye and Kumaraswamy (2016) stated that the 10^{th} Development Plan announced by the Turkish government includes a roadmap for the PPP applications in the country.

2.2.5.4.4 United Kingdom

According to the literature, the United Kingdom takes the first place in performing studies about PPP projects in terms of the number of published papers. In fact, the published literature considers the United Kingdom as the founder country of the PPP concept. According to Ke *et al.* (2009), the countries that follow are the United States, Singapore, Hong Kong, Australia, China and Germany. According to Chou and Pramudawardhani (2015), the United Kingdom is considered as the most successful country in adopting PPP projects which amounted to approximately £10 billion from 1992 and until 1999. There is a term used in the UK called Private Finance Initiative (PFI) which is considered as one of the types of PPP. It is based on the fact that the public sector pays periodically (monthly or annually) the private sector provider for the supply of service or project delivered through an asset developed by or transferred to the private sector provider (Quick 2006) (Marques 2010). This type of partnership started for health projects (such as hospitals) and educational projects (such as schools) and is now used for other sectors such as transportation, water and wastewater treatment plants. This concept can be useful and effective in projects where costs are difficult to be paid such as projects in developing countries. This concept started to be widely used in the UK and was encouraged by the government in 1992. By 1997, PFI projects in the domains of transportation, health, defense, office accommodations, prison, education and water started to be delivered. In fact, 1997 is considered as the year when PPP projects were officially introduced in the English community (Ke *et al.* 2009). However, there was an obvious delay in the delivery of those projects. Since this date, various efforts have been undertaken to improve this concept in the UK through the Bates Committee who attempted to get the public sector more acquainted with PFI. In the year 2000, a major entity mainly owned by the private sector was established in order to further develop PFI concept by offering the public sector project management skills, by providing support to them and by providing initial capital for projects. New guidelines were established as well for whole life cycle service costing for PFI. In the period from 1999 to 2004, the standardization of the PFI scheme continued over 4 editions (SoPC1, 2, 3 and 4) until reaching the phase where all PFI schemes in the UK should be compliant with this standardized form of Contracts. This standardization aims at reducing the time and costs associated with various negotiations throughout the project as well as allowing for a proper risk allocation technique instead of allocating all the risks to the private sector (Quick 2006). According to the National Audit Office report that is assessing the performance of PFI construction projects in the United Kingdom and that was issued in 2009, PFI projects were on time 69% of the time and on budget 65% of the time till that year (Quick 2006). In 2005, PPP formed around 15 % of infrastructure projects performed in the United Kingdom (Ke *et al.* 2009). Chou and Pramudawardhani (2015) explained that the success of PPP projects in the United Kingdom is due to the proper allocation of risks between the parties involved in the projects.

2.2.5.5 Asia

2.2.5.5.1 China

There were several studies performed regarding PPP projects in China. According to the study done by Xu, *et al.,* (2010), the Chinese economy has been recently prospering and growing at a fast rate: between 2006 and 2010, 2,400 infrastructure projects were developed with a total budget of RMB (Renminbi, the Chinese currency) 470 billion. This wide expansion is to serve the huge population of the PRC (People's Republic of China) which is expected to jump from 536 million in 2005 to 827 million in 2025. This makes the government or the public sector in general look for the intervention of the private sector. The Bird's Nest (National Stadium) in Beijing and Beijing Metro Line 4 (BJL4) are two major examples of PPP projects in China. Nevertheless, Akintoye and Kumaraswamy (2016) argues that the legal, regulatory and institutional frameworks for PPPs are still immature.

In order to ensure the success of the adoption of the PPP principle in China, studies were established in order to determine the critical success factors (CSF) for PPP projects. CSFs are defined as the areas of activity in which favorable results are crucial for a manager in order to achieve his goals. According to the study done in 2010, 18 critical success factors were identified in China and they were grouped into five main factors which are:

- Stable macroeconomics environment
- Shared responsibility between the public and the private sector
- Transparent and efficient procurement
- Stable political and social environment
- Wise government control and supervision

However, it is important to note that these main factors can change from year to another based on the actual conditions in the country and based on the time at which the study was made (Chan *et al.* 2010). The proof is that in 2001, the major critical success factors for BOT projects in China were slightly different (Hwang *et al.* 2012). Nevertheless, both studies seem to complement each other. The major critical success factors defined in 2012 were:

- Appropriate Project Identification
- Stable Political and economic situation
- Attractive financial package
- Acceptable toll/tariff levels
- Reasonable risk allocation
- Selection of Suitable Subcontractors
- Management Control
- Technology transfer

Table 4 is developed to show a comparison between the critical success factors associated with PPP projects identified in 2001 and the ones identified in 2010 (approximately 10 years later) in China.

***Table 4*. Comparison between Critical Success Factors for PPP projects in 2001 and 2010 (2012, 2010)**

	2001	2010
	Appropriate Project Identification	Stable macroeconomics environment
	Stable Political and economic situation	Shared responsibility between the public and the private sector

Critical Success Factors for PPP projects in China	Attractive financial package	Transparent and efficient procurement
	Acceptable toll/tariff levels	Stable political and social environment
	Reasonable risk allocation	Shared responsibility between the public and the private sector
	Selection of Suitable Subcontractors	Wise government control and supervision
	Management Control	
	Technology Transfer	

Source: Hwang et al. and Xu et al.

According to the study performed by Xu *et al.* (2010) and which is aiming to develop a model that helps in calculating the risk level of PPP projects in China, it has been found that the top 10 risks affecting PPP projects are:

- Government Intervention
- Poor public decision making process
- Government corruption
- Financing risk
- Inadequate law and supervision system
- Public credit
- Subjective project evaluation method
- Interest rate fluctuation
- Conflicting or imperfect contract
- Change in Market demand

These risks were obtained through and extensive literature review and a two round Delphi survey to reduce the identified list using a consensus approach amongst respondents. Data analysis was then performed through statistical and analytical tools in order to rank those risks, identifying the ten most significant.

2.2.5.5.2 Singapore

The first PPP project in Singapore was in 2003 (Hwang *et al.* 2013). According to Gunawansa (2010), the Public Utilities Board (PUB) awarded the first PPP project which was a desalination plant. Starting from 2003 and for the next 3 to 5 years, the government awarded projects worth $1 billion to the private sector (Li 2006). The number of completed projects reached 10 projects which were successfully completed while only 3 projects were unsuccessful and not completed (Gunawansa 2010; Weaver 2010). According to Hwang *et al.* (2012), the ministry of Finance (MOF) in Singapore specified in its PPP handbook published in 2004 that the PPP scheme is suitable for several sectors such as water and sewage, sports facilities, education, healthcare, roads and government buildings.

Hwang *et al.* (2012) also points out that despite the various efforts done to enhance PPP projects in Singapore, only little effort was deployed to study risk allocation.

2.2.5.5.3 India

According to Lyer and Sagheer (2010), the necessary financing for infrastructure projects in India for the next five years is approximately $ 448 billion in the water, ports, roads and airports projects. However, this cannot be achieved in India without the intervention of the private sector. Public Private Partnership is considered as a solution to enhance and improve India's infrastructure. One of the best models and examples for Public Private Partnerships comes within the Sustainable Cities Programme (SCP) which is supported by the United Nations Development Programme (UNDP) started in 1990. The main objective of the SCP is to provide an improved and enhanced environment for management and planning. The Indian City of Chennai joined the SCP in 1995. Accordingly, in order to implement such program which aims to improve the environmental and managerial conditions in the city, the private partner's participation along with the government is important and crucial and hence the "Private-Public Partnerships" (Sarangi 2002). According to Akintoye and Kumaraswamy (2016), despite the need for PPP projects and despite the fact that PPP projects started to be widely implemented in various sectors such as power, airports and infrastructure, there has been a recent "slowdown" in PPP projects. According to the study performed by Lyer and Sagheer (2010) which was conducted through and extensive literature review, interviews and case studies, the major risks affecting BOT projects in India are:

- Pre-investment risks: The project may be prone to cancellation or inadequate bid preparation.
- Delay in financial closure: The private party may not have enough financial ability to execute the project.
- Resettlement and rehabilitation operations: These may be necessary for habitants due to the new project, such as in the case of road projects requiring the displacement of habitants to allow the work to take place.
- Delay in land acquisition: This may be due to political opposition or delays in permits.
- Permit/approval risks: This may be due to the government corruption, poor documentation or poor coordination among the public sector parties.
- Technology risks: Sometimes, the technology adopted may not be beneficial or suitable for the project.
- Design and Latent Defect Risk: These risks may occur due to poor geological studies or deficiency in design.
- Cost Overrun risks: This risk occurs when the project cannot be completed within the specified budget. This can be due to a certain party's fault or may be due to reasons beyond the party's control such as inflation or interest rate fluctuation.
- Schedule risk: This risk occurs if the project cannot be completed within the expected time.
- Direct political risks: This may be due to changes in law, nationalization or problems in getting the necessary approvals for the project.

2.2.5.5.4 Taiwan

According to the New Institutional Economics (NIE) theory, a national PPP unit can be considered "an outcome of a game" (Tserng, *et al.* 2012). A national PPP unit is a large unit including several governments which is responsible for regulations and advice for PPP projects such as Treasury PPP Taskforce/ Partnerships UK, PFI Promotion Office in Japan, the National PPP taskforce on Taiwan and the Public and Private Infrastructure Investment Management Center in Korea. Taiwan has an abundant experience in PPPs. Of the 39 departments of the Taiwan government, only the Ministry of Transportation and Communications implements an average of

10 or more PPP projects annually (Tserng, *et al.* 2012). One of the largest PPP projects in the world is located in Taiwan, which is "Taiwan High Speed Rail Bank of Taiwan Project" (Tserng *et al.* 2012). PPP in Taiwan represent around 12.7 % of the annual investment of Taiwan in the domain of infrastructure. Table 5 provides a summary for the annual percentage of PPP in various countries with respect to the total number of projects in the country, according to 2011's statistics:

Table 5. **Annual PPP project percentage in different countries**

Country	PPP Contribution
United Kingdom	10-15 %
Australia	5-20 % (average 10 %)
Korea	5-14 %
Taiwan	12.7 %

Source: Tserng. et al. 2012

According to Tserng *et al.* (2012), the key to successful PPP projects is Government credibility at the public opinion. Therefore, the National PPP taskforce in Taiwan helps in enhancing and increasing the trust and credibility between the private and public sectors.

2.2.5.6 Middle East

2.2.5.6.1 Kuwait

Kuwait is rapidly moving to the increase of PPP projects on its land. The number of potential Public-Private Partnerships (PPPs) projects in Kuwait is probably the most significant in the Middle East with over $25 billion worth of projects whether under study or already started (2nd Annual PPP Investment Summit in Kuwait, 2009). In its attempts to improve the PPP scheme in Kuwait, the Kuwaiti Government has established a PPP project guidebook in addition to Law No. 7/2008 which established the basis for the application of infrastructure PPP Projects in Kuwait. According to the guidelines published by the State of Kuwait, the PPP law limits the PPP contract to 30 years. It can be however extended to a period that can reach 40 years. However, when no specific period is stated in the contract, it is deemed to be assumed as 25 years. A Project exceeding KD 60 million must be carried out by a PPP Project company that will be a special-purpose vehicle formed as a Kuwaiti

Joint Stock Company (Kuwait PPP projects: Project Guidebook 2009). The evaluation and supervision of PPP projects in Kuwait takes place in the Partnership Technical Bureau (PTB). The PTB helps in providing standardized PPP contracts, increase and enhance the credibility for the PPP market.

2.2.5.6.2 United Arab Emirates

The concept of PPP has been relatively recent for the United Arab Emirates especially that it was more common for the Emirati government to be responsible for the procurement for any project without much depending on a private partner. The studies related to PPP projects in United Arab Emirates are still incomplete. Actually, there are around 10 PPP projects all over the country which proves that PPP in the United Arab Emirates is still at its first stages of implementation. Therefore, political support is necessary in order to encourage the private partners to invest in the country. Also, it is crucial to get the end customer more knowledgeable about the PPP concept so that it can gain more credibility (Dulaimi *et al.* 2010).

2.2.5.6.3 Egypt

In Egypt, in an attempt towards economic reform, the involvement of the private sector with the government has increased. A legal framework for PPP projects in Egypt has been issued called the PPP Law (67 for the year 2010) in addition to the establishment of standard PPP Contracts, procurement documents as well standardized procedures. In addition to that, a new body has been established at the Ministry of finance called the PPP Central Unit. The PPP Law in Egypt is *"Law No. 67 for Partnerships with the Private Sector in Infrastructure Projects and Public Utilities."* It was approved by the Parliament in May 2010. It is divided into 4 chapters as follows (and 39 articles):

- Chapter 1: General Provisions
- Chapter 2: The Supreme Committee for Public Private Partnership Affairs and the PPP Central Unit
- Chapter 3: Tendering and Awarding Procedures
- Chapter 4: Substantive Provisions of the PPP Contract

This law aims at unifying and standardizing the PPP scheme in the various projects as the PPP scheme is characterized by uniqueness. According to the PPP Central Unit website, The PPP Central Unit is a unit that has been established by the Ministry of finance since June 2006 in order to supervise and assure the proper implementation of PPP projects in Egypt. The PPP Central unit seeks the help and advice of international experts in order to enhance the success of PPP Projects in Egypt through the following:

- Establishing standard contracts for PPP as well as proper guidelines and methodology,
- Coordinating the PPP program across Line Ministries, private sector and funding market,
- Providing technical supervision over PPP projects,
- Studying potential projects where PPP can be a better option ("PPP'able Projects"),
- Studying tender documents,
- Ensuring the application of proper risk allocation between the public and private sector,
- Benefiting from the previous experience of other countries in the domain of PPP,
- Acting as the "Public Face" for PPP in Egypt who is responsible for spreading news,
- Issuing a quarterly PPP booklet to all stakeholders,
- Hosting a yearly PPP summit called "MENA Region PPP summit",
- Providing sessions, trainings and workshops for both the private and public sector in order to get them more acquainted with PPP projects.

The first PPP project that took place in Egypt was "New Cairo Waste Water Treatment Plant". The PPP was an "Institutionalized PPP" in which the private sector's duties was to design, finance, construct, operate, maintain and transfer the waste water treatment plant whose capacity is 250,000 m^3/day (Tarek 2011).

The PPP's duration for this project is 20 years at the end of which the private partner should transfer the plant in good operational condition as mentioned in the Contract. The Public entities in this project were:

- The Ministry of Housing (MHUUD),
- The Ministry of Investment (MoI) and
- The Ministry of Finance (MoF) and more specifically the PPP Central Unit.

The main consultant for the PPP Central unit was the International Finance Corporation (IFC). The IFC is considered as "the private sector arm of the World Bank group." (Valente 2010). Since 2006, IFC in Egypt has been giving advisory services to the ministry of Finance in order to enhance the application of PPP aiming to improve the PPP at the country (IFC 2013). While the World Bank "provides support to governments on developing the enabling environment for PPPs and sector reform, through technical assistance and as part of broader sector support facilities or facilities to support the development of PPPs. The World Bank Group also supports a number of knowledge management tools and collaborates on initiatives to support governments" (World Bank 2013). The private partner was a joint venture between Orascom and Aqualia, a Spanish water company named "Orasqualia". The total value of Orasqualia's bid was $ 490 million. This joint venture is the one who won the bid face to other 6 bidders including Veolia, Befasa, Metito and Kharafi. In June 2009, the contract was signed. The Contract was signed between the New Urban Communities Authority (NUCA) and Orasqualia referred to as the Service Provider. NUCA is responsible for planning and developing new water and wastewater communities in Egypt (Osgood 2009). The main regulator of the project is the Water Sector Regulator (EWRA) which is responsible for supervising, reviewing and monitoring all activities related to the water and wastewater sectors (Osgood 2009). The project ended in 2012 with total project duration of 2 years (Draz 2012). Under the PPP scheme for water and wastewater projects in Egypt, the service provider (the investor or the developer) who is in this case Orasqualia will be periodically paid as soon as the plant enters in to the operation phase (Osgood 2012). New Cairo Wastewater Treatment Plant won the title of the "Water Deal of the Year" in 2009 which is a prize given by the Global Water Intelligence (GWI) (Tarek 2011). Figure 12 shows the project's structure:

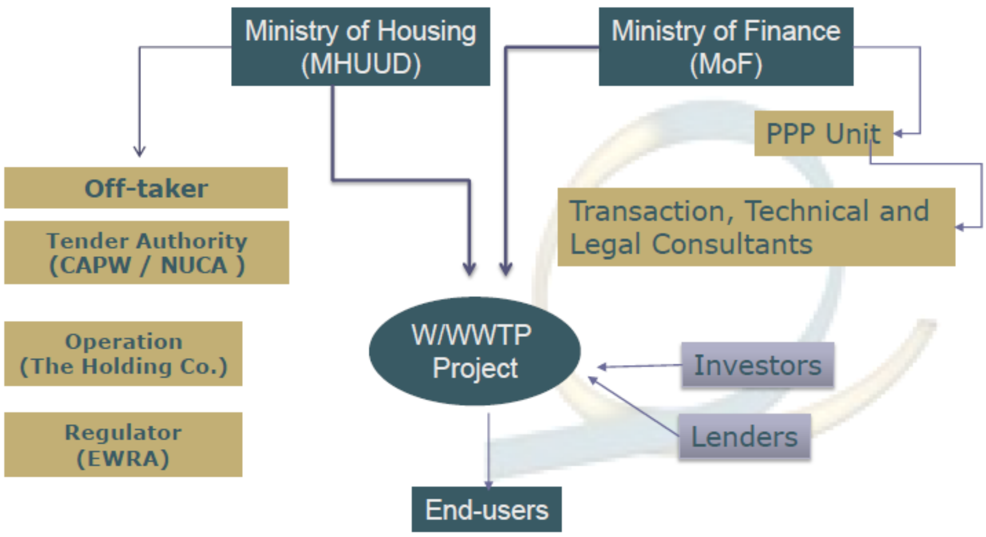


Figure 12. **Key Stakeholders in Water and Wastewater Projects**

2.2.5.7 Africa

In developing countries, the public sector is not the major responsible for development anymore. On the other hand, the private sector started to play an important role by taking part in the delivery of a public service, project or facility (Dansereau 2005). In Nigeria for instance, there has been an increase in the projects executed under PPP scheme especially when it comes to infrastructure projects. In order for Nigeria to improve its infrastructure to meet the standards, the country needs from $12 to $15 Billion annually, thus, the role of the private sector became crucial in such developing countries. According to a study done for the projects that are most suitable for PPP application in developing countries and especially Nigeria, it has been found that PPP scheme can applied in approximately all the project types whether water and wastewater, power and electricity, transportation, educational and real estate. The study's output was also to determine the critical success factors (CSFs) in order to ensure the success of PPP projects which were as follows:

- Competitive procurement
- Realistic assessment for costs and benefits
- Favorable framework
- Proper risk allocation
- Government intervention and guarantees
- Political support

- Stable economic conditions
- Sound economic policy
- Availability of suitable financial market

The above critical success factors should be studied with utmost care in order to endure the success of PPP projects (Babatunde 2012).

2.2.6 Advantages and criticism of PPP

Kwak *et al.* (2009) argue that the partnership between the Public and the Private entities can have several benefits especially to the government. The major benefit is to bring "value for money" by benefiting from the private sector's quality and experience. The Private partner will bear several risks that the government cannot bear such as the construction, financial and operation risks (Carbonara, *et al.,* 2014). Badala, *et al.,* (2018) provided support for the research conducted by Carbonara *et al.* (2014) and Kwak *et al.* (2009) by stating that the PPP scheme has several benefits and that the major benefit is bringing cost savings to the project. According to a research performed by Reuters in 2013, further explanation to the term "cost savings" was provided: in the case of PPP projects, the public sector usually signs a single contract with the private sector involving design, construction, operation and/or maintenance which eliminates the additional costs associated with entering into and signing a series of separate contracts with various contractors for each of the project phases. Reuters (2013) added an interesting observation: in the case of PPP projects, the fact that the PPP contractor will be responsible for the O&M during the entire concession period will make the PPP contractor focus during the design and construction phases on ways to reduce O&M costs afterwards. The integration of design, construction and operation will have a positive impact on the whole lifecycle cost of the project. Furthermore, Badala *et al.* (2018) argues that "project acceleration" is another main benefit of the PPP model as the private partner has the ability to deliver the project faster than the typical public owner. Reuters (2013) point out that bundling the design and construction process into a single contract will help decrease the duration of the project compared to the classic Design-Bid-Build project delivery method. Also, the high level of involvement of the private sector in PPP projects results in a higher quality project in terms of design and construction.

Nevertheless, Grimsey and Levis (2002) brought a rebuttal to this perspective by pointing out that despite the advantages that PPP projects can present, this scheme has some “drawbacks”. Such downsides arise from the complexities in planning, documentation, taxation, control, performance, “politics and policies”. According to Heravi and Hajihosseini (2011), such complexities cause risks to arise and to be associated with PPP projects. Reuters (2013) argues that in PPP projects, more risks are transferred to the PPP contractor than in the case of conventional Design-Bid-Build projects. This can be beneficial to the public sector as it transfers many (or sometimes all) project risks to the PPP contractor while remaining in control over the project.

2.3 Managing risks associated with PPP projects

According to Hodge and Greve (2007) and Kwak, Chih and Ibbs (2009), Public Private Partnership became a major scheme especially for infrastructure projects due to the several benefits such partnerships can bring to the governments. Nevertheless, Carbonara *et al.* (2014) argues that in order to gain all the benefits that could emerge of the partnership between the Public and the Private partners, several critical aspects should be managed and taken into consideration such as:

- The identification of risks associated with PPP projects
- The determination of the proper risk allocation for the identified risks
- Establishing a good financial plan
- A careful selection of the Private partner
- The presence of an optimum concession period

Hwang *et al.* (2012) points out that due to their complex nature, PPP projects include risks that are difficult to control and to analyze. Ke *et al.* (2009) reached the same conclusion by stating that risks in PPP projects are difficult to deal with which requires a proper management technique for risks.

2.3.1 Risk Management for PPP projects

ISO 2009 defines a risk as “The effect of uncertainty on objectives”. This means that risk is an uncertain event that can affect the project’s objectives or outcomes if it occurs. Risks can affect three major aspects of any project which are cost, time and quality. Because of the long term nature of PPP projects, which can range from 20 to 40 years or even sometimes exceeds this period, and because PPP projects are based on expected and pre-specified assumptions, sometimes, these expectations and forecasts lack accuracy to a great extent as it may be difficult to make accurate predictions for 10 years especially in unstable economic, technological and political conditions as well supply and demand forecasts (Cruz and Marques 2013).

According to Akintoye and Kumaraswamy (2016), there are seven main questions related to the use of PPP that have to be taken into account:

- Is having several PPP projects simultaneously in a short period of time a good solution?
- Does the government have the capability and skills to monitor the PPP project in light of its complex nature?
- Is the tender process sufficiently managed and regulated?
- Is PPP really the best and optimum solution for the project?
- Does the PPP contract contain proper financial assumptions?
- Is the risk identification and allocation clearly determined?
- Why, in several previous PPP projects, there has been a renegotiation of the contract terms and conditions leading to increased financial burdens on the public sector?

Hwang *et al.* (2012) argues that the long-term nature and the complexity of relationships between parties in PPP make “risks” an important and crucial factor to be studied and analyzed. A good and sound risk management can make the PPP project reach its objectives. When the Traditional procurement method is used, risks do not disappear, but they are simply passed to the end customer and taxpayers. Figure 13 provides an illustration showing the difference in principle between the traditional procurement model and the PPP model. When using the traditional model for delivering the project, the base cost is higher, in addition to the presence of a cost assigned for the inefficiency risk which is mainly due to the lack of experience of the government in certain areas such as construction and technology. However, in the case of project executed under the PPP scheme, along with a sound risk allocation between the private and public sectors, the base cost is reduced thanks to the PPP incentives. In spite of adding a risk premium to account for the different risks affecting the project in addition to the financing cost, the net result is that the total cost is less in the case of PPP projects than in the case of traditional project without passing the risks and the extra cost to the end user. Also, in general and in most of the projects executed under the PPP scheme, the payment to the private sector occurs when the project starts operating. This payment can be by the government (the public sector) or by end users. This is an incentive for the private partner to complete the project on time and within budget (Marques and Berg 2011)

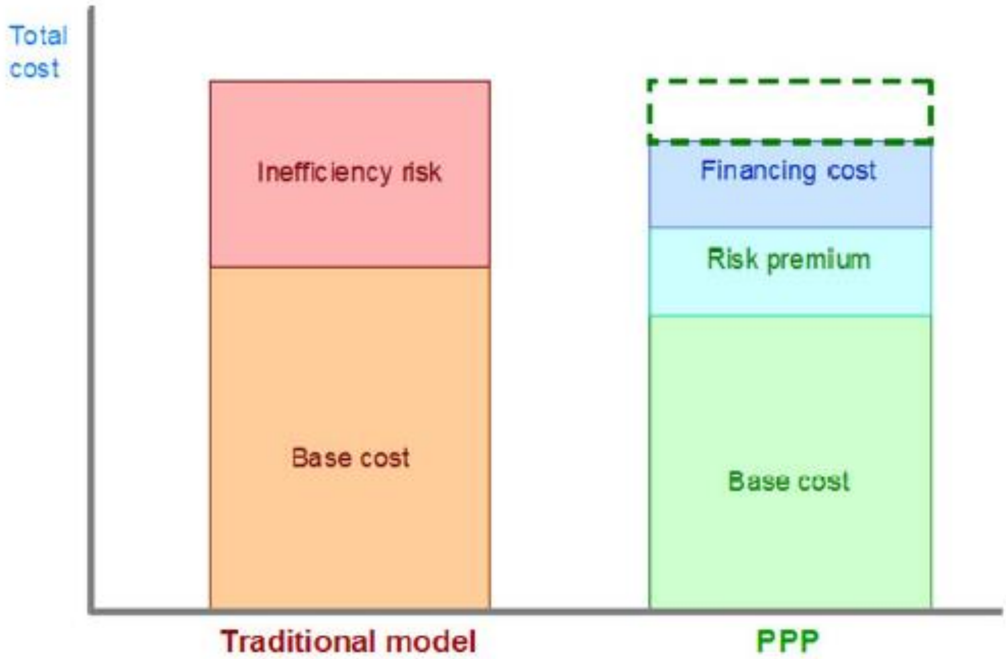


Figure 13. **Comparison between PPP projects and traditional projects in terms of cost (Marques and Berg 2011)**

However, there is a point of view mentioning that not all risks are harmful since they can carry opportunities as much as threats in some cases (Marques and Berg 2011). There are several risks that can affect PPP projects, especially infrastructure projects which are: technical, construction, operations, revenue, financial, resources, production, force majeure, political, regulatory, environmental, commercial and unforeseen risks (Marques and Berg 2011).

According to the Guidelines for Successful PPP Projects in Egypt published by the PPP Central unit, the most common risks affecting PPP projects are:

- Timing and Planning
- Unforeseen geotechnical conditions
- Technical design issues
- Operation Cost Overrun
- Time overruns during construction
- Supply and demand
- Operational service costs
- Inflation
- Change of legislation
- Insurance
- Technological risks

According to Marques and Berg (2011), the major risks affecting infrastructure projects executed under PPP scheme are:

- Technical risks
- Construction risks
- Operating risks
- Revenue risks
- Financial risks
- Force Majeure
- Regulatory/political risks
- Environmental risks
- Project default risks

2.3.1.1 Effects of risks on the project's time and cost performance

According to Hampton, Baldwin and Holt (2012, p.73), "delays are inherent throughout the construction process and can affect either a single activity in isolation or become the catalyst for delay of a group of activities" and subsequently the whole project.

Doloi (2012) argues that in order to evaluate the overall success of a construction project in light of the risks facing it, the following performances are the most important to observe:

- Time performance
- Cost performance
- Operation performance

Assaf and Al-Hejji (2006) points out that time and cost are different facets for the same issue and they provided evidence to support such supposition. They concluded that delay factors will ultimately have a financial impact on both the client and the contractor. This conclusion is similar to that reached by Trauner (1990) who explained the effect of the project's delays on the major project's parties. When the client is delayed in starting using the constructed facility, revenue is also delayed in being generated from it. On the other hand, in case of a project's delay, the contractor is exposed to the risk of Liquidated Damages (LDs). Furthermore, the contractor may be obliged to incur additional inflation costs while continuing to work on site after the original completion date of the project. Accordingly, in the absence of a proper risk management technique, each party can start blaming the other for delays in an attempt to alleviate its responsibility towards delays and associated costs. Chappell, *et al.,* (2006) argues that if the cause of delay is simultaneously due to different parties, it is often difficult to assign such delay in terms of responsibility and associated cost. Accordingly, analyzing the impact of risks on the project's schedule is a crucial step in order towards a proper risk management.

2.3.2 Importance of risk allocation

The topic of risk allocation in PPP projects was discussed in several studies conducted in the literature. Existing literature seems to complement each other in this issue. A proper risk allocation is beneficial as it can decrease economic costs to both parties (the private and the public sector) (Marques and Berg 2011). Furthermore, Alireza, *et al.,* (2013) points out that efficient risk allocation play a crucial role in reducing the disputes during the concession period.

The results of a survey conducted in 2006 by the Construction Industry Institute (CII) show that inappropriate risk allocation causes at least a 3% contingency in bids (CII 2006). Furthermore, Zaghloul and Hartman (2003) point out that using disclaimer clauses to allocate risks adds a premium of between 8% and 20% to construction project bids. Accordingly, improper allocation of risks will cause both parties to incur additional costs (Jin and Zhang 2011). Valipour *et al.* (2016) confirms that inadequate risk allocation can severely harm the PPP project. According to Kumaraswamy (1997), most of the claims and disputes occurring in the construction industry are caused by improper allocation of risks. Moreover, allocating the risk to the wrong party can cause the contractors to add a high contingency (risk premium) to their bids or can cause the contractors to sometimes delivery low quality of work (Khazaeni, *et al.,* 2012b, Lam, *et al.,* 2007).

Therefore, for each project, choosing the proper risk allocation will assist both parties to make more strategic decisions (Valipour *et al.* 2016). This will help in expecting the financial and economic consequences of these potential risks. On the other hand, Marques and Berg (2011) provided an interesting observation: according to their study, it should be noted that there is an optimal level of risk transfer beyond which, the desired Value for Money cannot be achieved for a specific project. This is because allocating more risks to the private partner may increase the project costs. The optimum level of the of risk transfer is illustrated in figure 14.

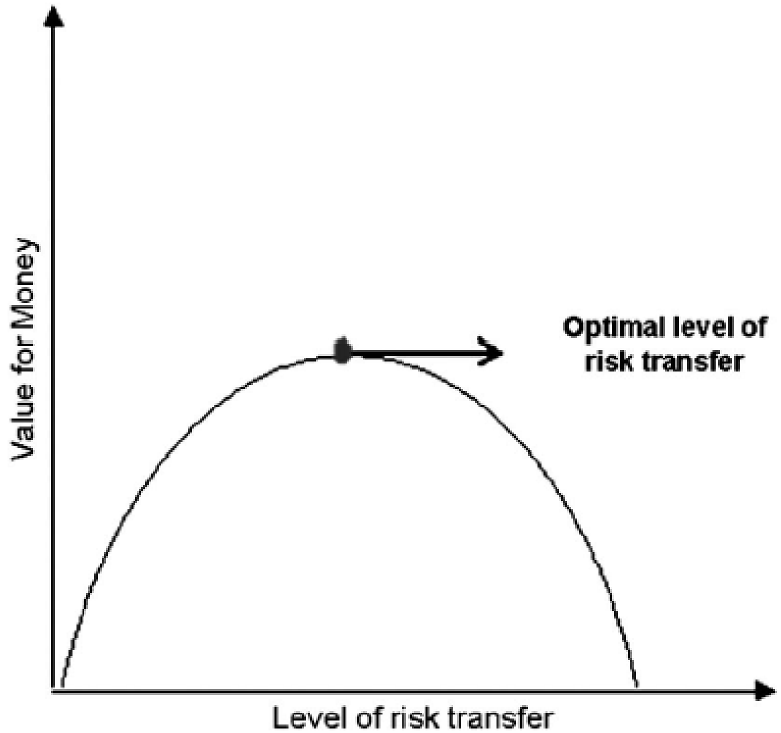


Figure 14. **Optimum Level of Risk transfer to ensure realizing the Value for Money (Marques and Berg, 2011)**

The most well-known and efficient concept for risk allocation is known as the "Abrahamson" principle which is based on allocating the risk to the party who will be best in managing this risk. There are criteria that make the party eligible for bearing the risk which are:

- Having a risk that is within the party's control and which can be dealt with efficiently.
- Having a risk that can be mitigated or transferred through different ways such as insurance or service premiums.
- Having a risk that gives the party bearing it an economical benefit (Quick 2003)

Therefore, the party who will be better in managing the risk means the party who can handle this risk at "the least cost*"* (Hwang *et al.* 2012). In other words, if the public sector is able to bear a certain risk; then it should not be transferred to the private sector as doing that may increase the project's costs. For instance, allocating customers related risks (e.g. supply and demand risks) to the private partner put its assets at the stake. On the other hand, the public sector (the government) can be better in knowing the consumption forecasts and accordingly can be more appropriate to bear such risk. Also, in order to conduct a proper allocation of risks, some known rules can be applied. For instance, it is believed that the environmental, political and regulatory risks should be borne by the public sector. On the other hand, production risks, construction risks, supply and demand risks should be borne by the private sector. Some risks, such as operation, maintenance and design depend on the project conditions and circumstances. Some risks are controversial such as Force Majeure. Figure 15 shows a typical risk allocation matrix for general risks affecting PPP projects developed by Marques and Berg (2011) in their study.

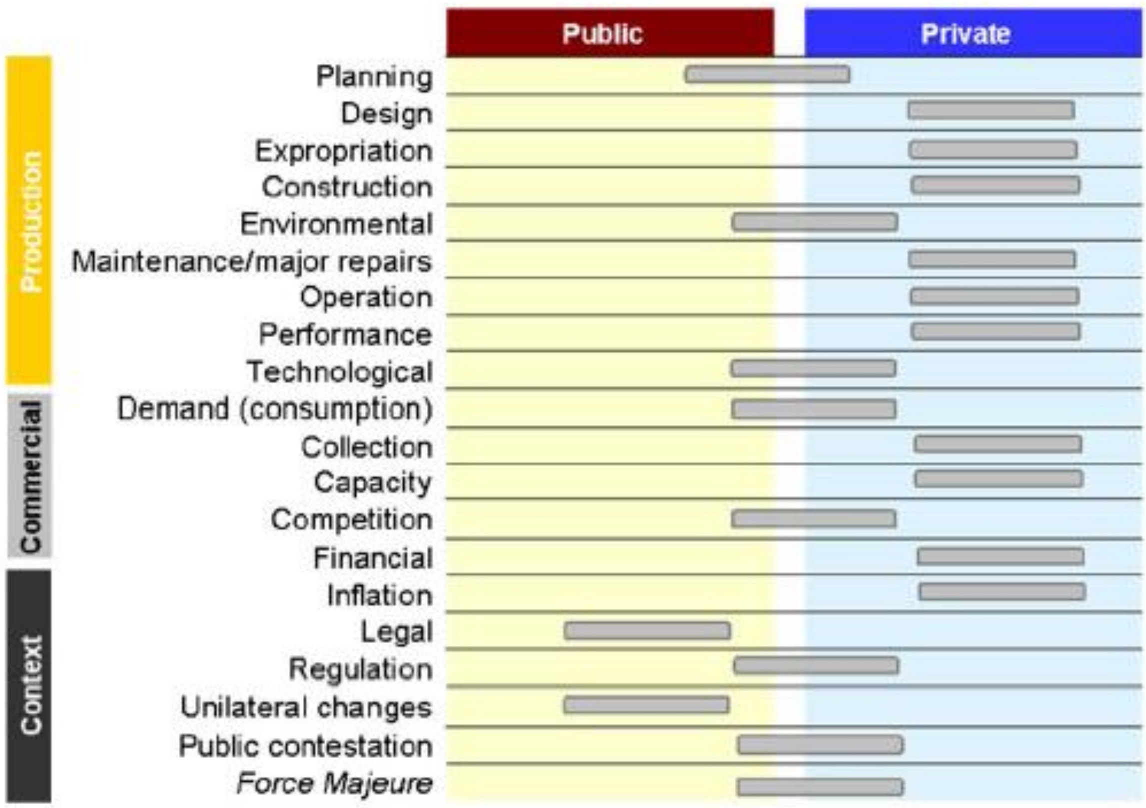


Figure 15. **Risk Allocation Matrix for PPP projects (Marques and Berg 2011)**

2.3.3 How to conduct a proper risk management for PPP projects

Marques and Berg (2011) proposed a useful methodology that ensures a proper risk analysis and evaluation which is illustrated in figure 16.

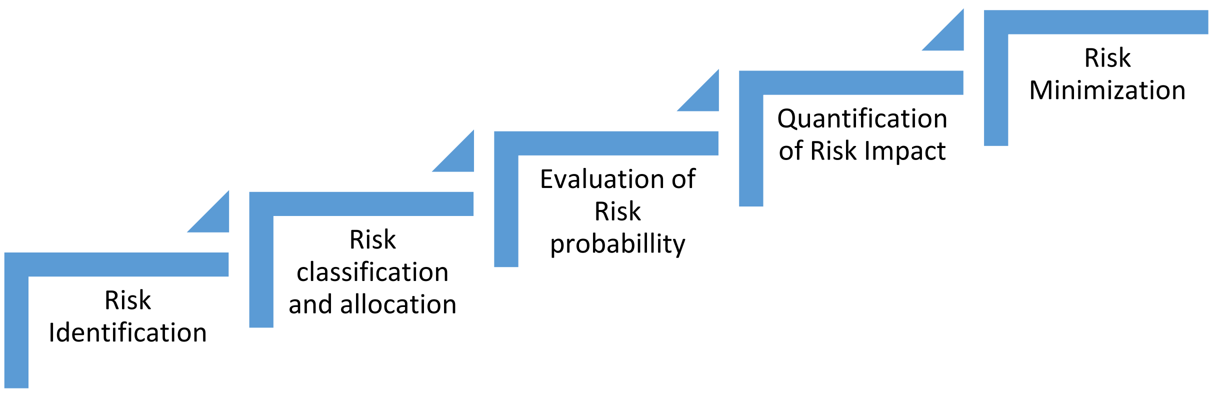


Figure 16. **Proper Risk Analysis Methodology**

This methodology starts by the step of the risk identification which is an essential step for the project and which should started as early as possible in the project's lifetime (Hwang *et al.* 2012).

In order to start a proper and effective risk management, first the risks that can affect a certain project have to be specified. Then the risks should be properly classified. There are various classifications of risks; for instance, one of the possible classifications is dividing the risks as follows (Marques and Berg 2011)

- Macro Level Risks: the Risks that are beyond the project's boundaries and however, have the power to affect the whole project,
- Meso Level Risks: the risks that occur within the project,
- Micro Level Risks: the risks that occur within the project parties in the project.
- In a previous study, Li, Akintoye and Edwards (2005) adopted a similar three-level way of classifying risks as follows:
- Macro-level risks: having effects beyond the project's limits
- Meso level risks: having effects within the project's limits
- Micro level risks: associated with the stakeholder relationships
- Another risk classification is dividing the risks into:
- Global Risks (General Risks): external risks affecting the project such as legal, political commercial and environmental risks
- Elemental Risks (Project Risks): risks within the project such as construction, operation, project default and revenue risks.

Figure 17 shows another way to classify risks associated with PPP projects by dividing the risks into three major categories: Production risks, commercial risks and context risks.

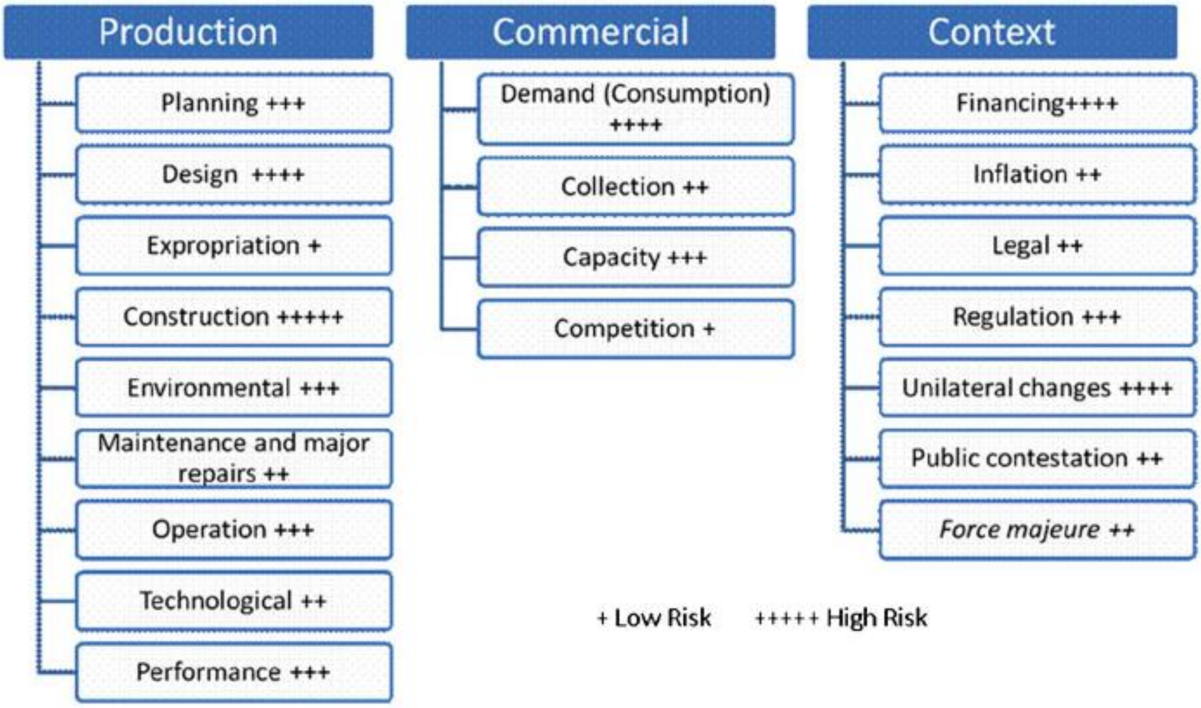


Figure 17. **One of the adopted risks classification techniques for PPP projects (Marques and Berg 2011)**

Then, the probability and impact of each risk should be quantified. The severity of each risk can be determined by multiplying the probability by the impact for each risk. This way, all the risks can be ranked for a specific project (Marques and Berg 2011). This stage has to be started from the bidding process. A complete risk matrix should be developed for all the risks associated with a certain project (Marques and Berg 2011).

2.4 PPP Stakeholders

2.4.1 Relationship Management in PPP

Zou *et al.* (2013) argues that due to the fact that PPP projects have a long lifetime, there will be a higher chance of problems/changes arising. Accordingly, a good risk allocation between PPP parties is crucial to ensure a successful PPP project. Nevertheless, many of the changes happening during the lifetime of the PPP project will be unanticipated for as potential risks and therefore, will not be accounted for in the PPP contract. Therefore, relying on the established relationships is needed to maintain the contractual bond. The quality of the relationship between public and private sector has been shown to be a key contributor to the success of a PPP project.

Smith *et al.* (2018) defines the concepts of “principal” and “agent” in the PPP context. The “principal” is the public partner, the “agent” is the private partner. The relationship between the principal and the agent is defined in the contract terms and conditions. Any problems occurring between the principal and the agent are known as “agency problems”. In fact, Eisenhardt (1989) offered a holistic view supported by robust explanation on five assumptions associated with the “agency theory” which are as follows:

- The presence of “conflict of interests” between the principal and the agent. Smith *et al.* (2018) provided some evidence to support this assumption by stating that one of the examples for conflict of interest in PPP projects is where the agent’s aim is to make profit while this is not the principal’s goal. The principal is concerned with cost-effectiveness only as “an ultimate goal”.
- The “rationality” which means that both the principal and the agent are looking first to their personal interest. Shrestha and Martek (2015) illustrate the problem of rationality by describing what happens in case the agent jeopardizes the quality of the works as well as the standards to make more profit. In their study, Mok, *et al.,* (2014) argues that sometimes, the stakeholders’ interests play a crucial role in the project as the interests and hence the priorities differ among the various project stakeholders. Such different interests can sometimes reach the point that stakeholders may use

strategies to influence the project decision-making just to realize their objectives. Accordingly, Missonier and Fedida (2014) confirms that stakeholder analysis plays a crucial role in stakeholder management.

- “Asymmetric information” which includes two major problems:
    - “Adverse selection” where the principal does not know what the agent knows. This problem occurs mainly before the signature of the contract. According to De Palma, *et al.,* (2012), this is the case in PPP projects where the private partner has skills, experience and knowledge that the public partner does not have (Missonier and Fedida 2012).
    - “Moral hazard” where the principal cannot watch the agent’s behavior. This problem usually occurs after the contract is signed.
- “Uncertainty” which is known in other words as “risks” which includes any unforeseen event out of the parties’ control and could not have been accounted for.
- “Risk-aversion” which assumes that the agent’s main role is to bear all risks associated with the project to protect the principal’s interests.

According to Smith *et al.* (2018), there is still a gap in the knowledge regarding the “agency problems” and the five assumptions stated above and which were developed by Eisenhardt in 1989.

Consequently, there has been an increasing attention towards the use of the term “Relationship Management” or “RM” in the domain of Construction Management and especially in PPPs. Zou *et al.* (2013, p.269) defines RM as “a set of comprehensive strategies and processes of partnering with selected counterparties, and the project stakeholders, to create superior value for the PPP project through developing sustainable relationships.”

2.4.2 Stakeholder concept and its relationship to PPP projects

The stakeholder concept appeared into the management domain for the first time in 1963 by the Stanford Research Institute in California. Stakeholders meant the institutions or individuals that are essential for any organization to exist (Freeman

1984). The traditional definition of a stakeholder is "any group or individual who can affect or is affected by the achievement of the organization's objectives" (Freeman 1984). Existing literature includes several definitions for "Stakeholders" which seem to be similar to a great extent. According to Missonier and Loufrani-Fedida (2014), the term "stakeholder" means any institution or individual having an interest or "a stake" in a certain project. As per the Project Management Institute (2008), "project stakeholders are individuals and organizations that are actively involved in a project or whose interests may be affected as a result of project execution or completion". According to Missonier and Loufrani-Fedida (2014, p.1110), Vidgen and McMaster (1996) define stakeholders as "human or non-human organization unit that can affect as well as be affected by a human or non-human organization's policy or policies". Generally, there two types of stakeholders: primary and secondary stakeholders. Primary stakeholders are the ones having a considerable impact on the success and survival of the organization. Secondary stakeholders are having an impact on the organization without being directly involved in it and are not crucial for the organization/project to survive (Schepper *et al.* 2014, Clarkson 1995).

Li, *et al.* (2012) suggested a different classification for stakeholders in the construction industry. According to their study, stakeholders are classified into two major types:

- "Internal stakeholders, who are located on the "demand side" such as employees, customers, end-users and financiers) and "supply side" (architects, engineers, contractors, trade contractors and material suppliers); and
- External stakeholders, including private partners such as local residents, landowners, environmentalists, and archaeologists and public partners such as regulatory agencies, and local and national government".

There are two major features for stakeholders which are:

- Being interested in the actions taken by the organizations
- Being able to influence the organization (Savage *et al.* 1991)

According to Donaldson and Preston (1995), there are three important perspectives the stakeholder theory is based on; which are as follows:

- Normative; which means that the stakeholders are institutions or individuals having a fundamental interest in the corporate activity. According to Donaldson and Preston (1995), the normative perspective considers the stakeholder theory “rooted in norms and traditions”.
- Instrumental; which verify whether the institutions goals are achieved by paying more attention to stakeholders and relationships among them. According to Crane and Livesey (2003), the instrumental form of stakeholder relationship is usually a single way of communication that does not give voice to stakeholders.
- Descriptive; meaning that “it describes the corporation as a constellation of cooperative and competitive interests possessing intrinsic value”. In other words, it describes what the project is and defines the project stakeholders. Amaeshi (2010) argues that it shows that theory goes in parallel with the reality without being neither judgmental nor prescriptive.
- Donaldson and Preston (1995) and Freeman (1984) point out that the normative aspect is considered as the “core” of the stakeholder theory. Accordingly, they suggest considering the three aspects as nested, this is illustrated in figure 18.

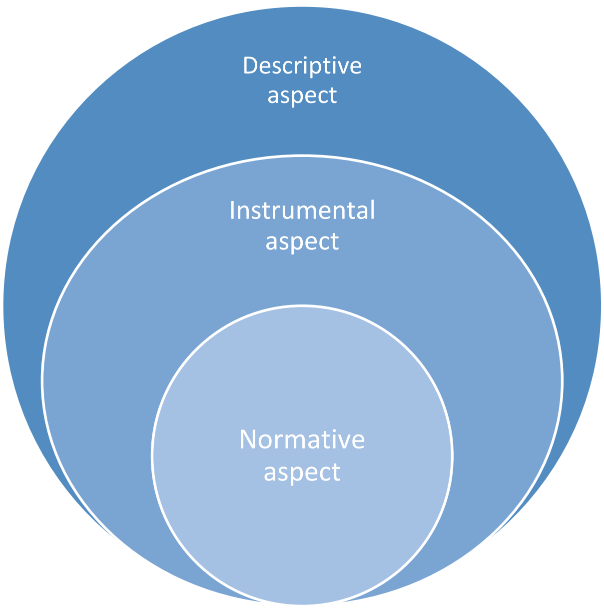


Figure 18. Stakeholder aspects

However, Henjewele *et al.* (2013) argues that the aforementioned paradigms are based on a “managerialistic” basis; this means that the paradigms assume that the managers are the ones who play a role in identifying the stakeholders. Amaeshi (2010) points out that this view is emerging from “the dependency on the centrality of manager’s perceptions in stakeholder-related decisions”. Mitchell, Agle and Wood (1997) and Agle, Mitchell and Sonnenfield (1999) confirm that this managerialistic view considers the stakeholder salience as the ability of stakeholders to influence managers’ decisions. Henjewele was even more forthright and advocated for his view by explaining that the perspectives of the stakeholder theory suggested by Freeman (1984) and Donaldson and Preston (1995), which is focusing only on managers had the following limitations:

- Managers are considered the center of the stakeholder theory. Consequently, managers were not developing new managerial/strategic directions (Freeman and Mcvea 2005).
- Managers are considered as autonomous actors. Nevertheless, Freeman and Mcvea (2005) points out that the common and shared interests should be taken into account.
- Perceptions of managers are valued more than the wider social system’s influence (Amaeshi 2010).
- On a separate note, Mitchell *et al.* (1997) offered a holistic study explaining the three major features characterizing stakeholders as follows:
- Power
- Legitimacy
- Urgency

2.4.3 Stakeholders power in PPP projects

Eesly and Lenox (2006) defines stakeholder power as the control of critical resources having an influence on the project. For instance, in PPP projects, the public partner chooses to transfer partial or full control over the project to the private partner which increases the power of the private partner in such case (Schepper *et al.* 2014). In defining the stakeholders’ power, Donaldson and Preston (1995) highlighted an interesting observation: there should be a clear difference between “influencers” and “stakeholders”. Some stakeholders have both “stakes” and “influence” on the project. Nevertheless, some “stakeholders” have no “influence” and some “influencers” have no “stakes” (Donaldson and Preston 1995). On a separate note, Schepper *et al.* (2014) outlines an important issue in the case of PPP projects: giving more power to the private partner in PPP projects; on the contrary to the case in a traditional project means a shift in the power position which may lead to an alternated assessment of the power relationships in the same environment. For instance, in the case of more power given to the private partner in PPP projects, the private sector can attribute more attention and importance to investors than the attention that the public sector could attribute in case the latter had more control over the project. Furthermore, Hodge (2010) argues that in PPP projects, with the private partner having more control over the project, there will be more pro-active involvement of shareholders. This is due to the fact the focus of the public sector is different than the focus of the private sector. The private sector's aim is to increase its profit or cash flow while the public sector's objective is to maximize the social benefit.

2.4.4 Stakeholders legitimacy in PPP projects

There is some debate in the existing literature regarding the definition of stakeholders' legitimacy in PPP projects. Suchman (1995) defines legitimacy as generalized perception or assumption that the actions of an entity are desirable, proper or appropriate within some socially constructed system of norms, values, beliefs, definitions. Mitchell *et al.* (1997) confirms Suchman's definition. On the other hand, Phillips (2003) argues that Suchman's definition lacks precision within the stakeholder literature and proposes to define stakeholder legitimacy based on contractual relationships or relationships that are based on general norms, values and beliefs. Accordingly, Phillips classifies stakeholders into: normative, derivative and non-stakeholders. Normative stakeholders are "those stakeholders to whom the organization has a moral obligation." Derivative stakeholders are the ones having an effect on the organization in addition to its normative stakeholders. Nevertheless, Phillips argues that the legitimacy of the stakeholders is more of a static characteristic.

2.4.5 Stakeholder urgency in PPP projects

Mitchell *et al.* (1997) defines urgency as the degree to which stakeholder claims call for immediate attention. The urgency includes two important aspects which are “time sensitivity” expressed by the extent to which a delayed response is unacceptable to the stakeholder and “criticality” expressed by the importance of the claim (Mitchell *et al.* 1997). Rowley and Moldoveanu (2014) explains that in the case of PPP projects, the fact that the project is owned by the public partner while it is realized and operated by the private partner makes specifying the stakeholder that a certain claim targets more challenging. Schepper *et al.* (2014) gave a robust example to such case dilemma: if there is a claim that a PPP project is not-complying with the environmental regulations, both the public and private partners may be responsible for that but in different aspects. For instance, based on the contract terms and conditions, the public partner may be responsible for the choice of the materials while the private partner may be responsible for the noise levels during construction works.

2.4.6 Limitations in studies about stakeholder analysis and engagement

Based on a study performed by Mok *et al.* (2014), table 7 shows scholars' contribution to stakeholders-related publications from 1997 and until 2014. Most of the research and efforts were deployed in the domain of stakeholders' analysis methods and engagement (21% and 28% respectively of the total publications in this domain) while only 18% of the publications were studying the stakeholders interests and influences.

***Table 6.* Scholars' contribution to stakeholders-related publications**

Research theme	Period (year)				Total	Percentage (%)
	1997–2000	2001–2005	2006–2010	2011–2014		
Stakeholder interests and influences	2	0	7	6	15	18
Stakeholder management process	3	4	13	8	28	33
Stakeholder analysis methods	2	5	8	3	18	21
Stakeholder engagement	0	1	13	10	24	28
Total	7	10	41	27	85	100

Source: Mok *et al.* (2014)

PPP projects are different in their nature from traditional projects. In traditional projects, the project stakeholders and their responsibility is clearly defined and not questionable. This is not the case in PPP projects. In PPP projects, on the other hand, there exists a much higher stakeholder complexity due to the number of stakeholders and the relationships among them (Schepper *et al.* 2014). Moreover, Schepper *et al.* (2014) argues that in a PPP project, the private partner enters into a contract with the private partner for the latter to design, build, finance and operate the project. However, in the case of a traditional project, “the government unbundles these phases and contracts them separately to other private contractors”.

According to Schepper *et al.* (2014), proper stakeholder management, the identification and classification of all stakeholders concern is indispensable to ensure the PPP project’s success especially in the early set-up phase. Nevertheless and despite the importance of stakeholder analysis and stakeholder engagement, there exist various limitations and gaps in the literature regarding these concepts (Missonier and Loufrani-Fedida 2014, Jepsen and Eskerod 2009, Littau, *et al.* 2010, Pacheco and Garcia 2012, Yang, *et al.* 2009). Achterkamp and Vos (2008) argue that the research examining the importance of stakeholder management and involvement in traditional construction projects is limited, even less so for PPP projects.

Jones and Fleming (2003), Yang *et al.* (2009) and Amaeshi (2010) specify that the general stakeholders’ literature and specifically the stakeholder literature related to the Construction Industry (CI) suffer several gaps. Such gaps are present in the research related to methods and tools used to identify stakeholders, the effect that stakeholders have on the project and how changes can affect stakeholders. According to Henjewele *et al.* (2013), the literature related to stakeholders in the Construction Industry did not tackle procedures used to manage the relationships between different stakeholders throughout the lifecycle of the construction project and which are crucial for its success.

Ng *et al*. (2012) argues that research papers and studies have not studied well enough and did not cover the stakeholder analysis during the initial feasibility stage of the project. Nevertheless, according to Keong, *et al.* (1997), this step is crucial to determine the success or failure of the project.
According to Henjewele *et al.* (2013), both the private and public partners took stakeholders and stakeholders management from a narrow perspective. El-Gohary *et al.* (2006) and Rwelamila *et al.* (2014) argue that such underestimation of the stakeholders’ effect and impact on the success of the project led to the failure of

several previous PPP projects. Henjewele *et al.* (2013) point outs that current stakeholders' models are inadequate for PPP projects.

Schepper *et al.* (2014) confirms that to date, no PPP research has addressed the concept of identifying, mapping, processing and controlling of stakeholders in PPP projects. In fact, Missonier and Loufrani-Fedida (2014) classified the gaps in the following areas of literature: "relevance, dynamic and emergence". According to Schepper *et al.* (2014), no research primarily described the dynamics of stakeholders in an analytical way. Consequently, there are no clear paths to a solution or a way to manage stakeholders. Nevertheless, El- Gohary *et al.* (2006) deployed considerable efforts in discussing stakeholders' involvement in PPP infrastructure projects. Nevertheless, El-Gohary *et al.* (2006) focused more on the "public" or "end-users" as stakeholders without putting much emphasis on the "public partner, also known as the principal" and the "private partner, also known as the agent". In fact, Smith *et al.* (2018) identified a gap in the knowledge in this area especially regarding the "agency problems" related to "conflicting interests, self-interest and rationality, asymmetric information, uncertainty and risk behaviour".

Regarding the relevance of the stakeholders to the project, it is admitted that there were efforts previously deployed in order to have a clear identification, classification, categorization and analysis of behavior for stakeholders in various projects (Crawford 2005, Cummings and Doh 2000, Mitchell, *et al.* 1997, Savage, *et al.* 1991). However, Missonier and Loufrani-Fedida (2014) argues that those previous studies lack a proper way of identification of stakeholders along with their interests. Concerning the dynamic nature of the stakeholders' relationships; according to Eskerod and Vaagaasar (2012), the stakeholder analysis and engagement are a "dynamic" process in the project's lifetime. This fact is often overlooked in several projects and was thus not thoroughly covered in literature. Thirdly, Missonier and Loufrani-Fedida (2014) argues that several researches have studied the "resultant" of the relationship between different stakeholders. However, "the co-evolution of the stakeholder identity and the project over time" has not been addressed. Such evolution constitutes the "emergent effects of stakeholder networks". Pacheo and Garcia (2012) argues that the evolving of the stakeholders throughout the project's lifetime is "understudied".

Pouloudi, *et al.* (2004) argues that the definition of stakeholders includes both individuals and institutions that are affected by the project, meaning that there are human and non-human. Nevertheless, the analysis of stakeholders only included human stakeholders without paying much attention to non-human stakeholders. Since the introduction of the concept of stakeholders in 1984, the only concentration was on the mutual relationship between the stakeholders and the organization (Missonier & Loufrani-Fedida 2014). However, Rowley (1997) argued that in studying such relationship, stakeholders shall not be treated together as one set; they shall be treated as a "network" where the multiple and interrelated relationships between stakeholders are studied instead of the "dyadic" perspective. Schepper *et al.* (2014) argues that only limited resources have studied stakeholders aspects throughout all its life cycle phases, starting from the initiation phase, operational phase and coming to the phase starting after the contract ends.

2.4.7 Changing the "PPP" nomenclature (introducing a 4th P)

According to Schepper *et al.* (2014), there are at least two main organizations involved as stakeholders In PPP projects which are: the public sector and the private sector, being involved in the project as a "SPV" (Special Purpose Vehicle). Rwelamila *et al.* (2014) argues that in PPP projects, the public sector is recognized as a crucial player in the partnership while the "general public" is often neglected and not taken into account. Consequently, the general public suffers a lack of trust in regard to the effectiveness of the PPP projects (Henjewele *et al.* 2013) (Shaoul 2005). According to Henjewele *et al.* (2013, p.211), "for the partnership to work there should be a nurtured trust between the demand and supply sides, which is built on the understanding that both parties work towards a common goal".

2.4.8 Instances showing the power of the general public in PPPs (Failure and success stories involving the general public)

El-Gohary *et al.* (2006) offered one of few studies completely concerned with the stakeholder management for PPP projects. In their study, el-Gohary *et al.* (2006) argues that the major cause of failure of many PPP projects is the "public opposition". There were evidence to support this supposition. For instance, as a result of public opposition to the involvement of the private partner in PPP hazardous waste disposal projects in the United States, such projects had only a three percent chance of success (Ibitayo 2002). This was supporting Abdul-Aziz's studies (2001) explaining that Malaysia failed in privatizing its sewer system because of public opposition as such transfer to the private partner occurred without informing the public which was considered as "a lack of transparency". The public opposition's strength reached a point that the government was obliged to re-buy the sewer system. El-Gohary *et al.* (2006) argues that such failure were mainly due to the lack of education of the public regarding the concept of PPP. Moreover, no detailed information was provided to the public. According to Henjewele *et al.* (2013), in West Newcastle, in Ireland, a public private partnership was established in order to clear slum areas and to develop education action zones (EAZ). Unfortunately, such partnership failed because what was intended to be an economic transformation ended up by being a partnership that excludes the community.

Monbiot (2000) illustrated another case indicating the extent of the power of the general public. It is the Skye Bridge in Scotland. It was a BOOT contract signed in 1991. The scope of work of the Private Partner consisted of building a toll bridge reaching the Isle of Skye off the west coast of Scotland. The bridge was supposed to become toll free within 17 years of its operation. Nevertheless, the toll price was high which made the public use the ferry instead of the bridge. Consequently, the concession period which was originally accounted for around 17 years had to become longer to overcome the losses. Furthermore, there was another public protest against the design of the bridge which led to the application of discounted tolls starting from 1998. Afterwards, the bridge became toll-free before the anticipated concession period which led to an early end of the partnership.

De Lemos, *et al.* (2004) and De Sousa (2012) point out to another PPP project illustrating the power of the general public. It is the Lusponte concession in Lisbon Portugal. The private partner's role was to design, construct, finance, operate and maintain the new Vasco Da Gama Bridge in addition to operate and maintain the existing bridge to Lusoponte. The project's initial cost was € 850 million. The bridge was supposed to be a toll bridge with the concession duration to end on 14 March 2028 or at a total traffic flow of 2,250 million vehicles, whichever comes earlier.

However, some internal disputes, it was agreed that the concession duration will be changed to end on 24 March 2030, two years after the planned concession end irrespective of the traffic flow. This led to an increase in the tolls imposed on the public. On 24 June 1994, large protests took place to the extent that the bridge was blocked by trucks carrying sand. Such huge reaction made the government annul the tolls and make taxpayers bear the difference. All of these issues led to various renegotiations and compensations reaching €408 million.

On the other hand, Henjewele *et al.* (2013) illustrates a successful example of partnership between the private and the public sectors in Sao Paulo in the domain of education remodelling as all the stakeholders' objectives and interests were taken into consideration in a way that all the objectives continue to be met even after the private sector is disengaged.

Furthermore, another successful example of partnerships is the "sustainable school design to improve learning" in Bristol. It is an educational ten year partnership aiming to establishing four schools in poor areas between 2007 and 2009. The second phase of the project consisted of establishing nine more secondary schools and two primary schools. The aim of the project was to establish new better schools with enhanced education, safety and facilities. Before the start of the work, Local Educational Partnership (LEP) team had several meetings with the parents, teachers and students "so that the schools would be fit for purpose" and in order to know the exact requests of the "users". The results were that the parents accepted to send their children to these new schools. The statistics showed the safety performance (students feeling safe) increasing from 30 to 87 percent. The educational level of students improved by 15 percent and the percentage of content of students going to these schools increased from 43 percent to 77 percent.

2.4.9 Importance of stakeholders involvement

As it was discussed in the previous sections, there are different concepts associated with stakeholders when it comes to their relationship to projects. There is a difference between "stakeholder management", "stakeholder analysis" and “stakeholder engagement” (Missonier & Loufrani-Fedida 2014); also known as “Stakeholder Involvement” (El-Gohary *et al.* 2006).

Missonier and Loufrani-Fedida (2014) have argued that it has been concluded based on several studies that a project failure is not attributable to wrong project management practices but is rather due to “inappropriate social interactions between project stakeholders”. In fact, Schepper *et al.* (2014) confirms that one of the causes of the lack of success of PPP projects is due to the presence of a “gap between different stakeholders involved in PPPs on the desired process or outcome of the project” which is caused by improper stakeholder management. Stakeholder Management (SM) can be done by taking the stakeholders’ concerns into consideration and attempting to develop and maintain strong relationship between stakeholders (Mok *et al.* 2014). Pouloudi (1999) argues that co-operation and mutual trust between any institution and its stakeholders will decrease contracting costs and will result in “more efficient transactions”.

El Gohary *et al.* (2006) explains that in several PPP projects, the public is only considered as end customers who will pay the tariffs associated with the project which make them feel marginalized to the extent that they do not become involved at all in the project and are just outsiders. Furthermore, Rwelamila *et al.* (2014) argues that stakeholders’ management and involvement issues especially the marginalization of the public are one of the most critical factors increasing the complexity of PPP projects.

Henjewele *et al.* (2013) argues that in order to ensure the success of the PPP projects, the public sector, the private sector and the public should be involved. Stakeholder engagement means involving and building relationships with different stakeholders as early as possible in the project’s lifetime (Missonier and Loufrani-Fedida 2014). Similarly to the concept of stakeholder engagement, el-Gohary *et al.* (2006) discussed the concept of “Stakeholder Involvement” (SI). They argue that the concept of “Public involvement” is now being replaced by the concept “Stakeholder involvement”. In their research, El-Gohary *et al.* (2006) discusses the fact that “stakeholders” primarily mean “the general public” not the “public partner”. They argue that stakeholders should be involved in the project starting from the planning and design phase; where they should be part of the decision-making process and until the construction phase. The involvement of the public in the design process will be a 2-way process where the public feedbacks must be obtained. Nevertheless, the involvement of the public in the construction process is only a one-way process aiming to transferring information and knowledge to the public such as the sequence of work, the road closures, etc. Nevertheless, El-Gohary *et al.* (2006) never provided substantial evidence to support the conclusion they reached regarding "stakeholders" being mainly "the general public" instead of the "public partner".

Henjewele *et al.* (2013) argues that based on a study in the UK, getting early feedback from the stakeholders can help avoiding doing many changes afterwards during the project's lifetime which can reduce cost overruns and poor VFM. It was also proved that PFI projects that paid attention to public needs resulted in less changes during operation.

In an attempt to decrease the debate and in order to reach unanimity regarding the PPP project stakeholders, Zhang (2012) and Kumaraswamy *et al.* (2015) suggested introducing a 4^{th} P (People) "in order to cement the relationships with a focus on sustainable overall value to the end user and community in specific disaster management scenarios". Kumaraswamy *et al.* (2015) point out that adding the People/Public to the equation will provide the "missing link" as it will help in always responding to people's needs throughout the project. The long life span, complex nature and large magnitude of the PPP project need "ex ante" inputs from the projects end users. The introduction of the "public-private-people" partnership was previously studied by Ahmed and Ali (2006) for Solid Waste Management (SWM) in Bangladesh and by Majamaa (2008) by involving the public in PPP-based urban development processes. Furthermore, Kumaraswamy *et al.* (2015) studied such partnership specifically in disaster management for PPP projects and for a general scenario. In disaster management, Kumaraswamy *et al.* (2015) considered the fourth "P" as local communities and NGOs in addition to professional bodies, academia and media. These groups usually can collaborate with the public and private partners in case any disaster happens. Such "social infrastructure" is of utmost importance in post-disaster reconstruction (Zhang 2012) and in risk management. Kumaraswamy *et al.* (2015) illustrated this issue by pointing out to the 8.0 Richter scale earthquake in Schuan Province, China on 12 May 2008 causing tens of thousands of deaths. During this disaster, the importance of the local communities assisting both the private and public partners to rebuild its infrastructure and overcome the damages was very clear. Kumaraswamy *et al.* (2015) reached the conclusion of the necessity of involving people in PPP projects, arguing that in light of the complex nature of PPP projects and with the disputes that may arise between the private and public, people will act as the "cementing agent" or "the link" connecting the public to the private partner. It will be in the project's benefit to engage the general public as early as possible in the project in order to unify the goals, objectives and benefits of all the stakeholders as marginalizing the general public could lead to detrimental results.

2.4.10 How are Risk Management and Stakeholder Management related?

The relationship between risk management and stakeholder management will be explained in this section. Valipour *et al.* (2016) argues that there are several barriers that may prevent the implementation of a proper risk allocation such as the ability of both parties to manage the risks and "the attitude of stakeholders towards shared responsibility" (Iqbal, *et al.* 2015) and risk (Lam *et al.* 2007, Zhang, *et al.* 2002, Tserng, *et al.* 2014). Furthermore, poor stakeholder management causing problems in cooperation, teamwork, negotiation and trust is a major barrier to risk allocation (Valipour, *et al.* 2014). Xu *et al.* (2010) points out that recognizing the barriers to proper risk allocation in PPP projects will help in achieving better risk allocation.

As it has been shown throughout this section concerning stakeholders and their presence in PPP projects, the quality of the relationship between public and private sector on one side and the end users on the other side has been shown to be a key contributor to the success of a PPP project. In fact, the real case projects that were discussed can be considered as clear evidence to support the following statement "Many of the risks affecting PPP projects arise due to poor management of stakeholders". Therefore, analyzing the risks caused by inadequate management of stakeholders and determining their effect on PPP projects compared to their effect on traditional projects is a way of mitigation of a significant number of risks affecting PPP projects which is step towards better Risk Management for PPP projects.

2.5 Chapter Summary

This chapter has presented an overview of PPP history and start along with the two major PPP types: contractual and institutionalized. Furthermore, the major types of contractual PPP were explained which are detailed in what-so-called "PPP spectrum". The categorization of PPP in the PPP spectrum is based on the degree of the public and private sector involvement and based on the extent of risk allocation between different parties. The stages of PPP are also explained. Then, an overview of PPP around the world is presented along with associated failure and success stories. From these stories, it is confirmed that managing risks associated with PPP projects is of utmost importance in order to ensure the success of PPP projects. Also, due to the fact that PPP projects have a long lifetime, there will be a higher chance of problems/changes arising, many of which will be of unanticipated nature. Therefore, relying on the established relationships is needed to maintain the contractual bond. The quality of the relationship between public and private sector has been shown to be a key contributor to the success of a PPP project. This highlights the importance of stakeholder management in PPP projects. Consequently, analyzing the risks caused by inadequate management of stakeholders and determining their effect on PPP projects' completion time compared to their effect on traditional projects is a way of mitigation of a significant number of risks affecting PPP projects which is a step towards better risk management for PPP projects.

Chapter 3– Research Strategy and Methodology

3.1 Chapter Introduction

Remenyi *et al.* (1998) explored the fact that there are three important questions that should be considered by researches and which are:

1. What to research?
2. How to research?
3. Why research?

The answer to the first question is mostly related to the researcher's own academic interests. However, the answers to the second and third questions are interrelated. The "how of research" is the research methodology. The methodology is a summary for the research process and is the way the research will proceed. Choosing the methodology involves a deeper concept needing *a philosophical* solution and this is where the answer to the third question "Why research" comes.

In order to build the methodology for any study, there should be a standpoint regarding the following seven terms: paradigm, theoretical framework, research approach, data collection, data analysis, ethics and validity (Chilisa and Kawulich 2012).

Chilisa and Kawulich (2012) performed a robust study regarding how to select a research approach. In this regard, they suggested that in order to better understand each of the aforementioned terms, some questions should be asked as follows:

- Paradigm: What is the paradigm that is informing the methodology?
- Theoretical framework: What are the theories mostly affecting the following aspects of the research:
    - Research topic
    - Research questions
    - Literature review
    - Data collection techniques
    - Data analysis and interpretation

- Research approach: Based on the research questions, what research approach shall be adopted?
- Data collection: How to collect the data necessary for the study? What is the type of data that shall be collected?
- Data analysis: How does the theory assist in the data analysis and interpretation?
- Ethics: Based on the paradigm, theoretical framework, research approach, data collection and data analysis, what shall be the ethical considerations?
- Validity: How can the research design, data collection and data analysis be verified to endure their reliability?

Understanding those terms is the key to developing the methodology. Methodology is the area where the paradigm, theoretical framework, research approach and ethics meet. Figure 19 shows how it is important to place the specific methodology used in this research within those terms.

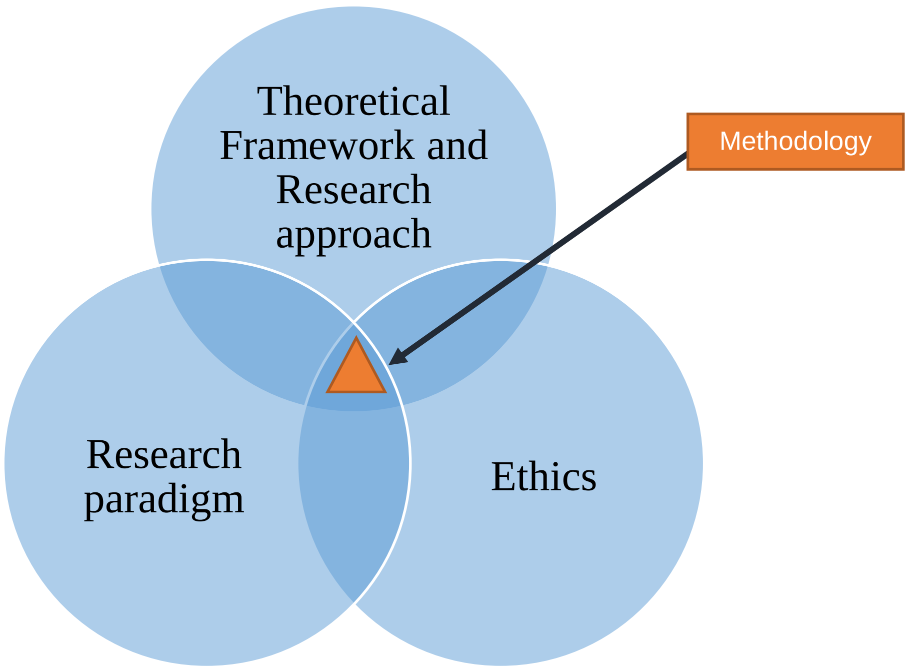


Figure 19. **Methodology as the convergence of 3 terms (Chilisa & Kawulich 2012)**

Creswell (2014) offers a more holistic assessment that aligns, to a great extent, with the views of Chilisa and Kawulich (2012). Nevertheless, instead of using the term “methodology”, Creswell is using the term “broad research approach” which, according to him, represents the intersection between the philosophical worldviews, research designs ad research methods.

Creswell (2014 p.5) defines the research approach as "the plan or proposal to conduct research, involves the intersection of philosophy, research designs and specific methods." Creswell suggests the framework for research according to the illustration in figure 20.

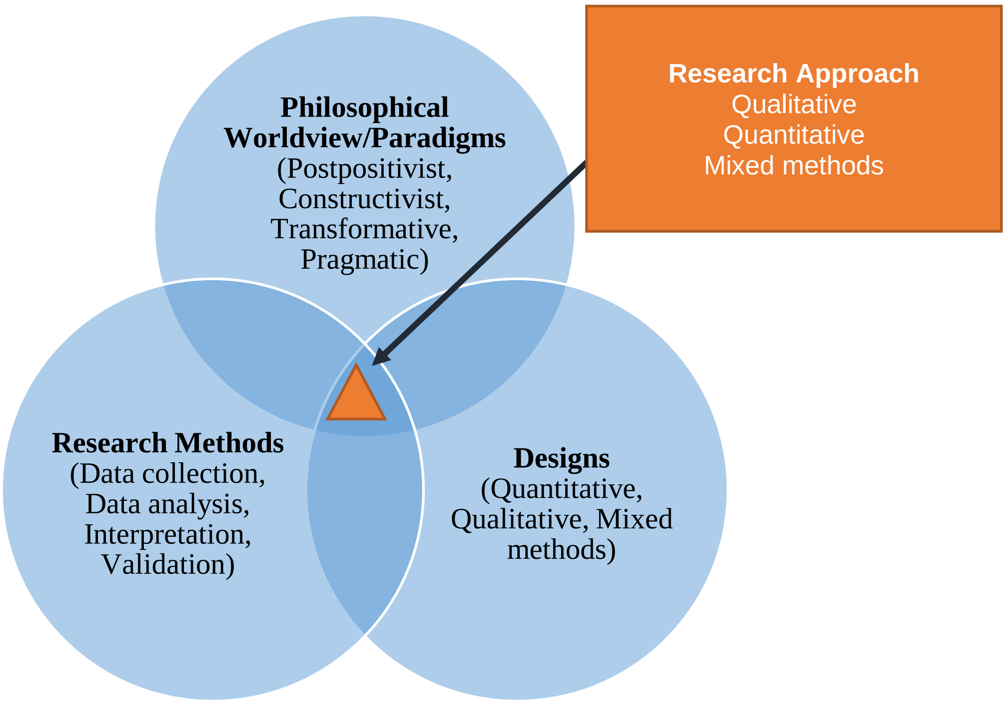


Figure 20. Framework for research (Creswell 2014)

Accordingly, from both point of views presented, it is essential to place the methodology used in this research in the context of "all" research methodology and within the framework for research, which will be done in this chapter.

This chapter will present justifications for adopting the research approach in light of the various philosophical perspectives. This chapter will also explore the experimental framework that based on which the modelling aspect of the research shall be performed. Artificial neural networks will be thoroughly discussed including their applications, strengths, weaknesses and the reasons they were selected for this study.

3.2 Research approach

There are three research approaches:

- Qualitative
- Quantitative
- Mixed methods

The qualitative technique is the open-ended information obtained through interviews while quantitative technique consists of closed-ended exact figures calculated from questionnaires. Both types of techniques are crucial to the research. In the domain of PPP projects, qualitative techniques are used to evaluate subjective risk elements of PPP projects that are not possible to quantify in terms of monetary values. On the other hand, quantitative technique is used to work on risks that were first identified and ranked through the qualitative approach (Boussabaine 2014). One of the major advantages of the mixed-method approach is the possibility of use of "triangulation" which consists of using various methods to examine the same phenomenon.

However, Creswell (2014, p.3) brings an interesting side to that topic by both agreeing on the fact that qualitative and quantitative approaches are not "rigid, distinct categories, polar opposites or dichotomies. Instead they represent different ends on a continuum" while the mixed methods research is located in the middle of this range as it equally includes essentials of both qualitative and quantitative approaches. Based on the literature, the major research approaches can be defined as follows:

- **Qualitative research:** It is an approach used for exploring and studying the meanings that groups or individuals attribute to a social or human problem. In order to conduct a qualitative research, first the data is collected, and interpretation is performed for the collected data. The outcome is a report characterized by its flexible nature (Creswell 2014).
- **Quantitative research:** It is an approach used for examining the relationships between different variables, which are measured numerically. The obtained data is analyzed using statistical methods. Usually the final report is structured by consisting of an introduction, literature review, method, results and discussion. Researchers adopting the quantitative methods

should generally develop assumptions, avoid bias, be open to alternative solutions and explanations and be able to replicate the findings (Creswell 2014).

- **Mixed methods research:** It is an approach consisting of collecting both quantitative and qualitative data and combining them together. Researchers adopting the mixed method research ensure that the problem is approached equally from both views in order to have a better understanding for the studied problem (Creswell 2014).

3.2.1 Adopted research approach in this study

According to Creswell (2014), a study can be more qualitative than quantitative and vice versa. Accordingly, and based on the above explanations and justifications, the adopted research approach of this study is mainly a quantitative research approach with some elements of qualitative approach. As it was previously stated in Chapter one: Introduction, the research started by defining the problem statement, aim and objectives of the research and the research questions. Then a thorough exploration and critique of the existing literature review on failure and success stories of PPP projects, risk management and stakeholder management in PPP projects was conducted. The literature review analyzed and made explicit the gaps in the knowledge which clarified the initial aim and objectives. An experimental approach is then designed in order to collect the data from real projects and develop the mathematical approach modelling the risks associated with construction and poor stakeholder management in a comparative analysis between PPP and traditional projects. The final section includes conclusions, recommendations and future work. The adopted research approach is illustrated in Figure 21.

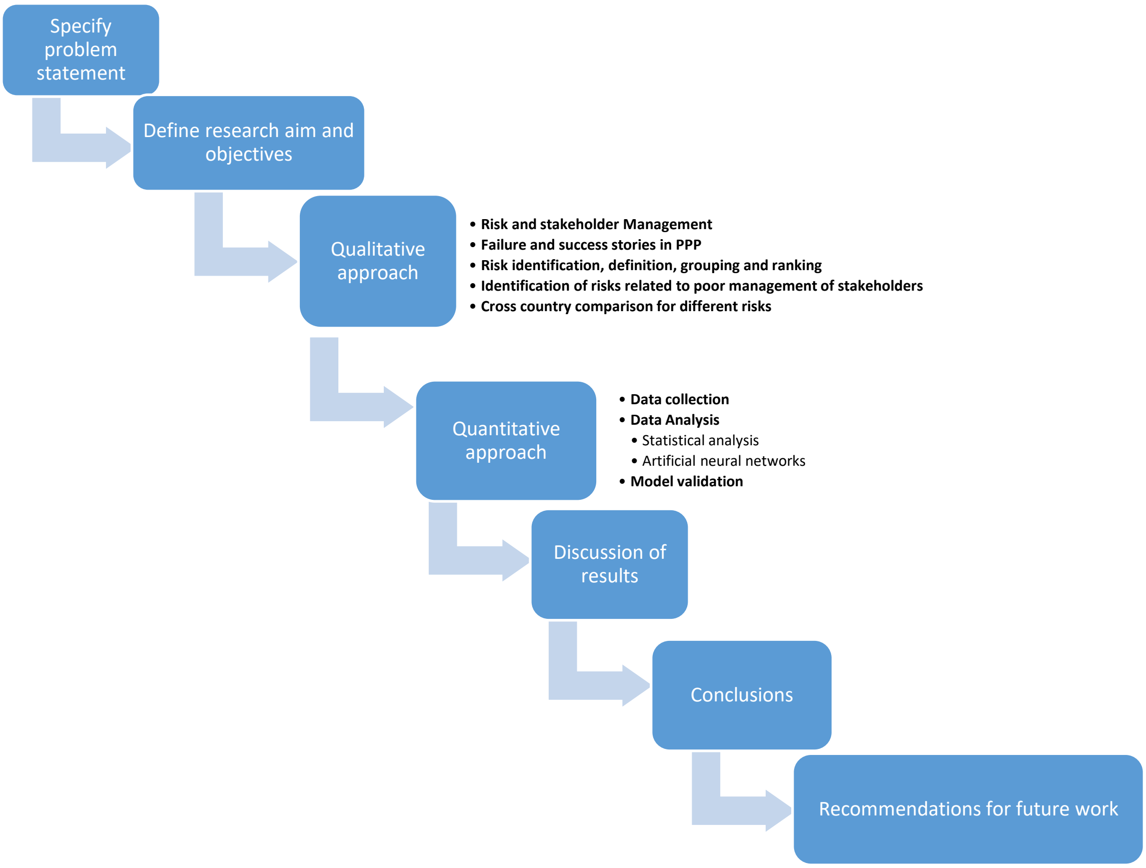


Figure 21. **Adopted research approach**

3.3 Developing the philosophical perspective

Developing the philosophical perspective was explored and discussed by Burrell and Morgan in 1979. The dimensions of the philosophical perspective are illustrated in Figure 22.

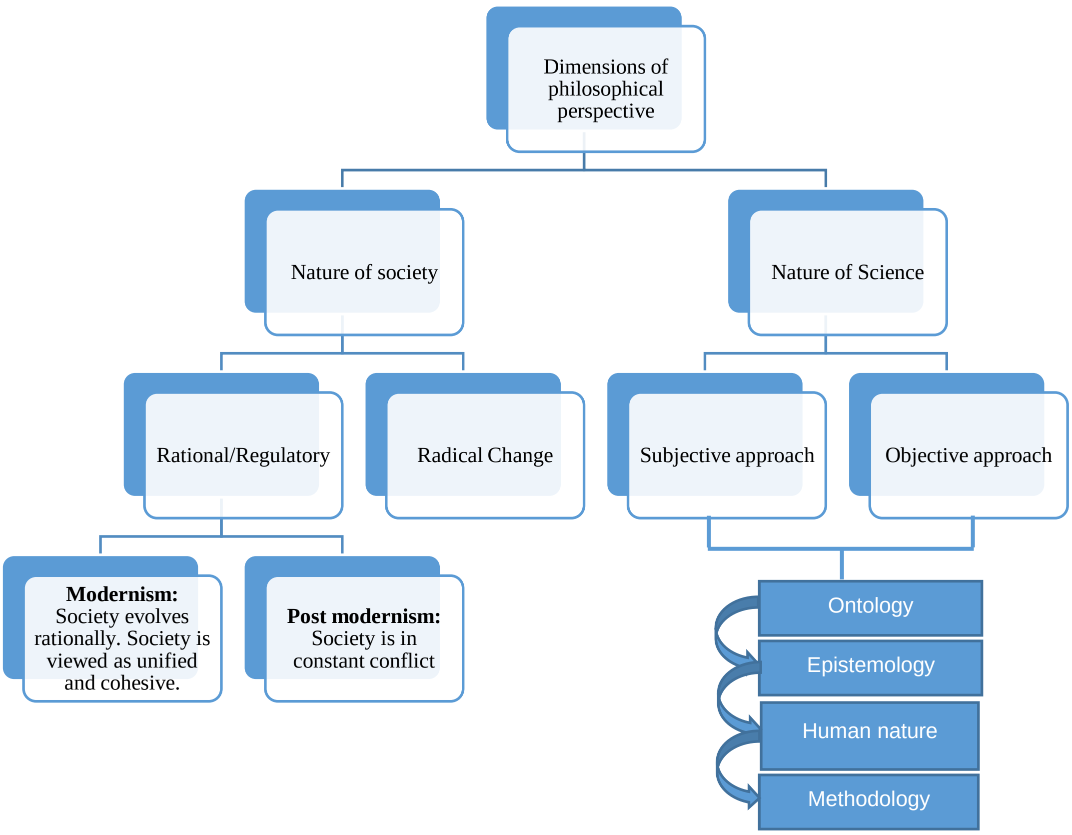


Figure 22. **Dimensions of philosophical perspective**

In order to develop a philosophical perspective, the researcher should make the assumptions regarding two dimensions: the nature of society and the nature of science.

The sociological dimension

This dimension involves a choice between two opposing views of the society: the rational view; where the society is viewed as unified and cohesive which is the basis of modernism and the radical change perspective, which is the basis of the post modernism and which assumes that the society is in continuous conflict. The postmodernism lacked the analytical nature and thoughts were completely based on belief as humans were striving to free themselves “from the domination of societal structures” (Burell and Morgan 1979). The sociological dimension will not be the subject of this research as, in light of its nature, it is concerned with the scientific dimension of the philosophical perspective.

The science dimension

Holden and Lynch (2004) and Hussey and Hussey (1997) point out that this dimension includes two opposite approaches: subjective and objective. Nevertheless, there is no unanimity in the literature when it comes to the nomenclature of the two opposing approaches. For instance, Easterby-Smith, Thorpe, Richard and Andy (1991) names the approaches as “positivism” and “phenomenology” while Hughes and Sharrock (1997) name them as “positivism” and “interpretive alternative”.

In this research, as most of the literature studies named the approaches as “subjective” and “objective”, this nomenclature will be used. Figure 23 shows a general comparison between both approaches.

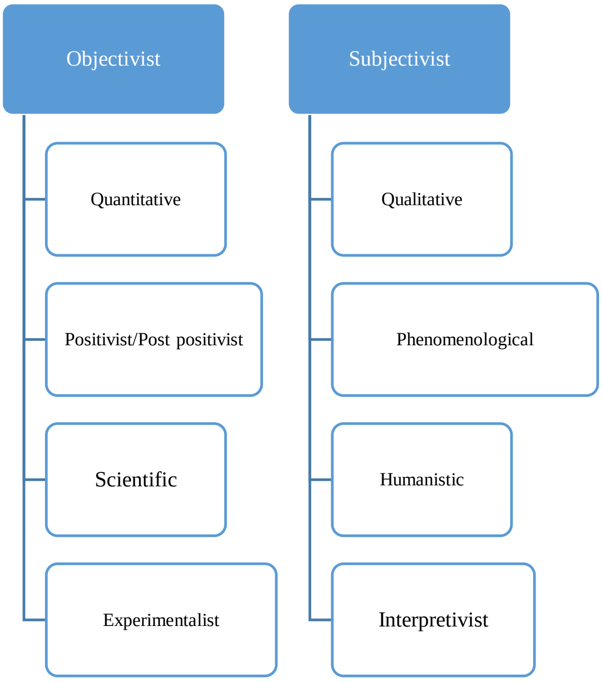


Figure 23. **General comparison between subjective and objective approaches**

3.3.1 Research paradigms

Whether the research is approach is subjective or objective, the two approaches involve a set of core assumptions concerning the following aspects:

- Ontology: what is the nature of reality?
- Epistemology: how do we know what we know? What is the evidence?
- Axiology: What do we believe is true?
- Methodology: How should we study the world?

According to Chilisa and Kawulich (2012), those four assumptions form the core of the philosophical paradigms. The paradigm is a shared world view that represents the beliefs and values in a discipline and that guides how problems are solved. The term "paradigm" was used by researchers such as Lincoln, Lynham and Guba (2011) and Mertens (2009). However, Creswell (2014) used the term "worldview" instead of the word "paradigm" and defined it as "a basic set of beliefs that guide action" which is similar to the definition of "paradigm" provided by Chilisa and Kawulich (2012), Lincoln, Lynham and Guba (2011) and Mertens (2009). Other researchers such as Crotty (1998) called them *epistemologies and ontologies* or *broadly conceived research methodologies*. In all cases, there was a unanimity on the definition of the terms among all researchers.

Despite the fact that much debate in the existing literature is present regarding what paradigms/worldviews/beliefs bring to inquiry, researchers seem to agree that the major research paradigms that are widely discussed in the literature are the following:

- Post-positivism
- Constructivism
- Transformative
- Pragmatism

Each one of the aforementioned paradigms has its own four core assumptions which are: ontology, epistemology, axiology and methodology. In this section, the major philosophical paradigms will be explored in order to justify the philosophical position of this research along with its own core assumptions.

3.3.1.1 Post-positivism

Several literature sources use the words “positivism” and “post-positivism” interchangeably. Nevertheless, there exists some differences between “positivism” and “post-positivism”. Chilisa and Kawulich (2012) and Bodgan and Biklen (2003) agree on the fact that the term “positivism” was first used by Auguste Compte to reflect that knowledge is based on experience. Chilisa and Kawulich (2012) point out that “positivism is based upon the view that science is the only foundation for true knowledge”. Creswell (2014) draws on this concept and argues that the positivism paradigm is sometimes called *the scientific method.* Crotty (1998) uses the evidence presented by physicists Werner Heisenberg and Niels Bohr to provide a rebuttal to the positivism perspective by portraying the scientist as the person who builds knowledge instead of just observing the laws of nature. Accordingly, the post-positivism appeared as a less stringent form of positivism in which the establishment of a theory, data collection that either supports or refutes the theory and additional tests should be conducted in order to determine the associated effects or outcomes (Creswell 2014). According to Chilisa and Kawulich (2012), the positivism/post-positivism’s position about the four assumptions of this paradigm are:

3.3.1.1.1 Ontology: what is the nature of reality?

According to positivism, there is only one tangible and objective reality that does not change across time and setting (which is considered as naïve realism). The researcher’s role is to uncover such reality. On the other hand, according to post-positivism, reality exists but because of the researcher’s limited human nature, reality can never be known perfectly.

3.3.1.1.2 Epistemology: how do we know what we know? What is the evidence?

Positivists believe that the right data gathering technique is a tool that ensures the production of absolute truth. These data gathering techniques are usually questionnaires, observations, tests and experiments. Post-positivists believe that absolute objectivity cannot be achieved.

3.3.1.1.3 Axiology: What do we believe is true?

Positivists believe that the scientific data gathering techniques should be used objectively. Post-positivists provided a rebuttal to this perspective by pointing out that the hypothesis, theories and background of the researcher can have an influence on what is studied and observed.

3.3.1.1.4 Methodology: How should we study the world?

Both positivists and post-positivists adopt a quantitative methodology consisting of theories and ideas, measurement of variables, scientific data gathering techniques and experimental, quasi-experimental, correlational, comparative and quantitative research designs.

3.3.1.2 Constructivism

Chilisa and Kawulich (2012) and Creswell (2014) called constructivism “interpretivism”. The major characteristic distinguishing constructivism from post-positivism is that in post-positivism, researchers start the study with a theory while in constructivism, a theory is generated as a research result. Lincoln *et al.* (2011), Mertens (2010) and Crotty (1998) developed robust studies on constructivism in which they agree on the fact that the goal of the research for a constructivist is to depend on the participants’ backgrounds and views on the studied situation that is why constructivists study the interaction process between individuals. According to Chilisa and Kawulich (2012), the constructivism’s position about the four assumptions of this paradigm are:

3.3.1.2.1 Ontology: what is the nature of reality?

Chilisa and Kawulich (2012) provided evidence to support the studies presented by Creswell (2003) and Mertens (2009) and which state that reality is mind dependent depending on how individuals are constructing them. This is a challenge to positivists’ point of view which assumes that there is only one tangible reality.

3.3.1.2.2 Epistemology: how do we know what we know? What is the evidence?

Since knowledge is mind depended, then it is totally subjective. Accordingly, stories prevailing in communities can be considered as a legitimate source of knowledge.

3.3.1.2.3 Axiology: What do we believe is true?

Due to the fact that knowledge is mind depended and that knowledge is subjective, the researcher's values will affect the chosen paradigm, topic, data collection, analysis methods and interpretation of the findings.

3.3.1.2.4 Methodology: How should we study the world?

According to Mertens (2009), constructivists do not establish research questions until the study starts. The research questions are open-ended. The research methodology is quantitative with research designs that include phenomenology, biography, case study and grounded theory (Creswell 2003).

3.3.1.3 Transformative

Creswell (2014) and Mertens (2010) stated that the transformative paradigm "holds that research inquiry needs to be intertwined with politics and a political change agenda to confront social oppression at whatever level it occurs". Accordingly, issues such as oppression, suppression and alienation are the starting point of the study. In order to avoid such issue, participants take part in designing the research questions, collect data, perform data analysis and examine the results. According to Chilisa and Kawulich (2012), the transformative's position about the four assumptions of this paradigm are:

3.3.1.3.1 Ontology: what is the nature of reality?

The transformative paradigm is based on the fact that reality is continuously changing and that it has multiple layers.

3.3.1.3.2 Epistemology: how do we know what we know? What is the evidence?

In the case of the transformative paradigm, knowledge is constructed from the participants' frame of reference.

3.3.1.3.3 Axiology: What do we believe is true?

The transformative paradigm differs from the constructive paradigm in the fact that unlike the constructive paradigm where every opinion is correct, the transformative paradigm carries some correct views and other wrong views.

3.3.1.3.4 Methodology: How should we study the world?

The transformative paradigm can be studied using both qualitative and quantitative methods. The goal of the research is to replace false knowledge by correct one and empower people to transform society.

3.3.1.4 Pragmatism

According to Patton (1990), the major difference between pragmatism and post-positivism lies in the fact that the former arises out of actions, situations and results while the latter depends on previous conditions. Rossman and Wilson (1985) argues that in pragmatism, the main emphasis is on the research problem rather than on the research method. According to the studies provided by Creswell (2014) and Cherryholmes (1992), the pragmatism's position about the four assumptions of this paradigm are:

3.3.1.4.1 Ontology: what is the nature of reality?

There is no single reality for pragmatists. There is a freedom of research for researchers. Cherryholmes (1992) concluded that pragmatists believe that we need to stop asking questions about reality and the laws of nature.

3.3.1.4.2 Epistemology: how do we know what we know? What is the evidence?

Truth varies based on what is applicable at the time of research.

3.3.1.4.3 Axiology: What do we believe is true?

Pragmatists believe that the door is always open to multiple methods, different paradigms, different assumptions and different data collection techniques.

3.3.1.4.4 Methodology: How should we study the world?

Pragmatists believe that the best research approach for them is the mixed method approach as it includes equally quantitative and qualitative assumptions.

3.3.2 Adopted philosophical position for this research

Based on the aforementioned general background about the most popular and known research paradigms, and based on the problem statement as well as the research aims and objectives specified in Chapter One, the adopted philosophical position that is appropriate for this research is post-positivist where the establishment of a theory, data collection and additional tests should be conducted in order to determine the associated effects or outcomes.

3.4 Research Design

The research design is different from the research approach. Denzin and Lincoln (2011) call research design *"strategies of inquiry".* Creswell (2014) use the same terminology and defines the research design as "types of inquiry within qualitative, quantitative and mixed method approaches that provide specific directions for procedures in a research design". Table 7 provides an overview of the various research design studies in previous literature sources.

Table 7 : Various research designs

Quantitative	Qualitative	Mixed methods
•Experimental designs •Non-experimental designs	•Narrative research •Phenomenology •Grounded theory	•Convergent •Explanatory sequential •Transformative, embedded or multiphase

Source: Creswell (2014)

3.4.1 Adopted research design for this research

As previously stated, the research approach is mainly quantitative approach with some elements of qualitative approach especially in the early stages of the research. Regarding the particular research design adopted within the quantitative scheme, this research follows a *quasi*-experimental approach. According to the Center of Innovation for Research and Teaching (CIRT), quasi-experimental and true experimental research designs both attempt to determine causal relationships by applying a condition to one group and comparing the outcome with a control group. A true experimental design is the basic standard in assessing causal relationship because it depends on the fact that subjects are *randomly* assigned to the groups to avoid bias and it controls all extraneous variables. Accordingly, the quasi-experimental research design is referred to as the experimental research occurring within its natural setting, without randomization. The advantage the quasi-experimental research design offers over the purely experimental research design is that the former uses a broader and wider array of data collection techniques and statistical analyses than true experimental research. Meanwhile, the validity of quasi-experimental research design can always be improved by various methods that assist in decreasing bias and by using appropriate statistical analyses techniques.

3.5 Research methods

The research method includes the specific steps of data collection, data analysis and data interpretation (Creswell 2014).

3.5.1 Research method adopted for this study

3.5.1.1 Data pre-processing

The collected data will have quality if it fits the purpose for which it was collected (Han, Kamber and Pei 2012). Before using the collected data, the data will undergo extensive steps of preparation. According to Pyle (1999), correct data preparation prepares both the data miner and the data. Preparing the data means the model is built right. Preparing the miner means the right model is built. Accordingly, pre-processing the data will enable the modeler to fully understand the collected data. Furthermore, it is a crucial step ensuring the success of the model.

The steps that will be followed for data pre-processing are expected to be as follows:

3.5.1.1.1 Data cleaning

According to Han *et al.* (2012), if there are any reasons that make the modeler believe that the data collected is “dirty”, it is unlikely for them to trust the results emerging from such data. Furthermore, “dirty” data will certainly lead to unreliable results. Accordingly, data cleaning is a crucial process performed by filling in missing values, smoothing “noisy” data (data with random errors), identifying or removing outliers (data falling outside a cluster of other data), and resolving inconsistencies.

3.5.1.1.2 Data integration

Data integration is simply merging data from various databases after removing any conflicting information from those different sources. Meanwhile, Han *et al.* (2012) points out to the fact that data integration should be done carefully with the aim of avoiding redundancies and inconsistencies in the resulting dataset.

3.5.1.1.3 Data transformation

This is one of the most important steps in the data pre-processing operation. In this step, the data collected will be transformed or consolidated as a means to obtain more efficient results in the future and in order to make the patterns easier to understand.

3.6 Ethical Consideration

Data collection is one of the crucial steps in this research. The University of Salford has clear and specific requirements and standards concerning research involving human participants or sensitive data conducted by research degree candidates. One of the major steps is to apply for ethics approval from the relevant Ethics Panel before starting data collection and to be subjected to ethics panel´s scrunity. Accordingly, in this research and before commencing the data collection process, one of the crucial aspects to ensure was to carry out the research ethics in total compliance with the policy and approved requirements of the University of Salford. Furthermore, the researcher ensured the safety, privacy, dignity and wellbeing of participants for this research study.

3.7 Artificial Neural Networks

Boussabaine (1996) provided a simplistic but useful definition for Artificial Neural Networks (ANNs). He briefly defined ANNs as “systems that can learn”. In other words, when studying a particular problem, the Artificial Neural Network system can be trained based on a group of “input” and “output” data; it is based on such data that the Artificial Neural Network System can “learn”. Then, based on this training, the system can use what it “learnt” in order to predict new outcomes. This feature is what enables Artificial Neural Networks to be used in complicated problems in different disciplines. This section of the research provides an overview of ANN, its various applications in civil engineering and construction management in addition to some advantages and limitations. This section also uses this explanation in order to provide the justification for using such system for this research.

3.7.1 Background

Boussabaine (1996) provided a robust study on ANNs and their use in construction management. He started by explaining that the ANNs are like the human brain and they are designed to operate in the same way. The human brain learns from experience and ANNs can do the same. Nevertheless, Boussabaine went back and questioned the ability of ANNs to function exactly like the human brain as this practically impossible despite the analogies between the way the human brain and ANNs function. In a recent study, Waziri, Bala and Bustani (2017, p.50) defines ANNs as “computational mechanisms that have the ability to acquire, represent and compute function from one multivariate space of information to another given a set of data representing that function”. Figure 24 shows how biological and artificial operate and it illustrates the similarity in composition.

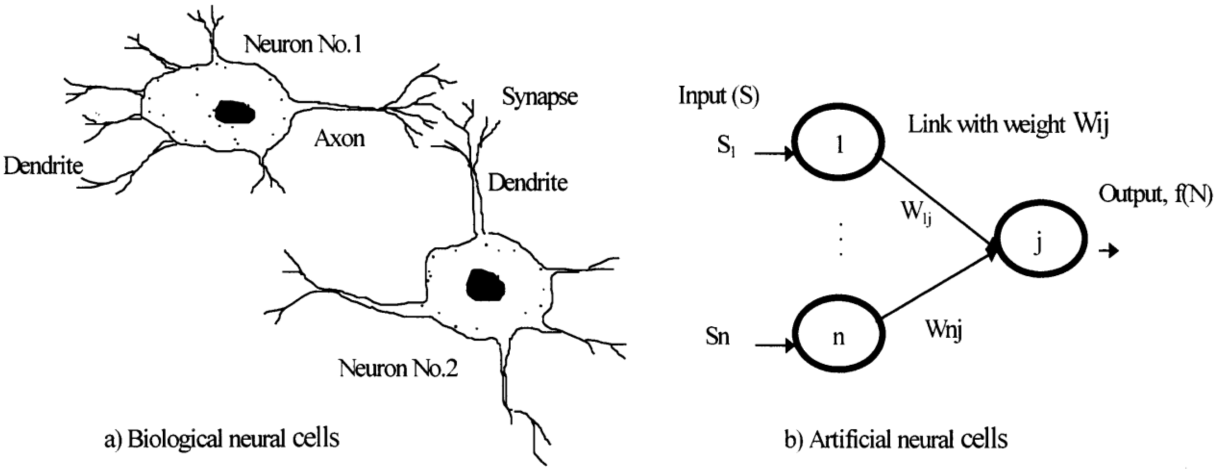


Figure 24. **Similarity in composition between biological and artificial neural cells (Bhokha & Ogunlana 1999)**

3.7.2 Components of ANNs

As the Artificial Neural Networks mimic the human brains, their components are named after the human brain’s components. ANNs consist of neurons (also named as cells, units or nodes) and synaptic transmissions with weight factors (Boussabaine 1996). Usually, an ANN consists of a number of layers, typically three layers: (1) Input layer, (2) hidden layer, and (3) output layer. Each layer consists of a number of nodes. Each node in a given layer is connected to each node in the next layer. Galkin (2002) points out that the node is considered as processing elements of the network. The nodes of the input layer and the nodes of the output layer are the nodes through which the communication with the outer world is established. The hidden layer, which is the middle layer, is the layer giving the "critical computational ability to the system". The way each node is connected to the other units in the network is called "the pattern of connectivity" or "network topology" (Boussabaine, 1996). Gunaydin and Dogan (2004) and Rafiq*, et al.* (2001) provide further explanation to the hidden layer highlighting its importance. They point out that the main role of the hidden layer is to extract and memorize the useful features from the input layers in order to determine the values of the output layer. Nevertheless, nothing in the existing literature provides a way to choose the number of processing elements or nodes. The conclusion reached by Gunaydin and Dogan (2004), Shtub and Versano (1999), Rafiq *et al.* (2001), Setyawati *et al.* (2002) and Albino and Garavelli (1998) is the same in this regard. These researchers agreed on the fact that the only way to determine the optimum number of nodes especially for the hidden layer is trial as there is no rule to calculate it. Figure 25 illustrates the structure of a typical three-layer neural network system.

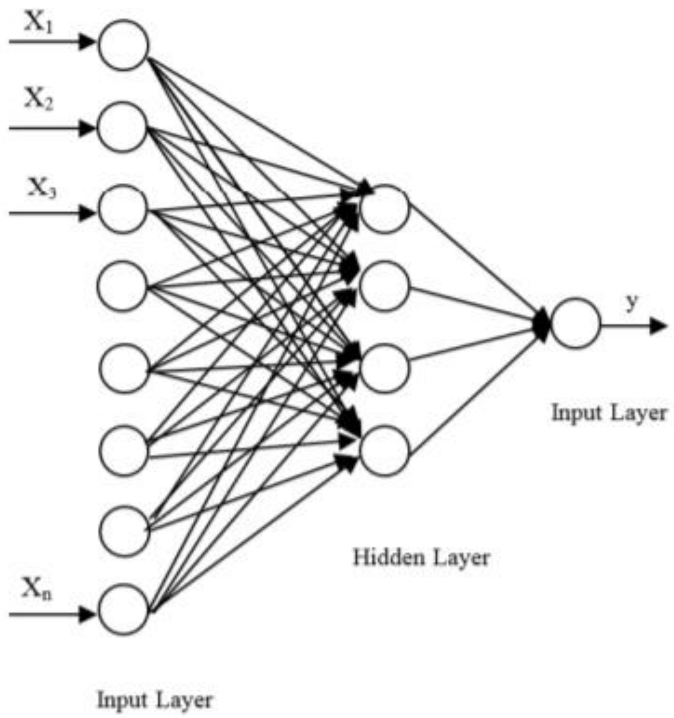


Figure 25. **The structure of a typical three-layer neural network system (Waziri *et al.* (2017)**

3.7.3 How do neural networks work?

The first attempt for a mathematical representation of a "node" was done in 1943 by the Neuro physiologist Warren McCulloch and the Logician Walter Pits (Galkin 2002). Figure 26 illustrates the activities occurring at each neural network node.

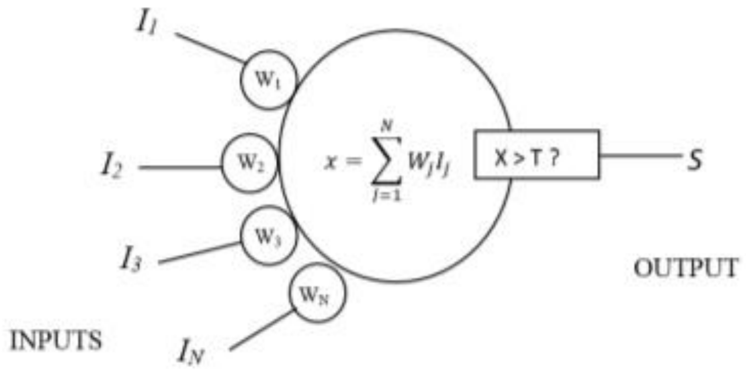


Figure 26. **Activities occurring at each neural network node (Galkin 2002)**

Each node receives a number of inputs "I" (I1 to In). Each input has its corresponding weight factor "W" (W1 to Wn). The weight varies based on the relative importance of each input data and it represents "the strength of the connection". Then, the node calculates the weighted sum I(1)W(1) + I(2)W(2) and generates an output value. This output value is then delivered to each node of the next layer following the same computational technique. This pattern continues for each node in each layer until reaching the final node situated in the output layer. At this stage, "the output value has reached its final destination" (Boussabaine 1996). Figure 27 illustrates how a typical ANN system works.

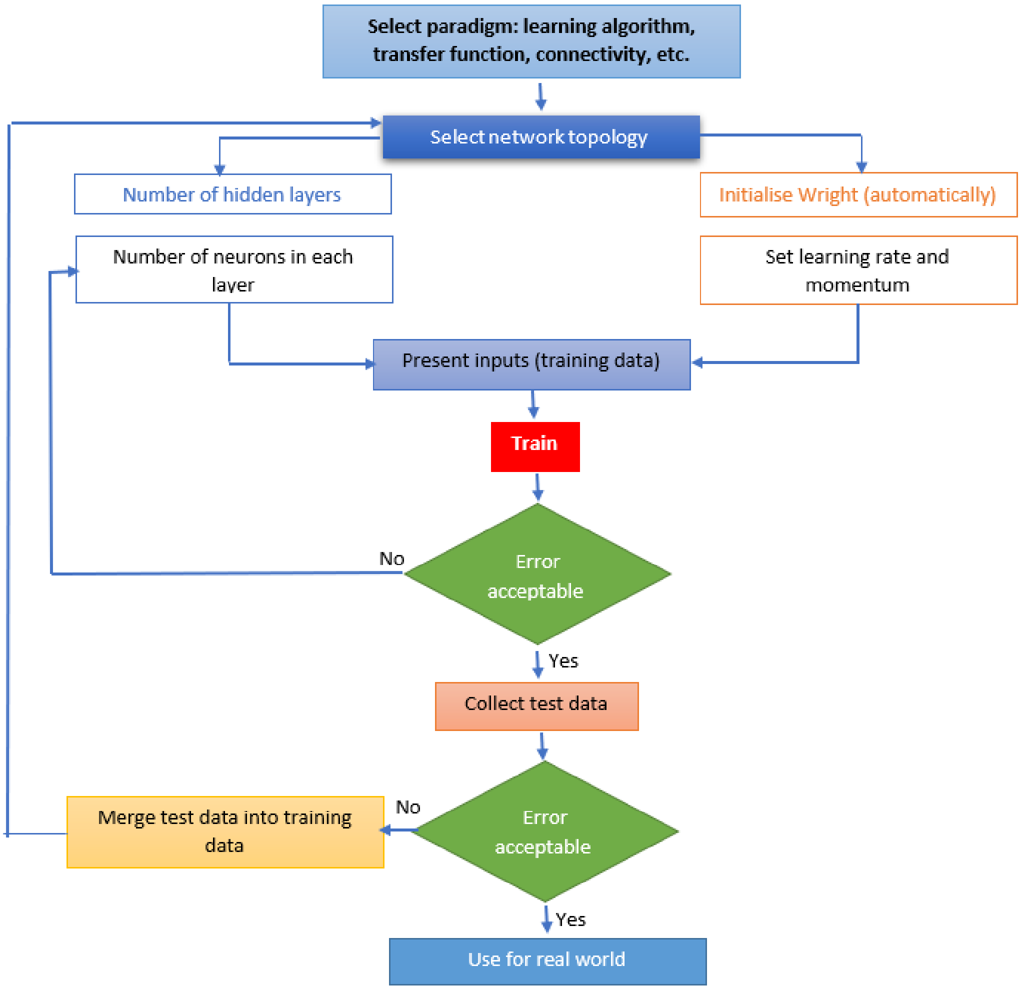


Figure 27. How a typical ANN system works (Boussabaine 1996)

The basis of operation of Artificial Neural Networks depends on two important features:

- Training and testing
- Validating

3.7.3.1 Training the system

As it was previously stated in this section, training the system means making the system "learn". There was unanimity among researchers regarding the classification of training techniques. According to Bailey and Thompson (1990), Masters (1993) and Boussabaine (1996), there are three main types of training: (1) supervised, (2) unsupervised, and (3) reinforcement learning. The selection of a specific training type depends on the available data as well as on the problem that is being solved. Below is an overview of each type of training:

3.7.3.1.1 Supervised training

At the start of the training session, a target value is specified. During the training, the nodes in the input layer transmits the pattern to all nodes in the hidden layer where all the computations occur. Then, the output value is calculated for each node following the weighted average way explained earlier in this sub-sub-section (3.6.3). Each output node does its calculation and transmits it to the next output node until reaching the final output node where the final actual result is calculated. This process is called "feed-forward" (Boussabaine 1996). The final actual output result is compared to the target value previously specified by the trainer and the output error is calculated accordingly. An illustration for these steps is presented in Figure 28.

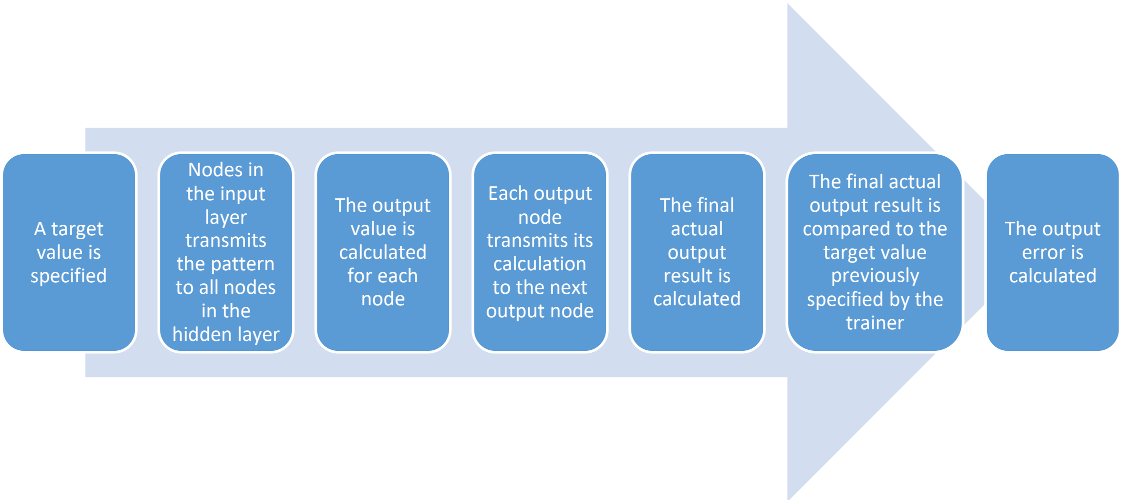


***Figure 28.* Steps of training the system**

If the error is accepted, then, the training is complete. In case the error is not within the acceptable ranges, this means that further training is required. According to Masters (1993), the "Mean Square Error" (MSE) is the way of evaluating the performance of the model during the training process. In this case, the derivatives of the error with respect to the weights that were assigned are calculated by the output nodes and the result is sent backwards through the hidden nodes in the hidden layer. At this stage, each node in both the hidden layer(s) and in the output layer adjust their weights in order to conduct the corrections. This process is called "backpropagation" (Boussabaine 1996). At this stage, the computations restart all over again following the normal feed-forward process explained earlier. The training can be done as many times as it is needed until the desired result is obtained, in other words, until obtaining a low MSE. At this stage, the training of the system is considered complete. When the training of the system is complete, this means that the system can be used “to predict the outcome of an input not previously seen by the ANN” (Boussabaine 1996) and this is the major aim of using ANNs. The supervised training is the type of training used in this research. According to Waziri *et al.* (2017), the backpropagation (BP) training algorithm is the most popular and the most used training technique used in ANNs.

3.7.3.1.2 Unsupervised training

In this type of training, the output target value is not specified. Instead, the training method changes the weights using the correlation between the various inputs and groups them in a way that similar inputs belonging to the same group will produce similar outputs (Boussabaine 1996).

3.7.3.1.3 Reinforcement learning

In this type of training, a group of inputs is specified in addition to only a grade as output (Boussabaine 1996).

Generally, to obtain good and accurate results, it is advised to have a large number of training samples. Nevertheless, there is no consensus within the literature on what represents a “large” amount of data in order to be able to use Artificial Neural Networks. The end of the training phase is an introduction for the start of the testing phase.

3.7.3.2 Validating the system

According to Moody (1991) and Boussabaine (1996), the first step in the validation process is to divide the data into training (learning set) which was explained in the previous section and test set. Moody (1991) added another step which is performing several independent divisions or “splits” and then averaging the results in order to determine an overall performance estimate for the whole system. Nevertheless, Boussabaine and Cheetham (1995) discussed a different facet regarding the error calculated on the training set, also known as the Root Mean Square error (RMS). A low RMS does not always mean that the training system is adequate. Sometimes, in case the system has too many nodes, too many hidden layers, the system can start memorizing the data and learning “irrelevant details about the individual samples rather than the basic structure of the data presented to it”. This problem is known as “over-fitting”. In this case, a large difference occurs between the training error and the testing error. Based on the previous explanation, Boussabaine and Cheetham (1995) provided evidence for the fact that RMS cannot differentiate between minor and serious errors. Masters (1992) discussed the same problem and suggested extensive solutions in order to avoid the drastic results that the RMS can generate. He argued that the absolute error, maximum absolute error and median error statistical measures are more robust and reliable than measures based on the RMS.

3.7.4 Applications of ANNs in civil engineering and in construction management

The literature review shows that the Artificial Neural Networks have been widely used in various domains (Boussabaine 1996) (Asakawa and Takagi 1994) (Widrow, *et al.* 1994). Widrow *et al.* (1994) provided evidence for such statement by explaining that ANNs have been used by banks in order to study the patterns of credit card usage for instance, in order to help them to predict any fraudulent transactions. Furthermore, ANNs are used by investment and financial firms a way to determine financial forecasting. Also, ANNs are used in the marketing domain by forecasting the potentially good prospected customers. The purpose in this research, since it is conducted in the context of the construction management, is to provide an overview of the applications of ANNs in the domain of construction management. Waziri *et al.* (2017) argues that ANNs have not been used in the domain of construction engineering until 1989 and ever since, they have been successfully used to solve several problems in engineering and management. Jain and Pathak (2014) points out that the first journal article on the use of artificial neural networks in the domain of civil/structural engineering was published by Adeli and Yeh (1989).

3.7.4.1 Cost estimation

According to Boussabaine (1996), ANNs started to be used in the domain of construction management from the early nineties. ANNs were widely used in the domain of cost estimation in construction management. For instance, according to Moselhi, Hegazy and Fazio (1991), an ANN model was developed to estimate the optimum markup in different bidding situations. The input layer for the model included different nodes representing the following:

- The different competitors
- The mean of the distribution of the ratio of the competitor's bid prices compared to the estimated costs by the contractors based on previous projects
- The standard deviation of the distribution of the ratio of the competitor's bid prices compared to the estimated costs by the contractors based on previous projects

The desired output (the optimum markup in different bidding situations) was determined based on three bidding strategy models and based on ten bid situations in training. Moselhi *et al.* (1991) argue that the ANN model delivered good results. Nevertheless, Boussabaine (1996) provided a rebuttal to Moselhi *et al.*'s (1991) perspective by highlighting that due to the fact that data sample used for training is relatively small, they may have been an overfitting problem. However, no more evidence was presented by Boussabaine (1996) to support his point of view.

Williams (1994) developed another ANN model that helps in predicting the changes in construction cost index. The input layer of the model consisted of nodes representing the recent trends, the prime lending rate, housing starts and the month of the year. The output of the model was compared to a forecast determined by linear regression model. Nevertheless, the model gave higher errors than the errors obtained by the statistical methods. This in fact contradicts what is stated in other literature sources regarding the fact that ANN have the ability of delivering better solutions than the conventional statistical methods. Williams (1994) was even more forthright and advocated for the results of his model by stating that the failure to his model may be caused by a bad selection and design of input data or a bad choice of the network topology. Geiger, Knoblach and Backes (1998) developed an ANN to predict the cost of metal sheets from direct material cost and cost of supplied parts. The model achieved an overall accuracy ranging from 5% to 15%. Setyawati *et al.* (2002) developed an ANN model in order to estimate the costs associated with institutional buildings. The developed model delivered an accuracy of 16%. Sodikov (2005) developed an ANN model estimating the total cost of highway projects. Based on the developed model, he concluded that ANN is an appropriate tool for solving complex problems as it can easily adapt to imprecise data. Yadav, Vyas and Vyas (2016) developed a cost estimation ANN model that predicts structural cost of residential buildings. Data covering a time span of twenty-three years was collected from bill of quantities for training and testing of networks. The data collected included several factors such as the cost of cement, sand, steel, aggregates, mason, skilled and non-skilled labour.

3.7.4.2 Construction scheduling

Flood (1989) described the development of an ANN model that was used for optimizing the sequence of construction activities in order to decrease the production time. The input layer consisted of several nodes representing the time spent for each activity and the output is the production of an optimum job sequence. Nevertheless, the model showed its limitations in case variance occurs between the different patterns. In 1997, Adeli and Karim developed an ANN model in order to solve the construction duration of highways. Waziri *et al.* (2017) stated that this method was satisfactory as it provided a basis on which more flexible and accurate scheduling systems can be developed. In 1999, Bhokha and Ogunlana developed an ANN model predicting the construction duration of high rise buildings in the pre-design stage. The network has the ability to forecast the construction duration at the pre-design stage with an average error of 13.6%. Yahia, Hosny and Razik (2011) employed ANN to develop an ANN model predicting the time contingency that should be added to the scheduled project completion time. Golizadeh *et al.* (2016) developed another ANN model which output was to determine the duration of major activities relating to the structural elements of concrete frame buildings.

3.7.4.3 Decision making

Boussabaine (1996) suggested that the use of ANN in the domain of decision making will be of great benefit as several managers take decisions based on incomplete knowledge obtained, most of the time, through probability and regression techniques. Due to the fact that ANN have the ability to learn and generate solutions from incomplete data, ANN can be a useful tool assisting users and managers in taking decisions. In fact, two years before Boussabaine's research, Murtaza and Fisher (1994) created an artificial neural network decision making model about construction modularization when building an industrial process plant. The decision attributes based on which the decision would be made were divided into five categories: plant location, environmental and organizational, labor-related, plant characteristics, and project risks. Masri *et al.* (1996) presented a neural network model detecting changes in the characteristics of structure systems relying on the use of vibration measurements from a "healthy" system to train a neural network for identification purposes. It was found that the proposed damage detection methodology is capable of detecting small changes in the structural parameters, even in case the vibration measurements are noise polluted (Pathak and Agarwal 2014).

3.7.4.4 Dispute resolution and litigation

Yitmen and Soujeri (2010) developed an ANN model to predict the effect of change orders on the project performance. The aim of the model was to predict the impact of projected disputes before they occur and hence avoid the lengthy litigation process. The study was mainly concerning projects in North Cyprus. Waziri *et al.* (2017) argued this model was efficient in determining the probability of disputes in a given project. In 2014, Fatima, *et al.* developed an ANN model which optimizes the frequency of dispute parameters aiming to minimize construction disputes.

3.7.4.5 Risk assessment

Odeyinka *et al.* (2002) developed an ANN model studying the impact of various construction risks on the total project cost. Backpropagation ANN model was used to develop the risk assessment model. The model was tested on 20 new projects in order to predict the impact of risks on those projects at 30%, 70% and 100% stages. Maria-Sanchez (2004) used the neural network approach to predict the impact of environmental risks on construction projects. Her study was on projects in Puebla, Mexico. The system offers the advantage of predicting the possible value of the total environmental risks affecting the project. Lhee *et al.* (2014) developed a two-step neural network model predicting the optimal contingency that shall be used in transportation projects. Another risk assessment model was developed by Liu and Guo (2014) for project construction quality. The model accuracy was tested using a dataset of residential building projects in the Guangzhou development zone.

3.7.4.6 Estimating excavation capacity and excavator efficiency

Chao and Skigniewski (1994) developed two ANN models. The first model's output was the estimation of excavation capacity based on the site conditions. The output of the first model was used as an input for the second model. The second's model output is the excavator's efficiency measured by hourly productivity. Despite the fact that the model was limited as it did not involve any possibility for changing the number of hidden layers, this model was considered as a start of application of ANN models to the estimation of construction operation productivity.

3.7.4.7 Use of ANN in the domain of PPP projects

The use of Artificial Neural Networks in the domain of PPP projects is still limited. Jin and Zhang (2010) developed an ANN model for modelling optimal risk allocation in PPP projects. A questionnaire was distributed among participants working in the construction industry in order to obtain the inputs for the model. Then, the model's output was compared to the results obtained from the traditional MLR (Multiple Linear Regression) mode. It was found that the ANN model delivered satisfactory results. A second attempt at using ANNs in the domain of PPP projects was taken by Chou (2012) with the development a model predicting dispute handling techniques in PPP projects. The aim of the model was to predict which dispute resolution technique shall be used (negotiation, mediation, litigation, arbitration or no dispute). The results delivered a total accuracy of 84.65%. Nevertheless, Waziri *et al.* (2017) argues that this method is more applicable at the start of the dispute. Nevertheless, it is noticed that the application of the Artificial Neural Networks is still at its start as it has not been extensively used in this domain, even less in the field of risks associated with PPP projects.

3.7.5 Neural Networks advantages and criticism

3.7.5.1 Neural Networks advantages

Providing better solutions for complex problems

Rumelhart, *et al.* (1994) stated that ANNs provide better solutions for problems involving complex non-linear relationships than conventional methods. This was the same conclusion reached by Boussabaine (1996). In their two studies published in 1994, Flood and Kartam (1994a, 1994b) provide evidence to the same conclusion by stating that the structure of ANNs enable them to easily "adapt" to solve non-linear complex problems even if the environment or the system being modelled changes with time. Jain and Pathak (2014), Adeli and Hung (1995), and Haykin (1999) all argue Artificial Neural Networks have high computational abilities enabling them to be used in the fields of "prediction and estimation, pattern recognition and optimization". Whilst Bhokha and Ogunlana (1999), espouse ANNs can provide accurate results even if the data includes errors or is incomplete. Moreover, ANNs have the ability to process information quickly if it is applied to solve real world problems.

ANNs have the ability to "learn"

Flood and Kartam (1994) point out that contrary to the conventional models, ANNs have the ability of "learning", "self-optimizing" and "adapting" to variables. Waziri *et al.* (2017) reached the same conclusion; according to them, ANNs provide the advantages of "adaptive learning", "self-organization", "real time operation" and "fault tolerance" when compared to the conventional statistical methods. According to Bhokha and Ogunlana (1999), ANNs can have a surprising number of the human brain's characteristics, such as learning from past experience and generalizing from previous examples to new problems.

ANNs can be used as a strong decision-making tool

Boussabaine (1996) confirms that ANNs have the ability of adjusting their weights automatically to match variables. In a complex industry like the construction industry, ANNs can be combined with statistical inference techniques in addition to the experts' experience in order to provide decision support for experts, decision makers and even to train inexperienced personnel. Furthermore, ANNs are considered as a powerful *"what if"* tool. In order to benefit from these wide ANNs' benefits, Boussabaine (1996) advised to avoid limiting the use of ANNs to simply modelling the decision-making behavior of the user.

3.7.5.2 Neural Networks criticism

Boussabaine (1996) argues that Artificial Neural Networks are similar to "the black-box". There seems to be unanimity among various researchers regarding this description. Jain and Pathak (2014) describes ANNs as "black-box, model-free and adaptive tools to capture and learn significant structures in data". Such black-box nature makes the data go in the model, be processed and then go out in the form of an output or prediction without giving the user the chance to understand what happens in between. In an attempt to solve such problem and in order to try to understand the nature of ANNs, it is important to conduct continuous research especially in the domain of construction management and develop several models using the ANN system in order to develop a pattern. The same criticism for ANN models has been reiterated by Paliwal and Kumar (2011) who suggest that despite the numerous advantages that ANN models can provide, there still exists ambiguity when it comes to explain the relationships between the parameters used for modelling. Consequently the solution Paliwal and Kumar (2011) avocate was that further research is needed to understand the framework and internal operation within the ANN in order to study the impact of the independent variables on the model.

3.7.6 Why ANNs for this research?

- As it was explained earlier and as the literature shows, ANNs have been extensively used in the domain of construction engineering and management. It is true that not all the developed models were successful. However, in the domain of construction management, the results associated with the use of ANNs were satisfactory due to their excellent learning and generalizing capabilities (Jin and Zhang, 2010).

- As this research aims to modelling the risks associated with PPP projects and related poor management of stakeholders, several variables will be inserted into the model. Also, not all the variables (risks) can be measured in the same way. Due to the wide mix of variables and their different scales of measurement, ANN a more suitable tool that will solve complex relationships.

- It is true that the MLR statistical approach is used to study the relative effect of several independent variables on a particular output, which is similar, to a great extent, to artificial neural networks. The MLR aims to minimizing differences between observed and predicted values. Nevertheless, MLR is suitable for “linear relationships”. As it will be demonstrated through the next chapter, non-linear relationships exist between most of the risks and the completion of the project. The MLR will model all the data to a “best-fit” line as illustrated in figure 29.

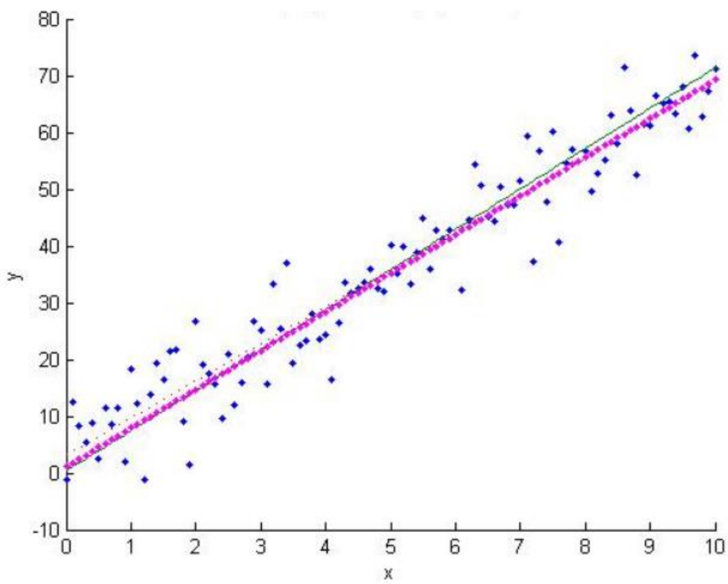


Figure 29. **Linear regression model**

Artificial Neural Networks, on the other hand, will model the non-linear relationship between variables as shown in Figure 30.

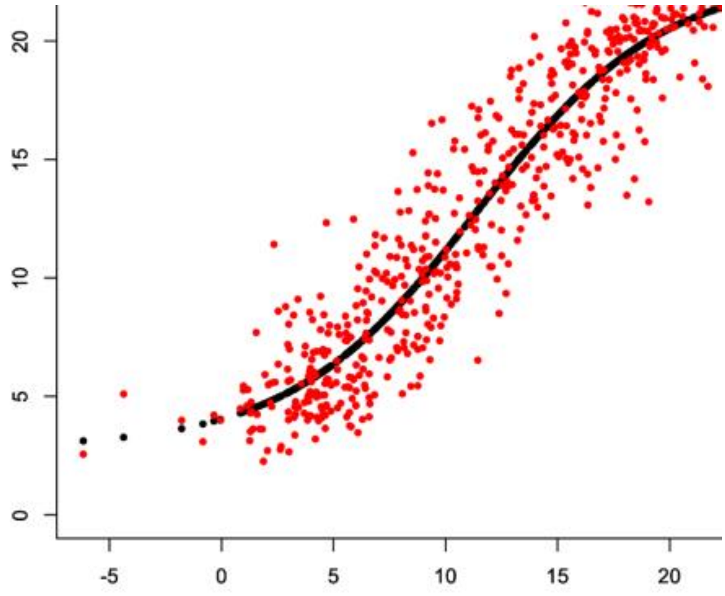


Figure 30. **Non-linear relationship modelling**

- In this research, the relationships between variables cannot be described using the conventional approaches. Elhag and Boussabaine (1998) point out that ANNs do not require to specify the relationship between the variables. This is a major characteristic that discerns ANNs from conventional MLR. In this research, due to the complex type of construction projects and especially PPP projects, as it will be illustrated in Chapter Four, there are several variables that are not directly related to each other. Accordingly, it is expected that ANNs will deliver better and more accurate results than classical mathematical and traditional procedures.

- As the literature showed, Artificial Neural Networks have been widely used since 1989 in the domain of construction management with minimal applications in PPP projects. Accordingly, since ANNs proved their success over conventional methods in the domain of construction management, applying ANNs to PPP projects especially in the domain of risk management will be an addition to the existing knowledge. It will be wrongful to expect this research and modelling approach to be immediately adopted but the domain of construction management is rich and rapidly changing. New studies and research are conducted every day. Accordingly, this research shall make an original contribution to the already-existing knowledge in this domain and can be an assisting tool for future studies.

3.8 Chapter Summary

This chapter has provided details of the research approach adopted in this research. A rationale for this approach has been detailed, along with a framework to guide the experimental exercise in this research. Based on the above discussion, the overall research approach adopted for this research can be summarized as follows:

- Research Approach: Quantitative with some aspects of qualitative approach
- Philosophical position: Post-positivist
- Research design: Quasi-experimental approach
- Research method: Data pre-processing techniques:
    - Data cleaning
    - Data integration
    - Data transformation
    - Data partitioning

An overview of artificial neural networks, with various applications in civil engineering and construction management such as cost estimation, construction scheduling, decision making, dispute resolution and litigation, risk assessment and PPP projects has also been provided. Some of the strengths and potential weakness of ANN have also been discussed along with the reasons for which ANN is used for this research.

Chapter 4 – Research findings

4.1 Chapter Introduction

This chapter is structured to first explain the steps performed to develop the list of risks affecting PPP projects. Then, the data collection and the modelling concept are explained with a special emphasis on the modelling philosophy adopted in this research. The data used for the modelling is also described as well as the data processing techniques used for training and validating the models that will be developed. The aim in this chapter is to extract the necessary information from the historical project data to build the delay estimation models studying the impact of stakeholders and construction related risks on both traditional and PPP projects. The actual methodology used in this research is illustrated in Figure 31.

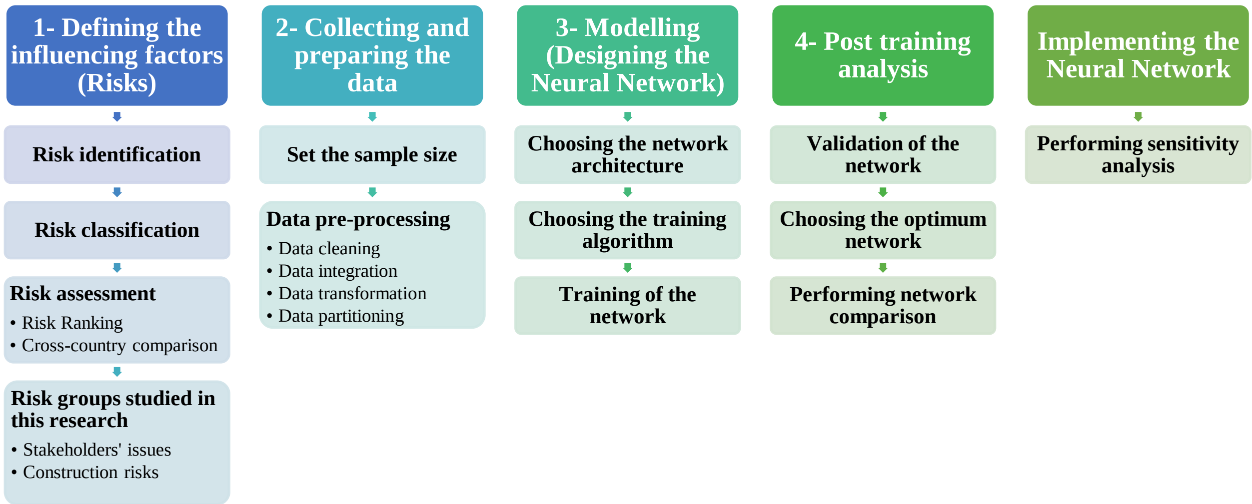


Figure 31. **Actual methodology used in this research**

4.2 Defining the influencing factors (Risks)

4.2.1 Risk identification

As it was previously stated in Chapter 2, generally, risk management includes: risk identification, risk assessment and risk response (AS4360 2004; PMBOK 2004; Al-Bahar 1989) as illustrated in Figure 32.

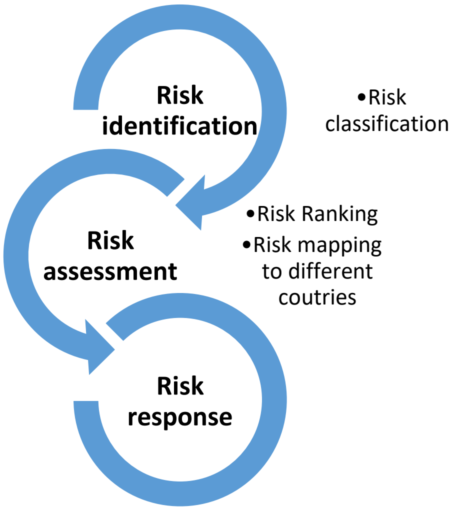


Figure 32. **General steps of risk management**

Wang, *et al* (2004) points out that identification of risks associated with PPP projects is a crucial phase in PPP projects and should be done at the early start of the project. Fang, *et al* (2004) argues that despite being a simple idea but developing a risk checklist can be a valid and effective risk identification method. Zou, *et al* (2007) confirms that in addition to risk identification, risk categorization is an important step towards sound risk management. Based on a study done by Hwang *et al.* (2012), risks are identified based on literature review and ranked based on “content analysis”. In this research, a comprehensive list of risks affecting PPP projects is developed following an extensive literature review based on various sources such as journals, articles, books, internet sources and informal discussions with experts and researchers (Valipour *et al.* 2016).

In order to ensure the significance and the correctness of this step, the sources (such as journals, articles, books, etc.) are chosen to be over a long-time span and covering several countries. This will make the list of identified risks as comprehensive as possible. According to another study done by Ke *et al.* (2010), the identified risks can be categorized by country, project and market risk. The identified risks can also be classified into Macro, Meso and Micro (Li *et al.* 2005).

In this research and in order to develop “the risks checklist”, an extensive literature review of 30 sources was thoroughly studied in order to develop the list of the risks affecting PPP projects. To properly develop a comprehensive list of risks, the journal papers, research and publications that were studied covered the time span between 1998 and 2018. Furthermore, the literature review performed for the sake of developing the risk factors was encompassing different countries. Some researches were studying the risk factors worldwide and others were dedicated to specifically study the risks associated with countries such as: the United Kingdom, Hong Kong, Scotland, China, Australia, India, Indonesia, Singapore, Iran, Malysia, Thailand, Portugal and South Africa. These countries were chosen to encompass different levels of PPP experience as previously explained in Chapter Two (Section 2.2.5: PPP around the world: success and failure stories). For instance, the United Kingdom is an experienced country with a long history in PPPs, China and India are considered countries with limited PPP experience while Portugal is considered a country with moderate PPP experience. The risks extracted from this literature review are the outcomes of previous research, interviews and questionnaires. Accordingly, a comprehensive list of 118 risks was developed. The list of risks developed is presented below in table 8:

Table 8. **List of 118 risks affecting PPP projects developed from an extensive literature review**

#	Risk factor	#	Risk Factor
1	Lack of support from government	16	Inconsistent legal framework
2	Unstable government	17	Change in tax regulation
3	Strong political interference	18	Public opposition
4	Corruption and bribery	19	Environment
5	Nationalization/Expropriation	20	Force Majeure
6	Poor financial market	21	Weather
7	Inflation	22	Geological conditions
8	Interest rate	23	Construction delays
9	Lack of legal/regulatory framework	24	Site safety and security
10	Poor quality workmanship	25	Design deficiency
11	Construction cost overrun	26	Scope variation
12	Excessive contract variation	27	Unproven engineering techniques
13	Material availability	28	Level of demand for project
14	Availability of finance	29	Site availability
15	High finance cost	30	Operation cost overrun
31	Financial attraction of project to investors	61	Low operation productivity
32	Delay in approval and permits	62	Maintenance cost higher than expected
33	Maintenance more frequent than expected	63	Labor availability
34	Residual asset risk	64	Construction/design changes
35	Inadequate PPP experience	65	Labor disputes/strikes
36	Lack of communication between stakeholders	66	Land use
37	Inadequate distribution of responsibilities	67	Waste of materials
38	Inadequate distribution of authorities	68	Construction completion
39	Lack of commitment between parties	69	Supporting utilities risk
40	Differences in working methods	70	Protection of geological and historical objects
41	Termination of concession by government	71	Operator default
42	Change in law	72	Quality of operation
43	Influential economic events	73	Condition of facility
44	Change in industrial code of practice	74	Contractual risk
45	Insolvency of Subcontractors	75	Third party tort liability
46	Ownership assets	76	Need for land acquisition
47	Insolvency of Concession company	77	Delay in resolving litigation or arbitration dispute
48	Insufficient income	78	Influential economic events
49	Fluctuation of material cost (by government)	79	Poor public decision-making process
50	Fluctuation of material cost (by private sector)	80	Sanction
51	Tariff change	81	Arbitrary definition of tariff of services by government

#	Risk factor	#	Risk Factor
52	Market demand change/Demand below anticipation	82	Competition
53	Exclusivity	83	Operating revenues below expectation
54	Foreign currency exchange	84	Lack of coordination and commitment
55	Residual risk	85	Need for environmental approval
56	Changes in value of granted land due to development	86	Third party delays
57	Changes in value of granted land due to inflation	87	Government intervention
58	Financial problems due to environmental protection	88	Government reliability
59	Need for land appraisal	89	Third-party reliability
60	Limited capital	90	Immature juristic system
91	Delay in resolving contractual dispute	104	Improper contract
92	Inadequate study and insufficient data	105	Delay in supply
93	Lack of standard model for PPP agreements	106	Technological risk
94	Payment risk	107	Constructability
95	Uncompetitive tender	108	Defects in construction
96	Consortium inability	109	Delay in operation
97	Private investor change	110	Excessive maintenance and refurbishment
98	Subjective evaluation	111	Failure/delay in commissioning test
99	Insufficient financial audit	112	Technical obsolescence
100	Change in output specification	113	Misunderstanding the role of stakeholders
101	Innovative design	114	Misinterpretation of contract
102	Design complexity	115	Stakeholder management
103	Low financial attraction of project to investors	116	Inadequate negotiation period prior to initiation
117	Staff crisis	118	Cultural differences between main stakeholders

4.2.2 Risk classification

The 118 identified risks were classified into various categories based on the source of each risk and on lifecycle perspective (Li and Zou 2012). Based on the research, the risks affecting PPP projects are classified into 16 different categories. Among the 16 categories, 6 categories are related to the life cycle of the PPP project which are: feasibility study, financing, design, construction, operation and commissioning. In this research, the specific stage in the lifecycle of the project where the risk appears is specified. However, some risks should be managed throughout the lifecycle of the project from the start till the end such as legal, political and stakeholders' related risks. The various risk categories along with the associated risks under each category are as follows:

1. Commissioning risks

Table 9. **Commissioning risks**

Risk factors	Risk group
Failure/delay in commissioning test	Commissioning risks

2. Construction risks

Table 10. **Construction risks**

Risk factors	Risk group
Geological conditions	Construction
Construction delays	Construction
Site safety and security	Construction
Poor quality workmanship	Construction
Construction cost overrun	Construction
Excessive contract variation	Construction
Material availability	Construction
Availability of finance	Construction
High finance cost	Construction
Site availability	Construction
Insolvency of Subcontractors	Construction
Labor availability	Construction
Labor disputes/strikes	Construction
Land use	Construction
Waste of materials	Construction
Construction completion	Construction
Supporting utilities risk	Construction
Protection of geological and historical objects	Construction
Third party delays	Construction
Government reliability	Construction
Third-party reliability	Construction
Delay in supply	Construction
Constructability	Construction
Defects in construction	Construction

3. Construction and design risks

Table 11. **Construction and design risks**

Risk factors	Risk group
Unproven engineering techniques	Construction and design
Construction/design changes	Construction/Design

4. Design risks

Table 12. **Design risks**

Risk factors	Risk group
Design deficiency	Design
Scope variation	Design
Change in output specification	Design
Innovative design	Design
Design complexity	Design

5. Economic and financing risks

Table 13. **Economic and financing risks**

Risk factors	Risk group
Poor financial market	Economic and Financing
Inflation	Economic and Financing
Interest rate	Economic and Financing
Change in tax regulation	Economic and Financing
Financial attraction of project to investors	Economic and financing
Foreign currency exchange	Economic
Changes in value of granted land due to development	Economic
Changes in value of granted land due to inflation	Economic
Financial problems due to environmental protection	Economic
Need for land appraisal	Economic
Limited capital	Economic
Payment risk	Economic and financing
Insufficient financial audit	Economic and financing
Low financial attraction of project to investors	Economic and Financing

6. Feasibility study

Table 14. **Feasibility study risks**

Risk factors	Risk group
Level of demand for project	Feasibility study

7. Legal

Table 15. **Legal risks**

Risk factors	Risk group
Lack of legal/regulatory framework	Legal
Inconsistent legal framework	Legal
Contractual risk	Legal
Ownership assets	Legal
Insolvency of Concession company	Legal

Risk factors	Risk group
Inadequate study and insufficient data	Legal
Lack of standard model for PPP agreements	Legal
Delay in resolving litigation or arbitration dispute	Legal
Need for environmental approval	Legal
Immature juristic system	Legal
Improper contract	Legal

8. Market

Table 16. **Market risks**

Risk factors	Risk group
Insufficient income	Market
Fluctuation of material cost (by government)	Market
Fluctuation of material cost (by private sector)	Market
Tariff change	Market
Market demand change/Demand below anticipation	Market/Operation
Exclusivity	Market
Arbitrary definition of tariff of services by government	Market
Competition	Market
Operating revenues below expectation	Market/Operation
Technical obsolescence	Market

9. Natural

Table 17. **Natural risks**

Risk factors	Risk group
Environment	Natural
Force Majeure	Natural
Weather	Natural

10. Operation

Table 18. **Operation risks**

Risk factors	Risk group
Operation cost overrun	Operation
Low operation productivity	Operation
Maintenance cost higher than expected	Operation
Maintenance more frequent than expected	Operation
Residual asset risk	Operation
Operator default	Operation
Quality of operation	Operation
Condition of facility	Operation
Residual risk	Operation

Risk factors	Risk group
Technological risk	Operation
Consortium inability	Operation
Delay in operation	Operation
Excessive maintenance and refurbishment	Operation

11. Organization and coordination

Table 19. **Organization and coordination risks**

Risk factors	Risk group
Lack of coordination and commitment	Organization and coordination

12. Political

Table 20. **Political risks**

Risk factors	Risk group
Unstable government	Political
Strong political interference	Political
Corruption and bribery	Political
Nationalization/Expropriation	Political
Delay in approval and permits	Political
Termination of concession by government	Political
Influential economic events	Political
Influential economic events	Political
Sanction	Political
Government intervention	Political
Uncompetitive tender	Political

13. Stakeholders' issue

Table 21. **Stakeholders related risks**

Risk factors	Risk group
Lack of support from government	Stakeholders' issue
Public opposition	Stakeholders' issue
Inadequate PPP experience	Stakeholders' issue
Lack of communication between stakeholders	Stakeholders' issue
Inadequate distribution of responsibilities	Stakeholders' issue
Inadequate distribution of authorities	Stakeholders' issue
Lack of commitment between parties	Stakeholders' issue
Delay in resolving contractual dispute	Stakeholders' issue
Need for land acquisition	Stakeholders' issue
Private investor change	Stakeholders' issue
Subjective evaluation	Stakeholders' issue
Misunderstanding the role of stakeholders	Stakeholders' issue
Misinterpretation of contract	Stakeholders' issue
Stakeholder management	Stakeholders' issue

In addition to the above classification of risks, in some cases the classification of the risks can be mixed. In other words, the same risk can fall under several risk groups such as the following risks:

14. Political and construction

Table 22. **Political and construction risks**

Risk factors	Risk group
Change in industrial code of practice	Political and construction

15. Political and feasibility study

Table 23. **Political and Feasibility study risks**

Risk factors	Risk group
Poor public decision-making process	Political/Feasibility study

16. Political, legal and financial

Table 24. **Political, legal and financial risks**

Risk factors	Risk group
Change in law	Political/Legal/Financial

4.2.3 Risk assessment

4.2.3.1 Risk ranking

As previously specified, the ranking of the risks identified through the literature review was done using the “content analysis”. According to Fellows and Liu (2003), content analysis is often adopted to determine the major aspects of a set of data and it is performed by simply counting how many times an activity occurs, or a topic is depicted. Weber (1990) argues that the content analysis method assists in classifying textual material to make it more manageable. In other words, in order to rank the risks identified through the extensive literature review, different sources are examined and studied in order to determine how many times the same risk was stated among the sources.

A complete table including the number of times each risk was repeated and mentioned in the literature in addition to the risk group to which each risk belongs is included in Appendix A. Appendix B includes a ranking of all risks based on the literature review. Appendix C includes the 30 different sources of the literature review from which the risks are extracted. Appendix D includes a definition for the risks identified in the risk checklist based on the literature review. Below is a summarized table showing the risk ranking and the top 50 risks out of the 118 identified risks:

Table 25. **Risk ranking of the top 50 risks out of the 118 identified risks**

#	Risk factors	Frequency cited (out of 30)	% of times cited	Risk group
1	Inflation	24	82.76	Economic and Financing
2	Interest rate	24	82.76	Economic and Financing
3	Force Majeure	20	68.97	Natural
4	Operation cost overrun	20	68.97	Operation
5	Material availability	19	65.52	Construction
6	Design deficiency	19	65.52	Design
7	Public opposition	18	62.07	Stakeholders' issue
8	Delay in approval and permits	18	62.07	Political
9	Change in tax regulation	16	55.17	Economic and Financing
10	Construction cost overrun	16	55.17	Construction
11	Change in law	16	55.17	Political/Legal/Financial
12	Weather	15	51.72	Natural
13	Market demand change/Demand below anticipation	15	51.72	Market/Operation
14	Nationalization/Expropriation	14	48.28	Political
15	Geological conditions	14	48.28	Construction
16	High finance cost	14	48.28	Construction
17	Construction/design changes	14	48.28	Construction/Design
18	Availability of finance	13	44.83	Construction
19	Unproven engineering techniques	13	44.83	Construction and design
20	Construction completion	13	44.83	Construction
21	Environment	12	41.38	Natural
22	Level of demand for project	12	41.38	Feasibility study
23	Site availability	12	41.38	Construction
24	Residual asset risk	12	41.38	Operation
25	Poor quality workmanship	11	37.93	Construction
26	Low operation productivity	11	37.93	Operation
27	Labor availability	11	37.93	Construction
28	Unstable government	10	34.48	Political
29	Maintenance cost higher than expected	10	34.48	Operation

#	Risk factors	Frequency cited (out of 30)	% of times cited	Risk group
30	Maintenance more frequent than expected	10	34.48	Operation
31	Exclusivity	10	34.48	Market
32	Residual risk	10	34.48	Operation
33	Site safety and security	9	31.03	Construction
34	Lack of communication between stakeholders	9	31.03	Stakeholders' issue
35	Insolvency of Subcontractors	9	31.03	Construction
36	Foreign currency exchange	9	31.03	Economic
37	Poor financial market	8	27.59	Economic and Financing
38	Inconsistent legal framework	8	27.59	Legal
39	Operator default	8	27.59	Operation
40	Third party tort liability	8	27.59	Stakeholders' issue
41	Ownership assets	8	27.59	Legal
42	Insolvency of Concession company	8	27.59	Legal
43	Need for land acquisition	8	27.59	Stakeholders' issue
44	Operating revenues below expectation	8	27.59	Market/Operation
45	Lack of support from government	7	24.14	Stakeholders' issue
46	Strong political interference	7	24.14	Political
47	Construction delays	7	24.14	Construction
48	Termination of concession by government	7	24.14	Political
49	Influential economic events	7	24.14	Political
50	Supporting utilities risk	7	24.14	Construction

As table 25 shows, based on the literature and researches, the top ten risks affecting PPP projects are: the inflation risk, interest rate fluctuation, Force Majeure, operation cost overrun, material availability, design deficiency, public opposition, delay in approvals and permits, change in tax regulation and construction cost overrun.

4.2.3.2 Risk mapping to different countries

In addition to the ranking and classification of risks into various risks categories, each one of the identified risks was mapped to its corresponding country. Appendix E includes the list of risks and each one of them is mapped to its corresponding country. The purpose of this step is to know the critical risks that the literature identified for each country in order to establish a cross-country comparison. An extract of the mapping step is highlighted in table 26.

Table 26. **Extracts of the outcomes of the risk mapping (Complete table in Appendix E)**

		Hong Kong	Hong Kong	Hong Kong	Hong Kong	Scotland	UK	UK	UK
1	Lack of support from government					▪			
2	Unstable government			▪					▪
3	Strong political interference	▪			▪				▪
4	Corruption and bribery	▪							▪
5	Nationalization/Expropriation	▪		▪					▪
6	Poor financial market						▪		▪
7	Inflation	▪		▪	▪		▪	▪	▪
8	Interest rate	▪		▪			▪	▪	▪
9	Lack of legal/regulatory framework				▪				
10	Inconsistent legal framework	▪			▪	▪			▪
11	Change in tax regulation	▪					▪	▪	▪
12	Public opposition			▪		▪	▪		▪
13	Environment					▪	▪	▪	▪
14	Force Majeure	▪		▪		▪		▪	▪
15	Weather			▪					▪
16	Geological conditions			▪					▪
17	Construction delays								▪
18	Site safety and security			▪					▪
19	Poor quality workmanship			▪			▪		▪
20	Construction cost overrun			▪			▪	▪	▪
21	Excessive contract variation						▪		▪
22	Material availability	▪		▪	▪				▪
23	Availability of finance			▪	▪				▪
24	High finance cost			▪			▪	▪	▪
25	Financial attraction of project to investors								▪
26	Delay in approval and permits			▪	▪		▪		▪
27	Design deficiency			▪	▪		▪	▪	▪
28	Scope variation				▪	▪			

4.2.3.3 Risk groups studied in this research

Based on the aforementioned risk identification and categorization, only the risks falling under the categories of “stakeholders’ issue” and “construction risks” are the subject of the study. Those risks were extracted, and the below tables show a separate ranking for the risks related to stakeholders’ issues and construction risks based on the “content analysis”.

4.2.3.3.1 Stakeholders' related risks

Table 27. **Stakeholders' related risks ranked based on content analysis**

Ranking of the risk	Risk factors	Total	% of times cited	Risk group
7	Public opposition	18	62.07	Stakeholders' issue
34	Lack of communication between stakeholders	9	31.03	Stakeholders' issue
40	Third party tort liability	8	27.59	Stakeholders' issue
43	Need for land acquisition	8	27.59	Stakeholders' issue
45	Lack of support from government	7	24.14	Stakeholders' issue
57	Inadequate distribution of responsibilities	6	20.69	Stakeholders' issue
73	Inadequate PPP experience	4	13.79	Stakeholders' issue
74	Lack of commitment between parties	4	13.79	Stakeholders' issue
76	Inadequate distribution of authorities	3	10.34	Stakeholders' issue
77	Differences in working methods/Knowhow between parties	3	10.34	Stakeholders' issue
86	Delay in resolving contractual dispute	2	6.90	Stakeholders' issue
89	Lack of coordination and commitment	2	6.90	Stakeholders' issue
91	Private investor change	2	6.90	Stakeholders' issue
97	Third party delays	1	3.45	Stakeholders' issue
104	Subjective evaluation	1	3.45	Stakeholders' issue
113	Misunderstanding the role of stakeholders	1	3.45	Stakeholders' issue
114	Misinterpretation of contract	1	3.45	Stakeholders' issue
115	Stakeholder management	1	3.45	Stakeholders' issue
116	Inadequate negotiation period prior to initiation	1	3.45	Stakeholders' issue
117	Staff crisis	1	3.45	Stakeholders' issue
118	Cultural differences between main stakeholders	1	3.45	Stakeholders' issue

It is worth mentioning that the public opposition risk, which has the highest ranking among the stakeholders related risks also occupies ranking # 7 among the overall risk ranking. Based on the assessment technique used in this research, the top 5 risks related to stakeholders' issues and affecting PPP projects are: the public opposition, lack of communication between stakeholders, third party tort liability, need for land acquisition and lack of support from government.

4.2.3.3.2 Construction risks

***Table 28.* Construction risks ranked based on content analysis**

Ranking of the risk	Risk factors	Total	% of times cited	Risk group
5	Material availability	19	65.52	Construction
10	Construction cost overrun	16	55.17	Construction
15	Geological conditions	14	48.28	Construction
16	High finance cost	14	48.28	Construction
18	Availability of finance	13	44.83	Construction
20	Construction completion	13	44.83	Construction
23	Site availability	12	41.38	Construction
25	Poor quality workmanship	11	37.93	Construction
27	Labor availability	11	37.93	Construction
33	Site safety and security	9	31.03	Construction
35	Insolvency of Subcontractors	9	31.03	Construction
47	Construction delays	7	24.14	Construction
50	Supporting utilities risk	7	24.14	Construction
59	Labor disputes/strikes	6	20.69	Construction
60	Land use	6	20.69	Construction
61	Waste of materials	6	20.69	Construction
62	Protection of geological and historical objects	6	20.69	Construction
65	Government reliability	6	20.69	Construction
66	Third-party reliability	6	20.69	Construction
68	Excessive contract variation	5	17.24	Construction
101	Delay in supply	1	3.45	Construction
109	Constructability	1	3.45	Construction
110	Defects in construction	1	3.45	Construction

It is worth mentioning that the material availability risk, which has the highest ranking among the construction risks also occupies ranking # 5 among the overall risk ranking. Based on the assessment technique used in this research, the top 5 risks related to construction and affecting PPP projects are: material availability, construction cost overrun, geological conditions, high finance cost/availability of finance and construction completion risks.

4.2.4 Risk checklist used in this study

In this research, and since the main focus of the research is the risks related to stakeholders and their impact on PPP projects especially during the construction phase in developing countries, out of the 118 risks obtained from the literature review, only the risks related to construction and stakeholders' issues are extracted for further investigation. From the analysis performed, the stakeholders' related risks are 21 risks while the construction risks are 23 risks. Accordingly, a total of 44 risks will be studied in this research. It is worth mentioning that 18 risks of those 44 risks (approximately 41%) fall within the top 50 risks identified and ranked in the risk checklist previously explained in Sections 4.2.1 and 4.2.3.1. The ranking of each of those risks within the comprehensive risk checklist is specified in the first column of tables 27 and 28.

4.2.5 Stage of PPP project studied in this research

As it was previously identified earlier in this Chapter and in Chapter Two (specifically in Section 2.2.3 titled *"Stages of PPP"*), the lifecycle of any PPP project can be divided into the following stages:

- Feasibility
- Financing stage
- Design stage
- Construction stage
- Operation stage
- Transfer stage

In order to obtain more accurate results and in order to maintain the consistency, the risks that will be investigated in this research and that will be later included in the neural network model will be studied for the period of construction. The construction period is chosen in particular as it is considered as an intermediate pivotal period in the lifetime of the PPP project, occurring between the pre-construction period (including the feasibility stage, financing stage and design stage) and the operation and maintenance period. It is a critical period in the project's lifecycle in which the impact of any risk event can be at its peak and could affect the commercial and technical feasibility of a project (Badala *et al.* 2018).

Figure 33 illustrates the impact of risks during the three main stages of any PPP project: pre-construction, construction and operation and maintenance (shown in years) and displays how the risks during the construction stage of the project reach their highest overall impact on the project.

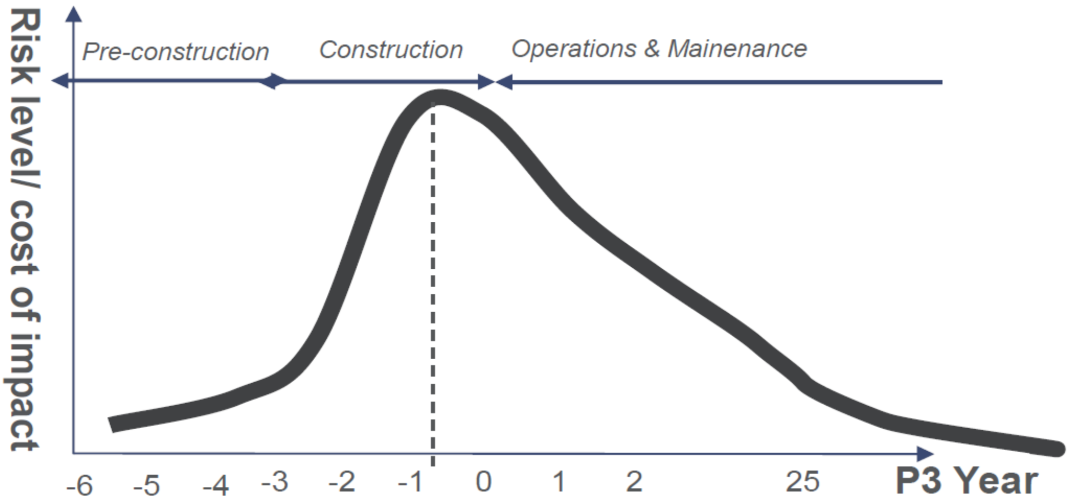


Figure 33. **Impact of risks during the three main stages of any PPP project: pre-construction, construction and operation- and maintenance (Badala *et al*. 2018)**

This conclusion is similar to a great extent to the one reached by Eldrup and Schutze (2013). Eldrup and Schutze demonstrated, based on qualitative analysis done for previous PPP projects, that PPP project risks are right skewed over time. This means that the majority of the risks occur at the beginning of the project's long lifecycle, and more specifically during the construction phase. Figure 34 illustrates that with the extended life span of any PPP project, the risks with the highest cost occur at the start of the PPP project and namely during the construction phase, then, they typically decrease significantly during the startup and operation phases.

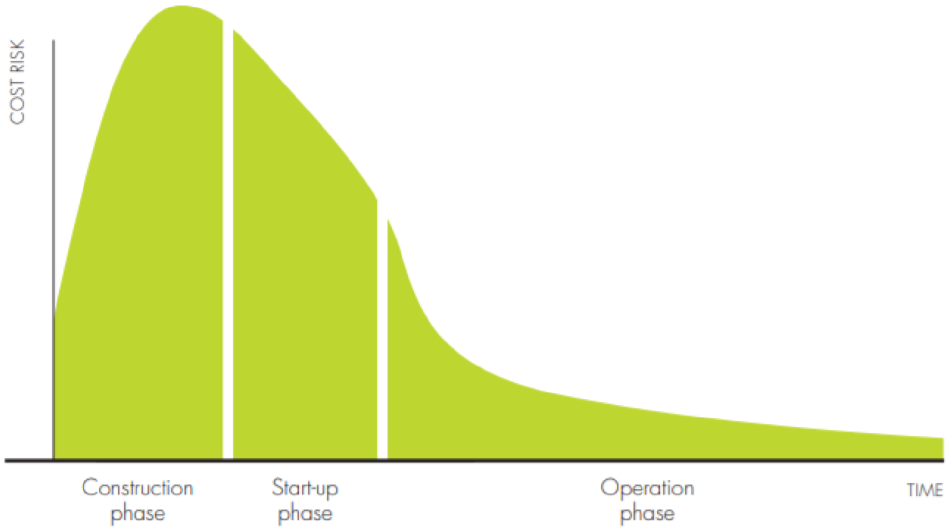


Figure 34. **Illustration of project risk over the PPP project's lifecycle (Eldrup and Schutze 2013)**

Accordingly, building the mathematical model to study the effect of stakeholders related risks and the construction risks in the construction period on the project's schedule will be of a significant importance as it studies the risks in the period when they occur the most and when they have the highest impact.

4.3 Collecting and preparing the data

4.3.1 Setting the sample size for the datasets

Since the mathematical model is focusing on determining the impact of the stakeholders-related risks and the construction risks on both conventional projects and on PPP projects in developing countries, data will be collected for real case traditional and PPP projects.

The data used in this research was collected as follows:

Dataset 1: Ten traditional projects, with a total value of $2,531,554,644.00 completed in Egypt between 2014 and 2019. The size of the sample was not very large because for all projects chosen, and in order to provide a common ground and a valid comparative study with PPP projects, the client in all projects in Dataset 1 is the Public Sector. The nature of these projects varies ranging from infrastructure, water treatment plant and power generation plants and other. The original duration for the projects in this dataset varies from 8 months and until 45 months.

Dataset 2: Two PPP projects, with a total value of $ 520,000,000.00 completed in Egypt between 2010 and 2019. Due to the fact that the number of executed PPP projects is far less than the number of traditional projects, accordingly, it was expected for the sample size related to PPP projects to be smaller than the sample size related to traditional projects. Nevertheless, as the number of potential and future PPP projects in Egypt and in developing countries is in continuous increase, the mathematical model is expected to be enhanced in the future to have a more comprehensive database.

The data collection process for both datasets involved an initial shadowing of the execution team for the various projects as a quasi-member of the team. This provided the opportunity to gain an initial understanding of how the data to be used for the modelling was generated and what different variables meant. It was followed by extracting the following details about each project:

1- The primary purpose of the project where the different categories are:
   - a- infrastructure including roads development as well as building networks of piping (storm water, potable water, sewage) and electrical.
   - b- electricity where the project is the establishment of a power plant
   - c- wastewater where the project consists of the construction of a wastewater treatment plant or other projects required for the transport or treatment of waste effluent from homes and industries though combined or sanitary sewer.
   - d- other where the project consists of any other type than the aforementioned types (such as the establishment of a hospital for instance or minor projects that would not merit the classification of major infrastructure, electricity or wastewater projects).

2- The project scope which differs from the primary purpose of the project as it means the scope of work of the particular project type and which is divided into the following categories:
   - a- Upgrade: which means that the facility already exists while the project consists of interventions regarding the evaluation of the existing structure, electromechanical installation, enhancement of surrounding area, etc. The upgrade can also include adding new buildings within the vicinity of the existing project.

b- Refurbishment: which includes the process of repairing existing structures having some issues that are preventing their "fit for purpose" from taking place. It also means repairing and restoring the plant or facility to sound working condition after it has been rendered unsafe or unfit for service by wear and tear, damage, failure of parts and the like. Refurbishment does not, however, include the replacement of any plant, facility or equipment or the improvement of any plant, facility or equipment by replacing material which is still in sound working condition with materials or equipment of a new or different kind, quality or design (Code of Federal Regulations 1984).

c- Replacement: means altering, modernizing, renovating or otherwise changing a building over in a different way. It can also include the replacement and/or installation of components of a building which prolongs the life and/or increase the value of the building (NYSED 2009).

d- New-build: means establishing a wholly new construction that was not present before.

3- The project cost which is the project's final cost.

4- The project duration divided into the following:

  a- The original project duration which is the initial duration as stated within the Contract documents as well as the baseline schedule.

  b- The final project duration which is the actual completion time of the project; taking into account all delays and variation orders that the project was subject to.

5- The construction years which is the period during which the actual project execution/construction took place.

6- For Dataset 2, which includes PPP projects, other information was specified regarding the PPP type in addition to a brief description of the Private Sector´s role in the partnership as well as the concession period.

4.3.1.1 Dataset 1

Dataset 1 includes the ten traditional projects included in the study. The major common aspect between these projects is the nature of the owner which is always a public/governmental entity. The first analysis of the projects included quantitative details such as the final cost, original and final durations, delay in months and construction year. On the other hand, qualitative information includes the primary purpose, project scope and location. Table 29 includes a summary of the major aspects for the projects in Dataset 1.

Table 29. **Major information concerning Dataset 1: Traditional projects**

Dataset 1 : Traditional Projects								
Project #	**Primary purpose**	**Project scope**	**Cost**	**Original duration (months)**	**Final duration**	**Construction years**	**Delay (months)**	**% Delay**
1	infrastructure	Upgrade	25,657,895.00	16	22	2015-2017	6	37.5
2	infrastructure	Refurbishment	13,589,460.00	13	18	2014-2016	5	38.5
3	infrastructure	Replace	347,751,310.00	45	54	2015-2018	9	20
4	Electricity	New-build	776,500,000.00	9	10	2014-2015	1	11.1
5	Electricity	New-build	343,500,000.00	8	10	2014-2015	2	25
6	Electricity	Upgrade	233,433,089.00	29	32	2015-2018	3	10.3
7	Electricity	Upgrade	527,687,890.00	30	32	2015-2018	2	6.7
8	wastewater	New-build	130,000,000.00	26	32	2016-2019	6	23.1
9	wastewater	New-build	118,000,000.00	24	26	2017-2019	2	8.3
10	other	Upgrade	15,435,000.00	20	30	2015-2018	10	50

Further explanation for the different columns in Table 29 is provided below:

4.3.1.1.1 Primary purpose of the projects

The nature of these projects were rather varied, ranging from infrastructure projects concerned with roads development and different networks underneath (such as potable water, storm water, electricity and sewage) which form 30% of the project cases used in this research, electrical power plants (which represent 40% of the project cases used in this research) and wastewater treatment plants (representing 20% of dataset 1) as illustrated in the histogram in figure 35.

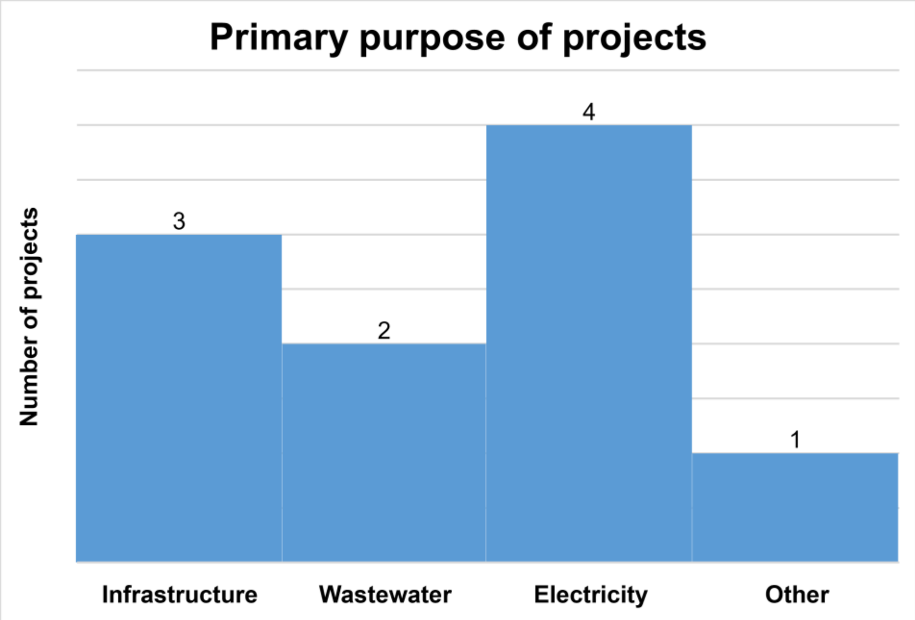


Figure 35. Histogram showing Primary purpose of projects

4.3.1.1.2 Project Scope

The dataset was chosen as to encompass various scopes of work. Figure 36 illustrates the different scopes of work for the different projects where four projects are upgrades, four are newly constructed projects, one project includes replacement while another one includes refurbishment as illustrated in the histogram in Figure 36.

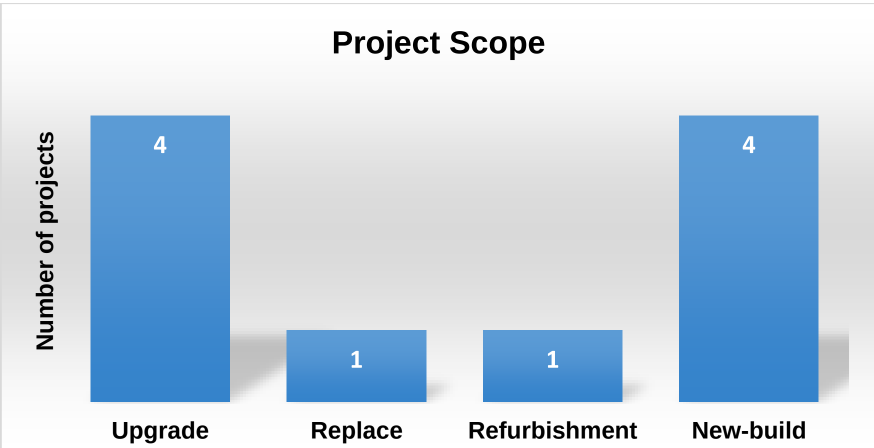


Figure 36. Histogram showing Project Scope

Table 30 includes a summary for the projects of Dataset 1 including their primary purpose as well as the project scope.

Table 30. Summary for the projects of Dataset 1 including their primary purpose as well as the project scope

Primary Purpose	Infrastructure	Wastewater	Electricity	Other
	3	2	4	1
Project Scope	Upgrade	Replace	Refurbishment	New-build
	4	1	1	4

4.3.1.1.3 Projects cost

The final cost for the projects is ranging from $20 million and reaching more than $100 million. As shown in the frequency table 31, Dataset 1 includes ten project cases with a total value of $2,531,554,644.00 executed between 2014 and 2019. The project costs range from $13 million for a refurbishment project to $700 million for new mega electrical power plants.

Table 31. Frequency table of final cost of projects

	Project Final Cost (in millions USD)	**Count**	**Cumulative count**	**Cumulative %**
Frequency table of Final Cost of projects	0<x≤20M	2	2	20
	20M<x≤40M	1	3	10
	40M<x≤60M	0	3	0
	60M<x≤80M	0	3	0
	80M<x≤100M	0	3	0
	x≥100M	7	10	70

As illustrated in Figure 37, about 70% of the total number of project cases cost more than $100 million with only two projects costing less than $20 million. On a cursory level, this might suggest that the models developed from the database will be more sensitive to projects costing more than $100 million.

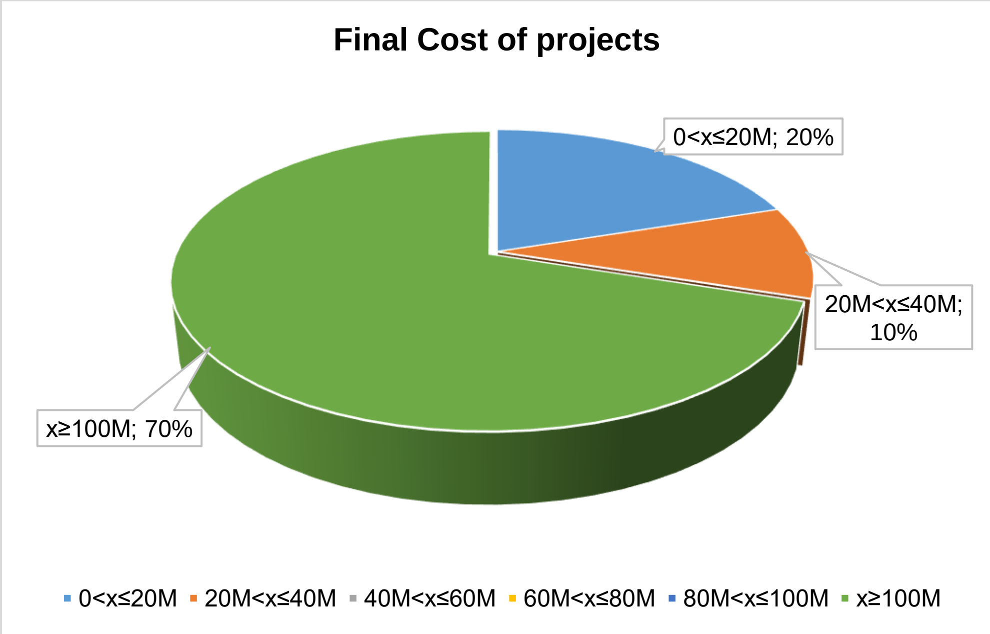


***Figure 37.* Final cost of projects- Dataset 1**

4.3.1.1.4 Projects duration

As shown in Table 29, the original duration of the projects is ranging from 8 months until 45 months with an average initial duration of 22 months. It is worth mentioning that all projects included in Dataset 1 were subject to delays and their execution time was extended. The delays affecting the projects range from one month on a 9-month project and until ten months of delay on a 20-month project. Figure 38 illustrates the initial and final durations for the projects forming Dataset 1.

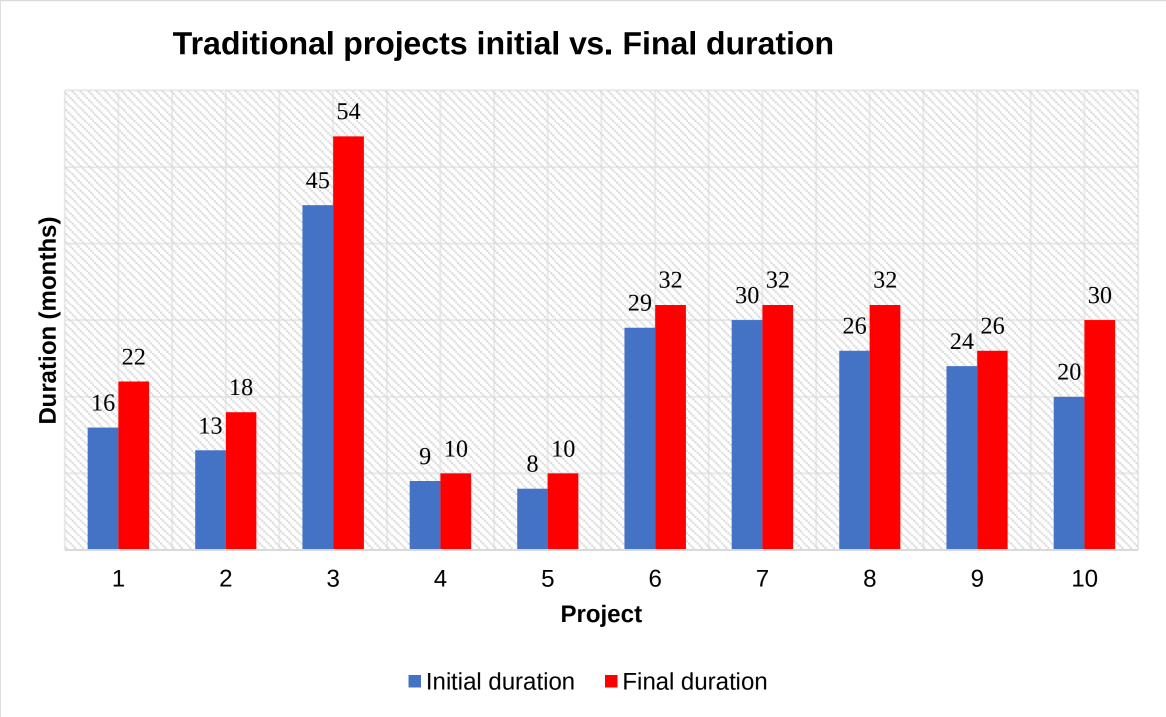


Figure 38. Initial vs. Final project duration for Dataset 1

Furthermore, Figure 39 shows the difference (in months) between the initial and final duration for each project illustrating the delays that each project was subject to.

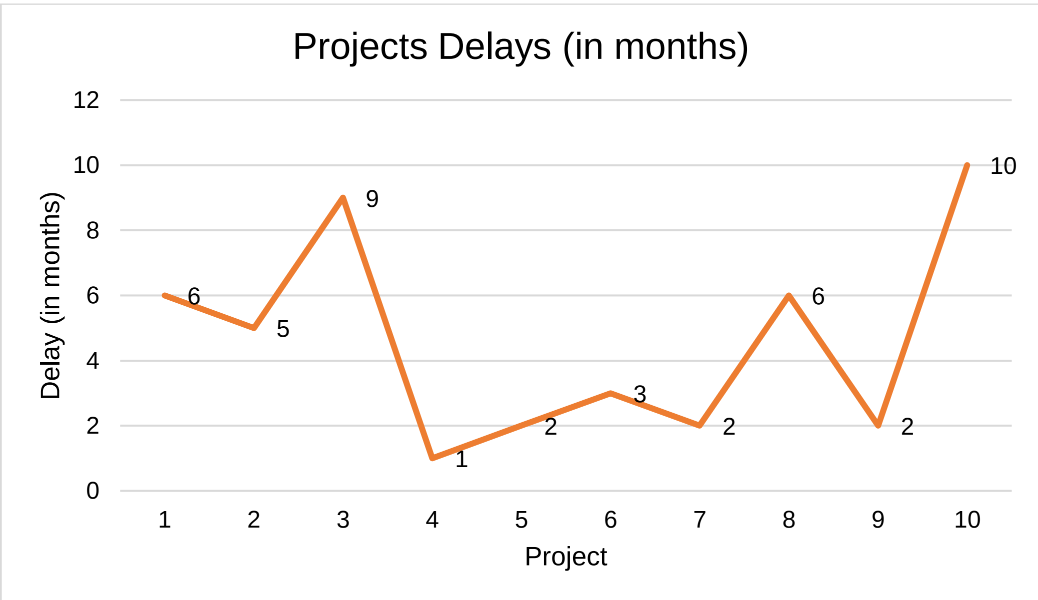


Figure 39. Project delays (in months)

A plot of project initial duration compared to project delays in Figure 40 does not show a linear relationship between the two factors. This can be an indication that linear modeling techniques such as linear regression might not be an appropriate modelling type for this data.

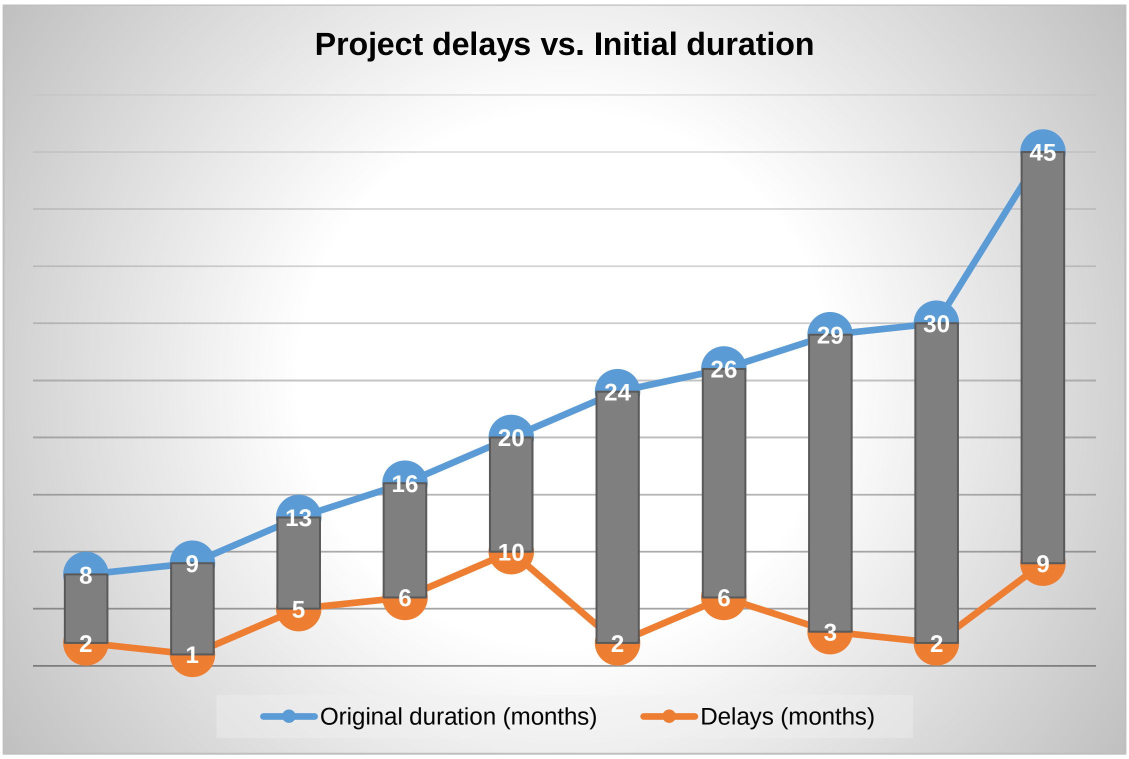


Figure 40. **Project delays vs. original duration**

4.3.1.2 Dataset 2

Dataset 2 includes two PPP mega projects which both are new-builds. These are actually the only PPP projects achieved in Egypt.

The first project is a wastewater treatment plant realized between 2010 and 2012. In this project, the private sector´s role is to design, finance, construct, start-up, operate, maintain and repair the plant (DFCOM). The PPP contract is expected to end on 28 June, 2029. The project´s capacity is an average daily flow of 250,000 m³/day. The Construction duration was extended from 21 months (initial duration) to 23 months. The total project cost is $140,000,000 million.

The second project is a Non-Conventional Renewable Energy (NCRE) wind project with an installed capacity of 262.5 MW. It is aligned with the Egyptian governmental policies to increase NCRE to 20% of total energy demand by 2020. The type of PPP for this project is COO (Construct, Own, Operate). The Construction started in 2015 with an initial duration of 44 months and ended in 2019 with an actual extended duration of 50 months. The total project cost is $380,000,000 million. Both projects have a concession period of 20 years.

Table 32 summarizes the general PPP projects information including each project´s primary purpose, scope of work, cost, original duration, final duration, construction years, concession period, PPP type and brief description of the private partner´s role.

Table 32. **Major information concerning Dataset 2: PPP projects**

Dataset 2 : PPP projects									
Project #	**Primary purpose**	**Project scope**	**Cost**	**Original duration (months)**	**Final duration**	**Construction years**	**Concession period (years)**	**PPP type**	**Description**
1	Wastewater	New-build	140,000,000.00	21	23	2010-2012	20	DFCOM	Design, Finance, Construct, start-up, Operate, Maintain and Repair
2	Electricity	New-build	380,000,000.00	44	50	2015-2019	20	COO	Construction, Own, Operate

4.3.2 Data pre-processing

The collected data will have quality if it fits the purpose for which it was collected (Han *et al.* 2012). Before using the collected data, the data will undergo extensive steps of preparation. According to Pyle (1999), correct data preparation prepares both the data miner and the data. Preparing the data means the model is built right. Preparing the miner means the right model is built. Accordingly, pre-processing the data will enable the modeler to fully understand the collected data. Furthermore, it is a crucial step ensuring the success of the model. In order to ensure that the data collected have quality, several factors should be taken into account such as: accuracy, completeness, consistency, timeliness, believability, and interpretability (Han *et al.* 2012).

The steps that will be followed for data pre-processing are expected to be as follows:

4.3.2.1 Data cleaning

According to Han *et al.* (2012), if there are any reasons that make the modeler believe that the data collected is "dirty", it is unlikely for them to trust the results emerging from such data. Furthermore, "dirty" data will certainly lead to unreliable results. Accordingly, data cleaning is a crucial process performed by filling in missing values, smoothing "noisy" data (data with random errors), identifying or removing outliers (data falling outside a cluster of other data), and resolving inconsistencies. In this research, the outliers (any data outside the predefined domain set between the 5th and 95th percentiles of distributions) was removed. In this research, the procedure of data cleaning is performed twice as follows:

4.3.2.1.1 Data cleaning results for Original, final durations, delay and delay percentage

The first step in the data cleaning was performed right after data for Datasets 1 and 2 was collected. In each project and for schedule-related data, the mean (μ), standard deviation (σ) and median are determined.

Accordingly, statistical calculations were performed for the following factors:

- Original duration
- Final duration
- Delay
- Percentage of delay

Then, the Minimum severity value and Maximum values are obtained for each factor.

Also, the minimum set value is obtained through the following formula:

$$Minimum\ Set\ Value = Mean - (2 \times Standard\ Deviation) \qquad (1)$$

The maximum set value is obtained through the following formula:

$$\boldsymbol{Maximum\ Set\ Value = Mean + (2 \times Standard\ Deviation)} \qquad (2)$$

If the minimum value for each of the aforementioned factors is smaller than the minimum set value or if the maximum value for each of the aforementioned factors is larger than the maximum set value by more than 5%, then, the data contains outliers that should be removed. After the outliers' removal, the mean (μ), standard deviation (σ) and median are calculated again to guarantee its improvement and hence the data cleaning procedure.

Finally, after the outlier removal, an average severity and standard deviation are obtained for each risk factor. These results are the ones which will be used in the future calculations of this study. This procedure is illustrated in the tables in Appendix F.

4.3.2.1.2 Data cleaning results for risk factors

This is the second time the data cleaning procedure is performed. After all the risk factors for each project are inserted into the overall risk matrix illustrated in Appendix G-A (for traditional projects) and Appendix G-B (for PPP projects), statistical calculations were performed on the magnitude of each risk. The magnitude of each risk is represented by the contribution of each risk to the overall project delay.

For each project, the mean (μ), standard deviation (σ) and median are determined for the risk factors associated with this specific project.

Accordingly, statistical calculations were performed for the following factors:

Then, the Minimum severity value and Maximum values are obtained for each factor.

Also, the minimum set value is obtained through the following formula:

$$\boldsymbol{Minimum\ Set\ Value} = \boldsymbol{Mean} - (\mathbf{2} \times \boldsymbol{Standard\ Deviation})$$

The maximum set value is obtained through the following formula:

$$\boldsymbol{Maximum\ Set\ Value} = \boldsymbol{Mean} + (\mathbf{2} \times \boldsymbol{Standard\ Deviation})$$

If the minimum value for each of the aforementioned factors is smaller than the minimum set value or if the maximum value for each of the aforementioned factors is larger than the maximum set value by more than 5%, then, the data contains outliers that should be removed. After the outliers' removal, the mean (μ), standard deviation (σ) and median are calculated again to guarantee its improvement and hence the data cleaning procedure.

Finally, after the outlier removal, an average risk magnitude and standard deviation are obtained for each group of risks affecting a specific project. These results are the ones which will be used in the future calculations of this study.

It is worth mentioning that extremely large (or extremely small) values can create biases in data analysis as they might appear more important as they really are. For example, in Dataset 1, there are projects which value exceed three-hundred million Us dollars while others are only between ten to fifteen million US dollars. This disparity in costs might have the potential of resulting in inconsistent predictions if included in the model. Such problem was overcome by not considering "cost" as a parameter in this study. In order to develop a model that adequately capture all possible ranges of cases when it comes to studying the cost necessitates sample data of different nature where the variance between costs is not significant. On the other hand, excluding the high-value projects from the study in such case may increase the chances that the model will not be representative for the real-case projects.

4.3.2.2 Data integration

Data integration is simply merging data from various databases after removing any conflicting information from those different sources. Since the data in this research will be collected from different databases and sources, the data integration in this case is an essential step. For instance, for each project, data will be collected from three different databases as follows:

- The first database is recording the general project information
- The second database is recording the project's schedule-related information. (Ahiaga-Dagbui 2014) (Han *et al*. 2012).
- The third database is the one including all progress reports (monthly and weekly), minutes of meeting, resolved claims and approved variation orders in order to determine the sources of delay and link them to their root cause. The root cause of each delay event is then attributed to the specific risk it falls under. This step in particular should be done carefully because it is the basis on which the model is built. In fact, Han *et al.* (2012) points out to the fact that data integration should be done carefully with the aim of avoiding redundancies and inconsistencies in the resulting dataset. All the above

three sources were merged-up, hence ‘integrated” while removing duplicated or aggregated information.

After the projects general and schedule-related information were collected, each project was studied in detail in order to study the causes of delay. The causes of delay were determined and illustrated in the following documents:

- Claims and responses to claims
- Monthly and weekly reports (the “critical issues” section in particular)
- Minutes of Meetings
- Baseline schedule compared to updated schedules
- Variation Orders
- Correspondences between different parties

In addition to the aforementioned documentation, and as it was previously mentioned in section 4.3.1, the data collection process included an initial shadowing of the execution team for the various projects as a quasi-member of the team in order to determine and get a detailed explanation for each source of delay.

4.3.2.2.1 Real-case example of data integration in the research

This section includes an example for the mechanism of data integration in this research. This example is for project # 1 which is an infrastructure upgrade project which construction took place between 2015 and 2017. The project’s cost is 25,657,895.00 US Dollars. The project’s initial duration is 16 months and was subject to 6 months of delay, equal to 37.5% of delay.

The delay events for this project were extracted by studying the project’s documents and integrating them together as it is illustrated in table 33.

Table 33. **Extract of data integration performed for project # 1 in Dataset # 1**

Project 1							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
16	0,216	22	0,273	6	0,556	37,5	0,712

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						% Contribution to total delay of the project (180 days)
	Direct effect (days)	Delay analysis method used	Combined Effect on final duration (days)	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	
Delay events															
te purchase of IT racks by Contractor	35	TIA	20	The Engineer specified its intention to change the type of IT racks. The Contractor inquired about the type of the racks several times but the Engineer did not reply on time which delayed the Contractor.	Stakeholders Construction	Lack of communication between stakeholders Delay in Supply	Owner /Engineer	Contractor	√	√	√	-	-	√ (Schedule update)	11,11
elay in installation of glass partitions	18	TIA	6	The glass partitions were not installed by the Contractor on time due to a lack of specialized personnel	Construction	Labor availability	Contractor	-	√	√	-	-	-	√ (Schedule update)	3,33
ecent modifications raised by Owner	54	TIA	28	There were several modifications raised by the Owner in the design which affected many subsequent activities such as construction, purchase of materials, etc. Such modifications were introduced late in the project which caused also rework activities.	Stakeholders Construction	Lack of coordination Excessive contract variation	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	15,56

In the first column, the delay events that the project was subject to are presented. These delay events are extracted from the different project documents (claims, letters, reports, etc.) in addition to execution experts that worked on the execution of the project. The next section titled “effect”, includes the result of each delay event in two dimensions:

a- Direct effect which means the number of days of delay such event causes to the time schedule.
b- Compiled effect which means, when compiled and analyzed with the other delay event, the net result by which each delay event affects the overall project schedule.
c- The delay analysis method that was used in the project to calculate the delay.

The next section titled “cause” explains in detail the root cause of each delay event.

The purpose of the next section is to translate the “cause and effect” of each delay event into “risk factors”. Through the detailed explanation of each delay event, it is then linked to its corresponding “risk” and “risk group”. The list of “risks” and “risks group” are basically the ones that were chosen to be used in this study and which were previously stated in section 4.2.3.3. The next section includes an allocation of each risk to determine which party is responsible for such risk. Then, in order to be able to track each delay events, the corresponding documents justifying the delay are specified (whether the delay event was determined through letters, minutes of meeting, claim, variation order, report, etc.). Finally, the last column shows the percentage of contribution of each delay event to the total project delay. This number represents the magnitude of each risk and will be one of the major factors in this research.

The list of tables showing each delay event with its corresponding details including cause and effect, risk groups and risk factors along with the percentage of contribution of each risk to the overall project delay for each project of Dataset 1 and Dataset 2 are illustrated in Appendix H-A and Appendix H-B respectively.

4.3.2.2.2 Real-case example of result of data integration in the research

From the aforementioned data integration procedure that was performed for the first project in Dataset 1, it is found that for this specific project, there were 3 stakeholder risks that caused time-overrun for the project in addition to 6 construction risks forming respectively a percentage of 33.3 to 66.67%. This is illustrated in Figure 41.

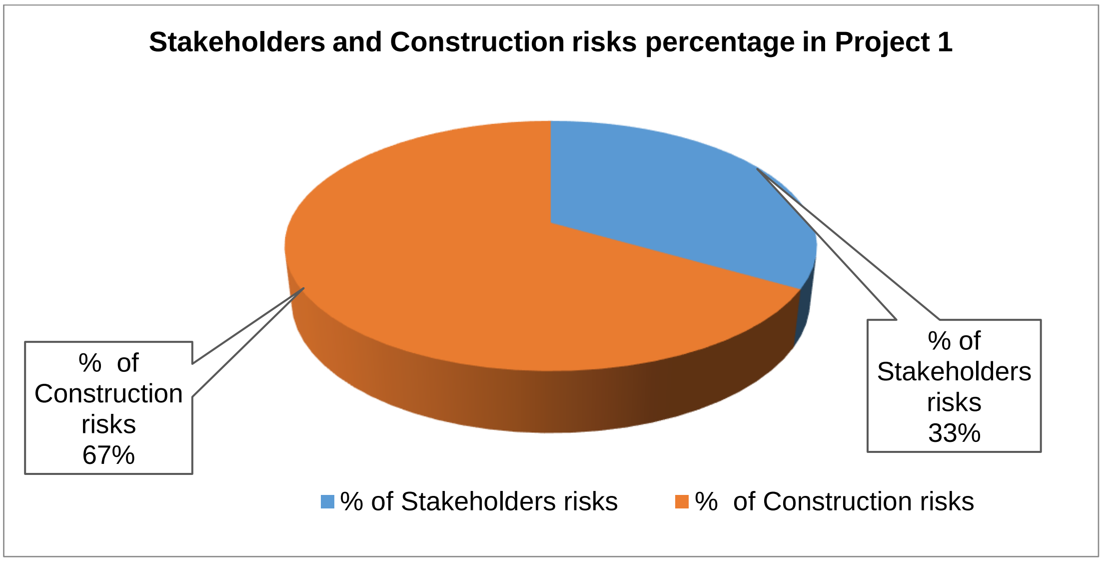


Figure 41. **Stakeholders and Construction risks percentage in Project 1**

4.3.2.2.3 Overall results of Data Integration

After performing the Data Integration for the entirety of the projects forming Dataset 1 and Dataset 2 following the steps explained in sections 4.3.2.2.1 and 4.3.2.2.2 mentioned above, the outcomes were consolidated to show the percentage of contribution of stakeholder and construction risks to total project delay in addition to the respective percentage of stakeholder and construction risks. The result of such consolidation is illustrated in Table 34. The complete results of Data Integration for Dataset 1 and Dataset 2 are illustrated in Appendix I-A and Appendix I-B respectively.

Table 34. **Results of Data Integration**

	Project #	Delay (months)	% Delay	% Contribution of Risks to total project delay	% Stakeholders risks	% Construction risks
Dataset 1: Traditional Projects	1	6	37.5	48.33	33.33	66.67
	2	5	38.5	96	50	50
	3	9	20	92.22	36.84	63.16
	4	1	11.1	96.67	41.18	58.82
	5	2	25	91.67	37.5	62.5
	6	3	10.3	91.11	37.04	62.96
	7	2	6.7	93.33	40.91	59.09
	8	6	23.1	85.56	30.77	69.23
	9	2	8.3	80	25	75
	10	10	50	88	42.86	57.14

Figures 42 and 43 illustrate the contribution percentage of stakeholder and construction risk tot total project delay along with the detailed respective percentage of stakeholder and construction risks for each project. Figure 42 shows that for 90% of the projects, stakeholder and construction risks constitute 80% or more of the sources of delay for each project. In six of the projects, they constitute 90% or more of the sources of delay. This in fact goes in line with the importance attributed to construction and stakeholder risks in the Literature review and highlights the importance of studying such risks in order to minimize cost overrun that occur mainly during the construction period.

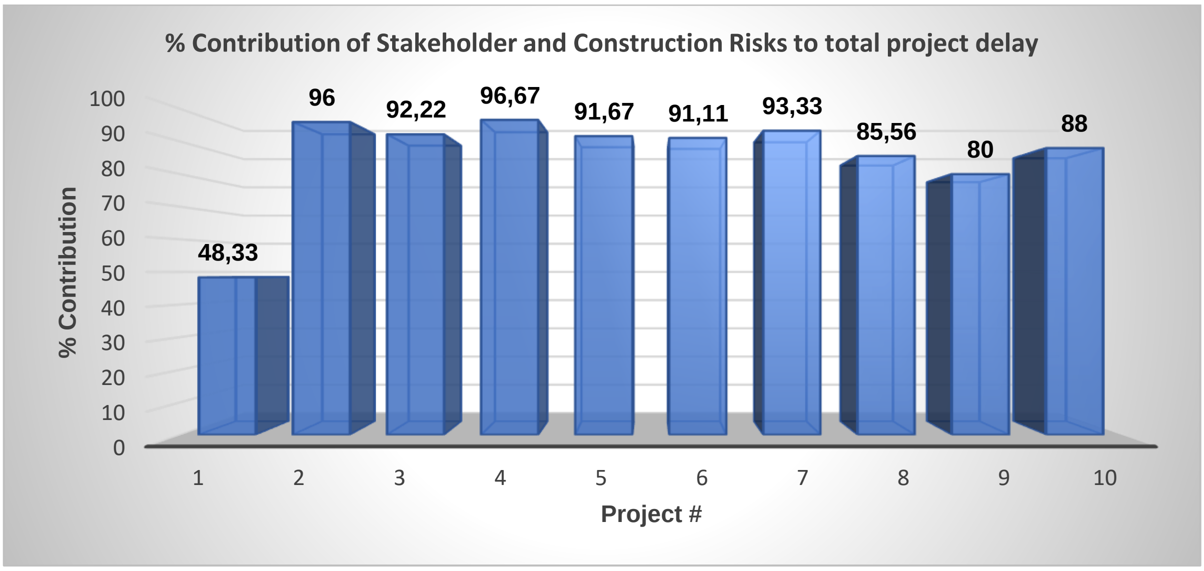


Figure 42. **% Contribution of Stakeholder and Construction Risks to total project delay**

Figure 43 shows the respective percentage of stakeholder risks compared to construction risks which varies according to the project. In 90% of the projects, the percentage of construction risks that occur in the project is higher than the percentage of stakeholder risks which may be due to the fact that the risk analysis in this research is conducted for projects during the execution phase, the phase in which the construction-related risks reach their peak.

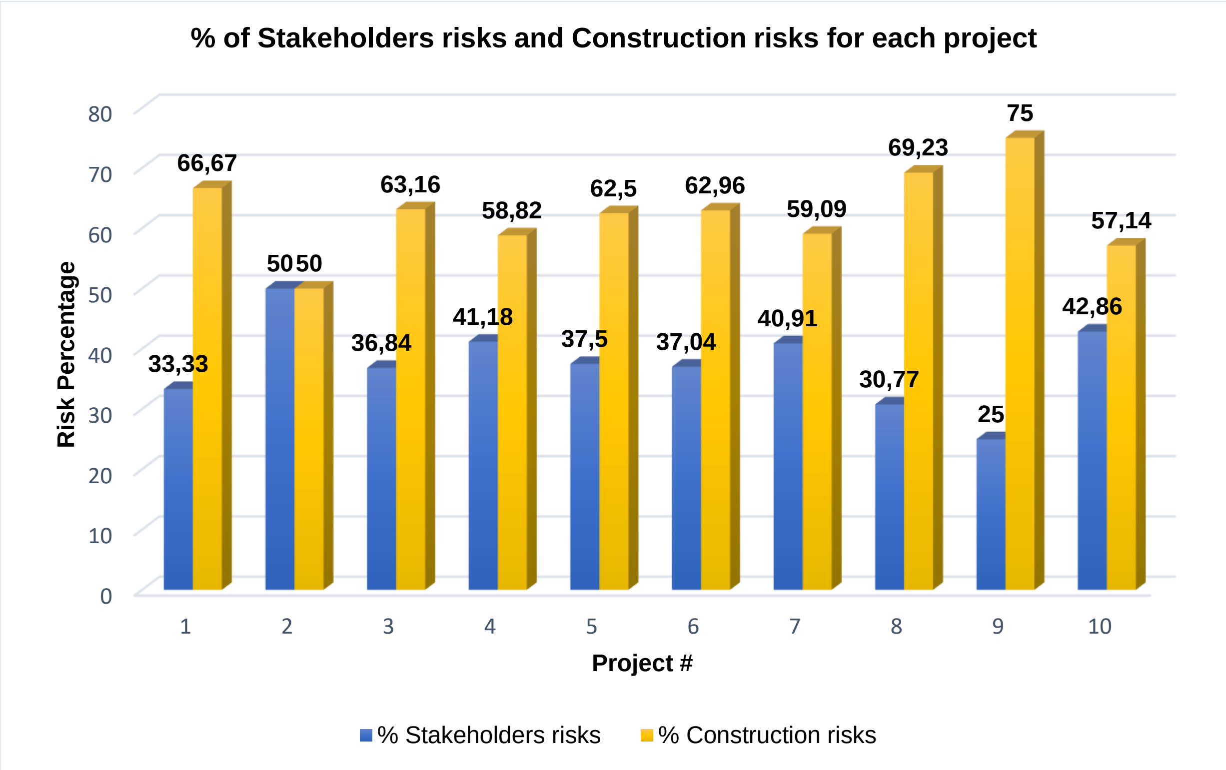


Figure 43. **% of Stakeholders risks and Construction risks for each project**

Furthermore, this data integration process shows that two construction-related risks occur in all projects which are the following risks:

1- Construction completion: the occurrence of such risk in all projects forming Dataset 1 is a natural result of all risks that the project was facing during execution. The magnitude of this risk is in fact the summation of all other risks that affected the project as the occurrence of delay events will have the natural effect of delaying the overall completion period of the project. In other words, to quantify this risk, the value of the delay it causes to the project is equal to the total project delay.

2- Additional incurred costs: This risk is associated with the additional costs incurred during construction. Costs overrun occur when the costs being incurred are in excess of the amounts that have been budgeted for. This risk is also a natural result of all the delays that occurred, it does not have a magnitude in terms of time, but it occurs as a collateral effect associated with delays.

4.3.2.3 Data transformation

This is one of the most important steps in the data pre-processing operation. In this step, the data collected will be transformed or consolidated into a small specified range as a means to obtain more efficient results in the future and in order to make the patterns easier to understand. One of the most common data transformation techniques is “the normalization” or “standardization” used to avoid depending on the choice of measurements units and in order to give all attributes an equal weight. It is a way of “standardization” of the data. After standardization, the data will fall within a smaller range such as [-1, 1] or [0.0, 1.0]. The “standardization” is discussed here in particular as it will be used in this research as a way to deal equally with the data collected. Usually, the standardization process is used in neural network backpropagation algorithm. Han *et al*. (2012) confirms that standardizing the input values for each attribute measured in the training tuples will help speed up the learning phase. This is the same conclusion reached by Ahaga-Dagbui (2014). Ahaga-Dagbui points out that several modelling techniques specifically Artificial Neural Networks “require” input data to be “standardized” before starting the training procedure. There has been unanimity in the literature regarding the standardization of the data used in neural network modelling. According to Squeria (1999), Flood and Kartam (1994) and Hegazy, *et al.* (1994), the standardization of the training data is proven to improve the overall performance of the network. Furthermore, standardization allows the time-related values to be comparable across different years.

Despite the fact that the terms “Normalization” and “Standardization” are sometimes used interchangeably, they in fact refer to two different things. Normalization is performed by scaling the variables to have values between 0 and 1. Its associated formula is as follows:

$$X\ (normalized) = \frac{x - x\ min}{x\ max - x\ min} \qquad (3)$$

Where: X is the actual value that needs to be normalized

X max is the maximum value of the set of values that will be normalized

X min is the minimum value of the set of values that will be normalized.

Standardization, on the other hand, means to scale a variable to a mean of zero and a standard deviation of 1. In other words, standardized value, or “z-score” measure how much a score deviates from the mean value of the distribution. For instance a z-score of 2.0 for the contribution of the risk of lack of coordination to the total project’s delay means that this risk affects this particular project twice more than the average in the database. Standardization was performed using the following rule:

$$Z\ score = \frac{xi - \mu}{\sigma} \qquad (4)$$

Where: Z score is the standardized value of a numerical input, xi

Xi is the actual value needing standardization

μ is the mean of the dataset

σ is the standard deviation of the dataset

The Data transformation is performed three times, as follows:

1- **For the whole dataset:** For all projects forming Dataset 1, statistical calculations and data cleaning are performed; then, normalization is performed for the projects’ general data.
2- **Per project:** For each project, after the data cleaning is performed, in other words, after the mean, standard deviation, minimum and maximum set values are obtained and the outliers are removed, normalization and standardization are performed for each risk affecting each project. This is considered as “vertical” data transformation.
3- **Per risk factor:** For each one of the 44 risk factors that are considered in this research, after the same data cleaning procedures are done and after the outliers are removed, the normalized and standardized values are

obtained for each risk factor across the whole dataset. This is considered as "horizontal" data transformation.

4.3.2.3.1 Normalization results for Original, final durations, delay and delay percentage

Similar to the statistical calculations that were performed in step 4.3.2.1, normalization was done on the same factors that were subject to data cleaning and which are:

1- Original duration
2- Final duration
3- Delay
4- Percentage of delay

Table 35 shows the results of normalization of those 4 factors.

***Table 35*. Normalization for Dataset 1**

	Project #	Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
Dataset 1: Traditional Projects	1	16	0.216	22	0.273	6	0.556	37.5	0.712
	2	13	0.135	18	0.182	5	0.444	38.5	0.734
	3	45	1.000	54	1.000	9	0.889	20	0.308
	4	9	0.027	10	0.000	1	0.000	11.1	0.103
	5	8	0.000	10	0.000	2	0.111	25	0.423
	6	29	0.568	32	0.500	3	0.222	10.3	0.085
	7	30	0.595	32	0.500	2	0.111	6.7	0.000
	8	26	0.486	32	0.500	6	0.556	23.1	0.379
	9	24	0.432	26	0.364	2	0.111	8.3	0.038
	10	20	0.324	30	0.455	10	1.000	50	1.000

4.3.2.3.2 Normalization and standardization results for risk factors

Based on the Data Integration results obtained in section 4.3.2.2, all the risk factors associated with stakeholders and construction risk groups are inserted into the overall risk matrix illustrated in Appendix G-A and Appendix G-B. This risk matrix includes the occurrence of each one of the 44 risks along with its magnitude (represented by the contribution of each risk to the total project's delay). The risk magnitude is determined by the effect this risk has on the overall delay of the project. At this stage, and after data cleaning is performed as specified in section 4.3.2.1.2, normalization and standardization occurs for each risk factor on two levels and in the following order:

1- On the project's level "Vertical data transformation" occurs. After the mean, standard deviation, minimum and maximum set values are obtained and the outliers are removed, normalization and standardization are performed for each risk affecting each project. This is illustrated in table 36 and the complete table is in Appendix G-A for Dataset 1 and Appendix G-B for Dataset 2.

Table 36. **Extract of the Data transformation on the project's level (the complete table is in Appendix G-A for Dataset 1 and Appendix G-B for Dataset 2)**

		Dataset # 2 (PPP projects)					
		1			2		
		Magnitude	Z value	Normalized value	Magnitude	Z value	Normalized value
#	Risk factors						
1	Public opposition						
2	Lack of communication between stakeholders						
3	Third party tort liability	20	0	0		0	0
4	Need for land acquisition		0	0	5.56	0	0
5	Lack of support from government	28.33	0.71067	1	5.56	0.707	0.804
6	Inadequate distribution of responsibilities		0	0	8.33	0	0
7	Inadequate PPP experience	33.33	0.707	1	28.33	0.707	
8	Lack of commitment between parties		0	0	16.67	0	0
9	Inadequate distribution of authorities		0	0	8.33	0	0
10	Differences in working methods/Knowhow between parties						
11	Delay in resolving contractual dispute						
12	Lack of coordination		0	0	20,56	0	0
13	Private investor change						
14	Third party delays	20	0	0		0	0
15	Subjective evaluation		0	0	10	0	0
16	Misunderstanding the role of stakeholders	33.33	0.70710678	1	10	-0.707107	0

2- On the risks level “Horizontal” data transformation occurs. For each one of the 44 risk factors that are considered in this research, after the same data cleaning procedures are done and after the outliers are removed, the normalized and standardized values are obtained for each risk factor across the whole dataset. Table 37 is an extract illustrating this step. Appendix J-A and J-B show the normalization and standardization performed for traditional and PPP projects respectively.

***Table 37.* Extract showing data transformation on the risks level across all projects (Complete table in in Appendix G-A for Dataset 1 and Appendix G-B for Dataset 2)**

							After outlier removal				
		Median	Minimum set value	Maximum Set value	Actual minimum value	Actual Maximum value	Mean	Standard deviation	Median	Actual minimum value	Actual Maximum value
#	Risk factors										
1	Public opposition										
2	Lack of communication between stakeholders	13.5	9.25	17.74	12	15					
3	Third party tort liability	8.89	5.529	14.45	8.33	13.33					
4	Need for land acquisition	11.39	-14.256	50.56	7.78	50					
5	Lack of support from government	15.925	-8.427	45.83	7.78	50	13.2	5.098	12.5	7.78	20
6	Inadequate distribution of responsibilities	6.945	0.1228	15.98	5	13.33					
7	Inadequate PPP experience										
8	Lack of commitment between parties										
9	Inadequate distribution of authorities	6,945	0,12288	15,98712	5	13,33					
10	Differences in working methods/Knowhow between parties	10	10	10	10	10					
11	Delay in resolving contractual dispute	10	-11,2702	40,93819	6,67	50	10.92	4.46	10	6.67	20.67
12	Lack of coordination	9,165	-0,58628	22,72028	4,44	19,45					
13	Private investor change										
14	Third party delays	8,33	5,050225	14,42692	8	13,33					
15	Subjective evaluation										
16	Misunderstanding the role of stakeholders										
17	Misinterpretation of contract	11,33	11,33	11,33	11,33	11,33					
18	Stakeholder management	6,945	0,12288	15,98712	5	13,33					
19	Inadequate negotiation period prior to initiation										
20	Staff crisis	6,485	5,961741	7,008259	6,3	6,67					
21	Cultural differences between main stakeholders										
#	Risk factors										
22	Material availability	8	8	8	8	8					
23	Construction cost overrun										
24	Geological conditions	7,04	2,234557	13,69344	4,44	11,67					
25	High finance cost	10	0,279801	21,4627	4	18,52					

Based on the above data transformation procedure, it is noticed that there are some risks which are not present at all in the data collected for Dataset 1 which are:

Stakeholder risks:

a- Public opposition
b- Lack of commitment between parties
c- Inadequate PPP experience
d- Lack of commitment between parties
e- Private investor change
f- Subjective evaluation
g- Misunderstanding of the role of stakeholders
h- Inadequate negotiation period prior to initiation
i- Cultural differences between main stakeholders

Construction risks

a- Protection of geological and historical objects
b- Constructability

The absence of such risks from Dataset 1 (Traditional Projects) makes sense as the data collected is for traditional projects while the risks such as public opposition, inadequate PPP experience, private investor change, subjective evaluation, misunderstanding the role of stakeholders and inadequate negotiation period prior to initiation are typical for PPP projects.

4.3.2.4 Data partitioning

It is not useful to design a neural network that simply memorizes a set of data. Instead, the neural network should have the ability to accurately perform on new data which will make the model able to "generalize". In order to achieve that, the collected data shall be divided into different subsets: training, selection (or testing) and validation.

The data for the ANN model shall be divided into three independent groups in the ratio of 66.7:16.7:16.7% as follows:

1- The first group is the training dataset: used to develop the ANN model and to identify the patterns and correlations

2- The second group is the testing (or selection) dataset: used to evaluate the performance of the ANN model, while it is still undergoing the training, to select the best model. Testing ensures that a robust network performance can be obtained (Flood and Kartam 1994). The testing (or selection) phase is used for choosing the ANN with best generalization properties. In this way, different models with the training subset are constructed and then, the one that works best on the selection subset is selected.
3- The third group is the validation dataset: used to establish the final assessment on the overall performance of the ANN model. The performance of the model is assessed by its ability to predict new data that has neither been used for training nor testing. Usually, as the iterative learning continues, the error decreases. However, at a certain point, the error may start to increase and this is when overfitting begins (Heravi and Eslamdoost 2015).

In other words, different models are trained with the training instances from the first group, the model with the "best performance" on the selection instances from the second group is chosen then its capabilities are validated using the validation dataset from the third group.

In this research, two validation methods were created: one automated verification of the performance of the model after training and one manual validation of the model through interviews. Further details of how training, testing and validation are performed will be provided at the actual modelling stage.

Out of the twelve project cases, eight projects (the traditional projects) forming Dataset 1 was selected as the training dataset. The remaining projects inn Dataset 1 (two projects) were selected for the testing and selection phase. The two major PPP projects forming Dataset 2 were selected for validation. Further details on the datasets used for the modelling is found in Table 38.

Table 38. **Data partitioning details**

Dataset	Percentage split	Number of cases (Total size =12)
Training	66.7	8

Dataset	Percentage split	Number of cases (Total size =12)
Testing (Selection)	16.7	2
Validation	16.7	2

The following pie chart is extracted from the actual ANN model and details the uses of all the instances in the datasets (1 and 2). The total number of instances is 12. The number of training instances is 8 (66.7%), the number of testing instances is 2 (16.7%) and the number of validation instances is 2 (16.7%).

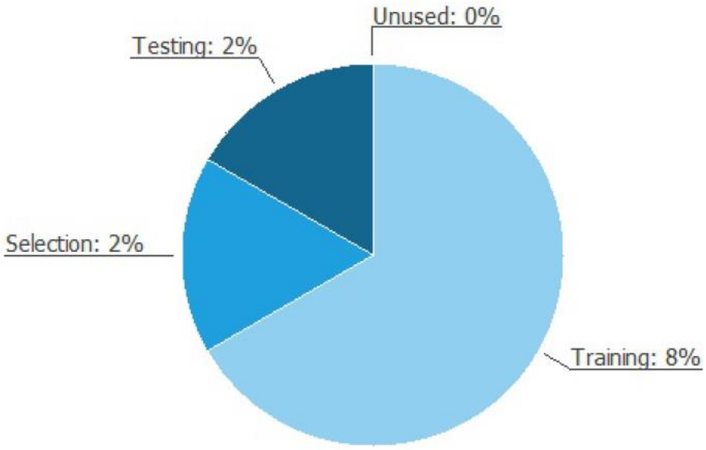


Figure 44. **The uses of all the instances in the datasets (1 and 2)**

4.4 The Artificial Neural Network in practice

The model was developed using Neural Designer ® Software. This software was used in particular as it is a powerful user-friendly interface able to make complex operations and build predictive models in an intuitive way with a graphical user interface. When any task is run, the results can be instantly visualized in tables, graphs or charts. The objective is that the user can understand and interpret each step in the analytics process. Also, it is compatible with the most common data files and databases and can operate the biggest datasets. During the selection phase of the software, the use of a user-friendly software was of utmost importance as it is meant for the model to be used and applied by users that may not specifically be experts in the domain of artificial intelligence and programming. With this software, there is no need for programming or building complicated block diagrams. Its interface guides the user through a sequence of well-defined steps, in order to simplify data entry. Furthermore, Neural Designer ® is outstanding in terms of performance when compared with other data mining platforms such as R ® and Java ®. As it is shown in the below graphs in Figure 45, Neural Designer ® is able to analyze datasets that are up to 1000 times bigger, nine times faster and 100 times more accurate than other software.

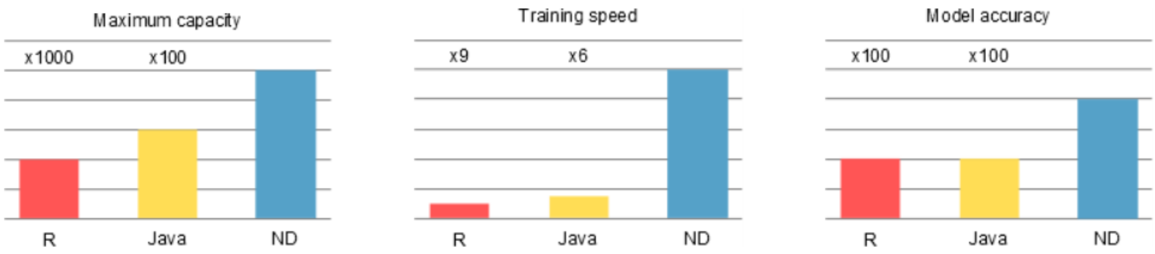


Figure 45. **Neural Designer capacities in terms of datasets size, training speed and accuracy compared to other data mining tools**

It is developed in C++ language for better memory management and higher processing speed. Nevertheless, the user still can export the resulting ANN model in any other programming language such as R or Python. One of the major advantages of Neural Designer ® for this research, is the inclusion of an advanced model selection framework, which allows the user to obtain the most relevant variables in a given process.

In this research, different models and networks were developed in a trial and error manner to identify the optimum network parameters and network performance.

4.4.1 Application type

The first thing to do when constructing the model is to decide whether this is an approximation or a classification project. This model is always an approximation project since the variable to be predicted is continuous (total project delay). The basic goal here is to model the total project delay as a function of the contribution of the 44 risk factors (divided into stakeholders and construction risks).

4.4.2 Dataset

To build the model, the first step is to prepare the dataset, which is the source of information for the approximation model. This step has already been performed in the previous sections of Chapter 4. In that way, this model has the following parameters:

1- The 44 risk factors used as input variables
2- Schedule Growth (or total project delay) used as target variables
3- The dataset contains 12 instances (or 12 projects). As per section 4.3.2.4 “Data portioning”, they are divided into:
    a. Training comprising 66.7% of the projects (8 traditional projects)
    b. Selection (testing) comprising 16.7% of the projects (2 traditional projects)
    c. Validation comprising 16.7 of the projects (2 PPP projects)

Once all the dataset information has been set, some analytics are performed in order to check the quality of the data and which will be explained in the next sub-sections.

4.4.2.1 Histograms for data distribution

Histograms are plotted for each one of the 44 input variables in order to depict how continuous variables are distributed. For instance, the below graph shows the distribution of the contribution of the government reliability risk to the total project delay. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 4, 6.11, 13.33, 17.78, 18.52. The maximum frequency is 25%, which corresponds to the bin with center 0. The complete plotted histograms and data distributions are present in Appendix K.

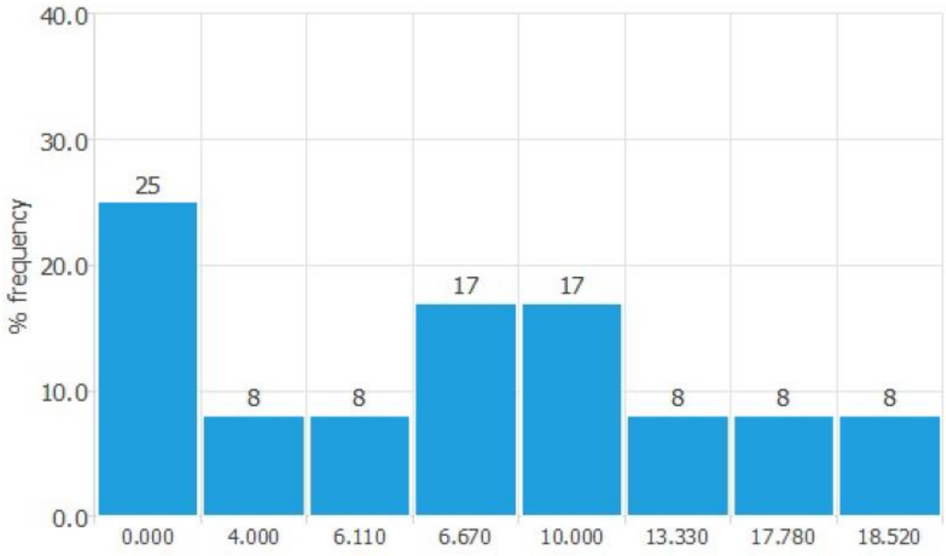


Figure 46. **Government reliability distribution**

4.4.2.2 Box plots for data distribution

Box plots are developed for each one of the 44 input variables which display information about the minimum, maximum, first quartile, second quartile or median and third quartile of each variable. They consist of two parts: a box and two whiskers.

The length of the box represents the interquartile range (IQR), which is the distance between the third quartile and the first quartile. The middle half of the data falls inside the interquartile range. The whisker below the box shows the minimum of the variable while the whisker above the box shows the maximum of the variable. Within the box, it will also be drawn a line which represents the median of the variable.

For instance, the below box plot shows the box plot for the contribution of the third part tort liability risk to the total project delay. The minimum of the variable is 0, the first quartile is 4.165, the second quartile or median is 8.61, the third quartile is 13.145 and
the maximum is 20.

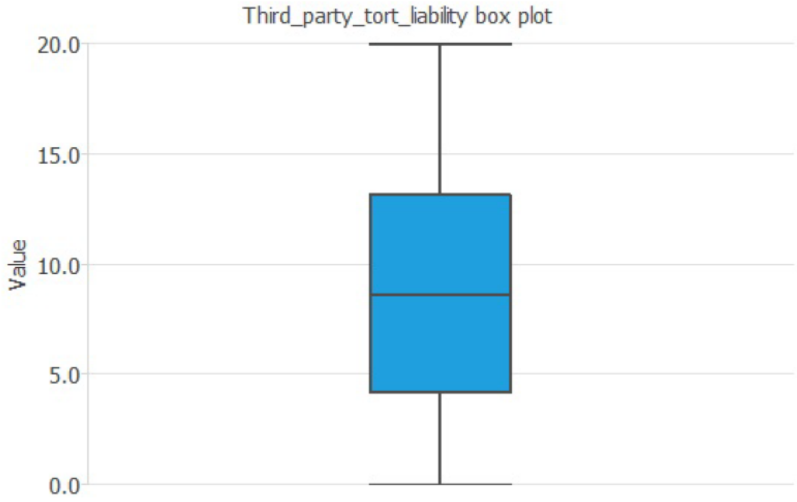


Figure 47. **Box plot for the contribution of the third part tort liability risk to the total project delay**

The complete plotted box plots for all risk factors are present in Appendix L.

4.4.3 Choosing the network architecture

The choice of the Neural Network architecture is a major step in the modelling phase. Determining the network architecture consists of establishing the internal structure and rules (Gunaydin and Dogan 2004). One of the first questions about choosing the network architecture is “in order to have an adequate model, how large should the network be?” In other words, how many nodes and hidden nodes should the network consist of?

There is no unanimity in the literature regarding the criteria based on which the “size” of the neural network should be designed. However, all perspectives in the literature were revolving around the same concept “the size and architecture of the neural network depends on the model that is being designed and depends on the desired model output as well as on the available data in terms of quantity and quality” (Anderson 1995).

In a feedforward neural network, the layers are grouped into a sequence so that neurons in any layer are connected only to neurons in the next layer. In fact, Demuth *et al.* (2009) recommends starting with three layers then gradually increasing the number of layers (increasing the hidden layers from one layer to two layers) in case the performance of the model is not acceptable.

4.4.3.1 Input layer

The input layer contains the input variables which are the independent variables in the model. They are also called “features” or “attributes”. Neurons at the input layer present values for the input variables used for predicting the project delay. In this study, the neurons of the input layer represent the 44 risks that will be investigated. Each node is for each one of the 44 risks. The risks are inserted as per their magnitude represented by the contribution of each risk to the total project delay. Table 39 shows the list of risks along with the corresponding node number in the input layer.

Table 39. **List of risks that will be inserted in the model along with the corresponding node number in the input layer**

Node #	Risk factors	Risk group
X1	Public opposition	Stakeholders' issue
X2	Lack of communication between stakeholders	Stakeholders' issue
X3	Third-party tort liability	Stakeholders' issue
X4	Need for land acquisition	Stakeholders' issue
X5	Lack of support from government	Stakeholders' issue
X6	Inadequate distribution of responsibilities	Stakeholders' issue
X7	Inadequate PPP experience	Stakeholders' issue
X8	Lack of commitment between parties	Stakeholders' issue
X9	Inadequate distribution of authorities	Stakeholders' issue
X10	Differences in working methods	Construction
X11	Delay in resolving contractual dispute	Stakeholders' issue
X12	Lack of coordination	Stakeholders' issue
X13	Private investor change	Stakeholders' issue
X14	Third party delays	Stakeholders' issue
X15	Subjective evaluation	Stakeholders' issue
X16	Misunderstanding the role of stakeholders	Stakeholders' issue

Node #	Risk factors	Risk group
X17	Misinterpretation of contract	Stakeholders' issue
X18	Stakeholder management	Stakeholders' issue
X19	Inadequate negotiation period prior to initiation	Stakeholders' issue
X20	Staff crisis	Stakeholders' issue
X21	Cultural differences between main stakeholders	Stakeholders' issue
X22	Material availability	Construction
X23	Construction cost overrun	Construction
X24	Geological conditions	Construction
X25	High finance cost	Construction
X26	Availability of finance	Construction
X27	Construction completion	Construction
X28	Site availability	Construction
X29	Poor quality workmanship	Construction
X30	Labor availability	Construction
X31	Site safety and security	Construction
X32	Insolvency of sucbontracctors	Construction
X33	Construction delays	Construction
X34	Supporting utilities risk	Construction
X35	Labor disputes/strikes	Construction
X36	Land use	Construction
X37	Waste of materials	Construction
X38	Protection of geological and historical objects	Construction
X39	Government reliability	Construction
X40	Third-party reliability	Construction
X41	Excessive contract variation	Construction
X42	Delay in supply	Construction
X43	Constructability	Construction
X44	Defects in construction	Construction

4.4.3.2 Output layer

The output layer contains the Target Variable. The Target Variable is the dependent variable in the model. The neuron at the output layer provides an estimate of the project delay. The delay shall be calculated from the difference between original contract completion time and final contract time of completion.

$$\textit{Schedule Growth} = \frac{\textit{Final Schedule} - \textit{Initial estimate}}{\textit{Initial estimate}}$$
(5)

In approximation (or function regression) models, the main issue is to fit a function from data. By training a dataset consisting of input-target examples, the ANN learns from knowledge. The basic goal in an approximation is to model one or several target variables, conditioned on the input variables. Accordingly, the targets are usually continuous variables. The major objective in this section of the research is to produce a model which exhibits good generalization, or in other words, a model which makes good predictions for new data.

The next chart extracted from the actual ANN model illustrates the variables use for the model. It depicts the number of inputs (44), target (one) and unused variables (zero).

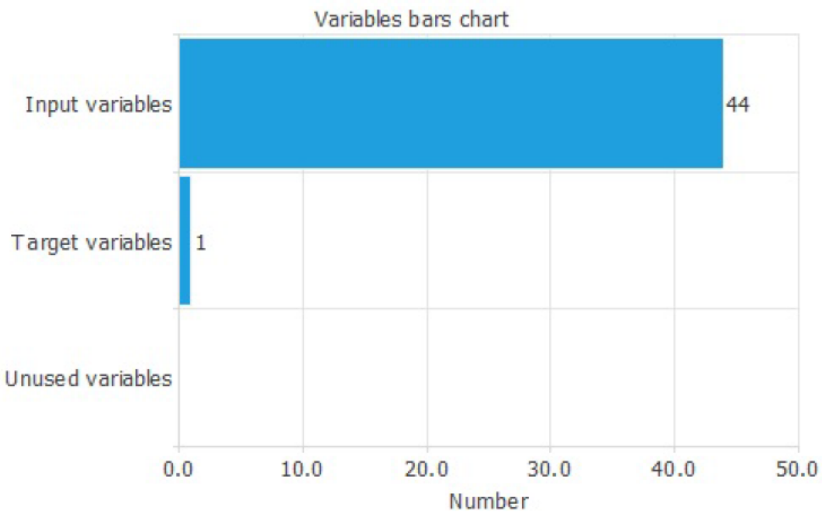


Figure 48. **Variables bar chart**

4.4.3.3 Hidden layer

As it was previously specified in section 3.6.2, the most important layer of an ANN is the "hidden layer" consisting of what is so-called "perceptron layers or dense layers". This is the layer that allows the ANN to "learn". These layers consist of "neurons", which are the basic units of perceptron layers or hidden layers. As per MY *et al.* (2001), the role of the hidden layer is to extract and remember the useful characteristics and features from the input layer in order to forecast the output layer.

As shown in Figure 49, the perceptron neuron receives the information as a set of numerical inputs x1, x2,….xn. Such information is then combined with a bias “b” and a set of weighs w1, w2,….wn. “C” represents the combination function.
The set of input values (x1, x2,….xn) is transformed using the combination function “C” in to produce a single combination or net input value through the following equation:

$$\boldsymbol{Combination} = \boldsymbol{bias} + \sum \boldsymbol{weights.inputs} \quad (6)$$

The activation function “a” defines the output of the perceptron layer in terms of its combination through the following rule:

$$\boldsymbol{Output} = \boldsymbol{activation}\ (\boldsymbol{combination}) \quad (7)$$

The aim of such arrangement is to produce a message in the form of a single numerical output “y”. The parameters of the neuron involve the weighs as well as the bias.

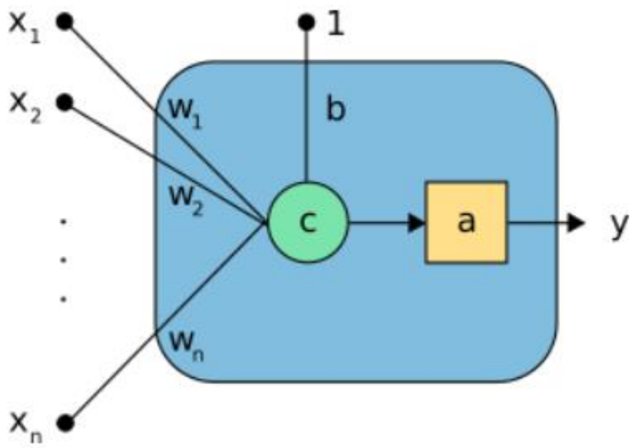


Figure 49. **Components of a perceptron neuron**

The optimal number of neurons in the hidden layer shall be kept as a parameter to be changed. Ahiaga-Dagbui (2014) points out that the number of hidden nodes should be as small as possible to avoid overfitting or memorizing which can affect the results. Demuth *et al.* (2009) had a different opinion by pointing out that the power of the network increases by increasing the number of neurons in the hidden layer. Nevertheless, the only drawback is that increasing the number of neurons in the hidden layer may increase the chance of overfitting. For the purpose of overcoming such issue, Lhee, Raja, Issa and Flood (2012) proposed to find the optimal number of hidden neurons during the training process by varying the number of hidden neurons and calculating the average error each time as illustrated in Figure 50.

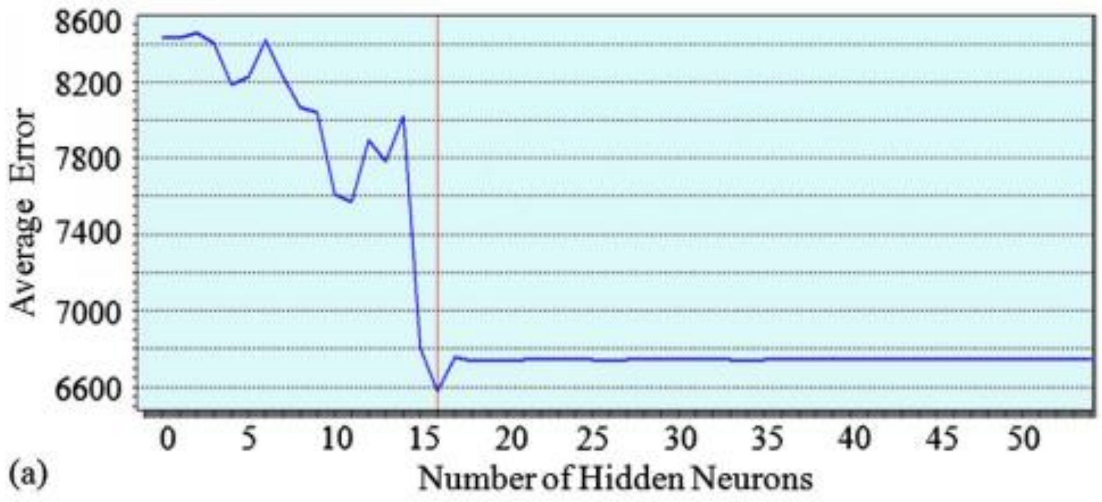


Figure 50. **Finding the optimal number of hidden neurons during the training process (Lhee *et al.* 2012)**

As per the above example, the optimal number of hidden neurons is 15 neurons for this particular model. This point is where the average error is minimum before starting to increase again.

4.4.4 Training strategy

The procedure used to carry out the learning process is called training (or learning) strategy. According to Heravi and Eslamdoost (2015), training the neural network is essential in tuning the values of the weights in order to optimize the network's performance. In other words, the training strategy is applied to the neural network in order to obtain the minimum loss possible. This is done by searching for a set of parameters that fit the neural network to the data set. The backpropagation training technique will be used in this model as, based on the literature, it has been used for problems of a similar nature and there are evidence, as per the literature, that such models were successful and delivered adequate results (Gunaydin and Dogan

2004) (Hegazy and Ayed 1998) (Al-Tabtabai, Alex and Tantash 1999) (Squeira 1999) (Setyawati, Sahirman and Creese 2002) and (Rumelhart 1986). In the initial model, all 44 risk factors will be initially considered. Heravi and Eslamdoost (2015) points out that multilayer feedforward neural networks use several training techniques and the most popular technique among them is the backpropagation. The training process of ANNs with backpropagation algorithm is illustrated in Figure 51.

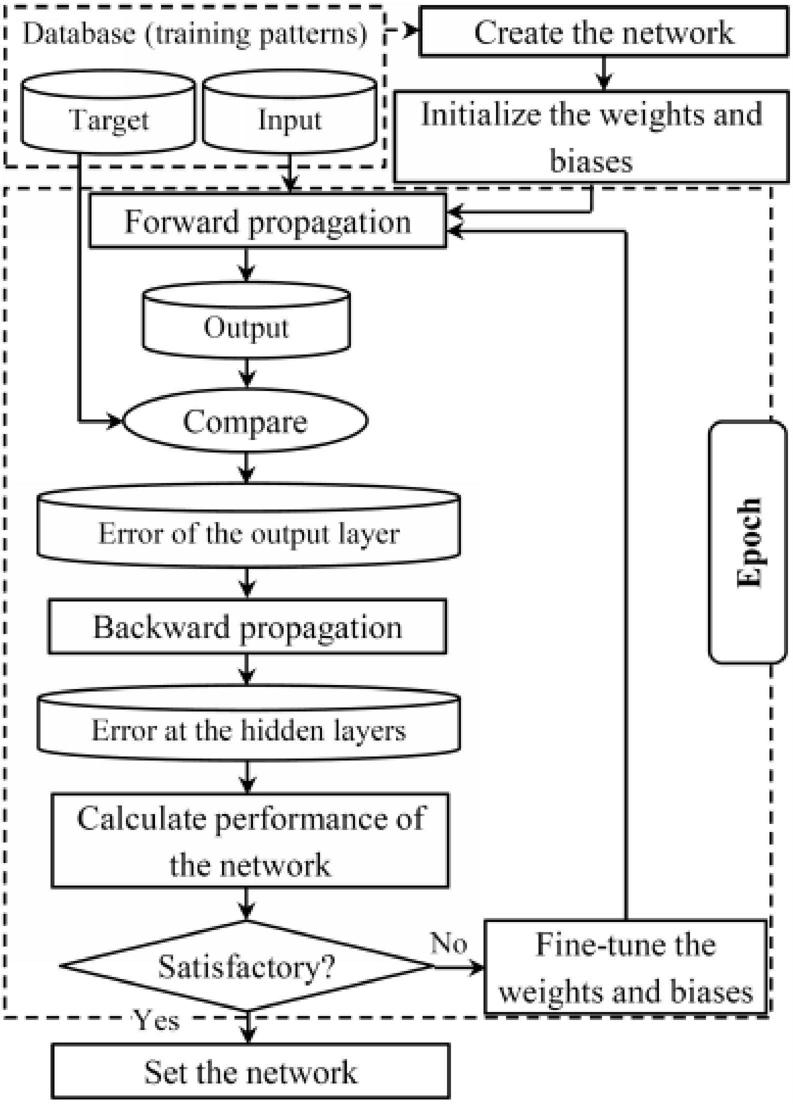


Figure 51. **Training process of Artificial Neural Networks with backpropagation algorithm (Heravi and Eslamdoost 2015)**

During the training phase, as it was previously explained, the neuron calculates the sum of the weighed inputs, subtracts its threshold from the sum and transfers the results by a transformation function or "activation function" (Gunaydin and Dogan 2004) explained by the following equation:

$$\boldsymbol{Yi} = \boldsymbol{fi}\,(\textstyle\sum_{j=1}^{n} \boldsymbol{wijxj} - \boldsymbol{si}) \qquad (8)$$

Where Yi is the output of the neuron which is the output in terms of the combination function, Wij is the weight assigned to the input value j, Si is the threshold value of the neuron and $\boldsymbol{fi}$ is the transformation function.

The above equation explains the concept in Section 4.4.3.3 which specifies that the activation function defines the perceptron output in terms of its combination as follows:

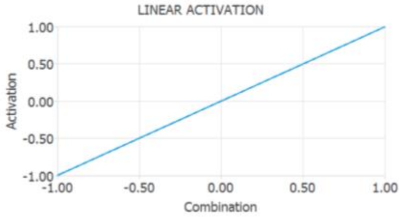
$$Output = activation\ (combination)$$

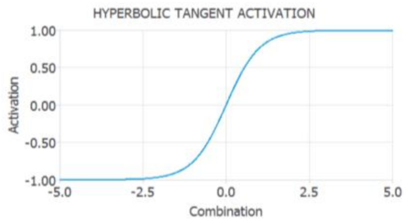
Thus $$\boldsymbol{Yi} = \boldsymbol{fi}\ (\textstyle\sum_{j=1}^{n} \boldsymbol{wijxj} - \boldsymbol{si})$$

4.4.4.1 Activation functions

The activation function "$\boldsymbol{fi}$" determines the type of function that the ANN represents. In other words, the activation function controls the behavior of the ANN during training. These mathematical functions determine the nature of the ANN weights that are transferred from one neuron to another. The activation functions are iterated in this research and are detailed in Table 40:

***Table 40.* Activation functions used in the research**

#	Function	Definition	Formula	Range	Graphic representation
1	**Linear (identity)**	The output of the neuron is simply the combination of this particular neuron.	$\boldsymbol{Activation} = \boldsymbol{combination}$ (9)	(-∞, +∞)	 ***Figure 52.* Linear activation function**

#	Function	Definition	Formula	Range	Graphic representation
2	**Hyperbolic tangent**	The most used activation functions in ANNs. It is a sigmoid curve. It is ideal for multilayer neurons, particularly the hidden layers.	$$activation = tanh combination \quad (10)$$	(-1, +1)	 *Figure 53.* Hyperbolic tangent activation function
3	**Logistic**	Another type of sigmoid functions; the only difference that discerns it from the hyperbolic tangent is that it varies between 0 and 1.	$$activation = \frac{1}{1 + e^{-combination}} \quad (11)$$	(0,1)	 *Figure 54.* Logistic activation function

4.4.4.2 Components of training strategy

In general, training strategy consists of two major concepts which are explained and subdivided through the chart in Figure 55:

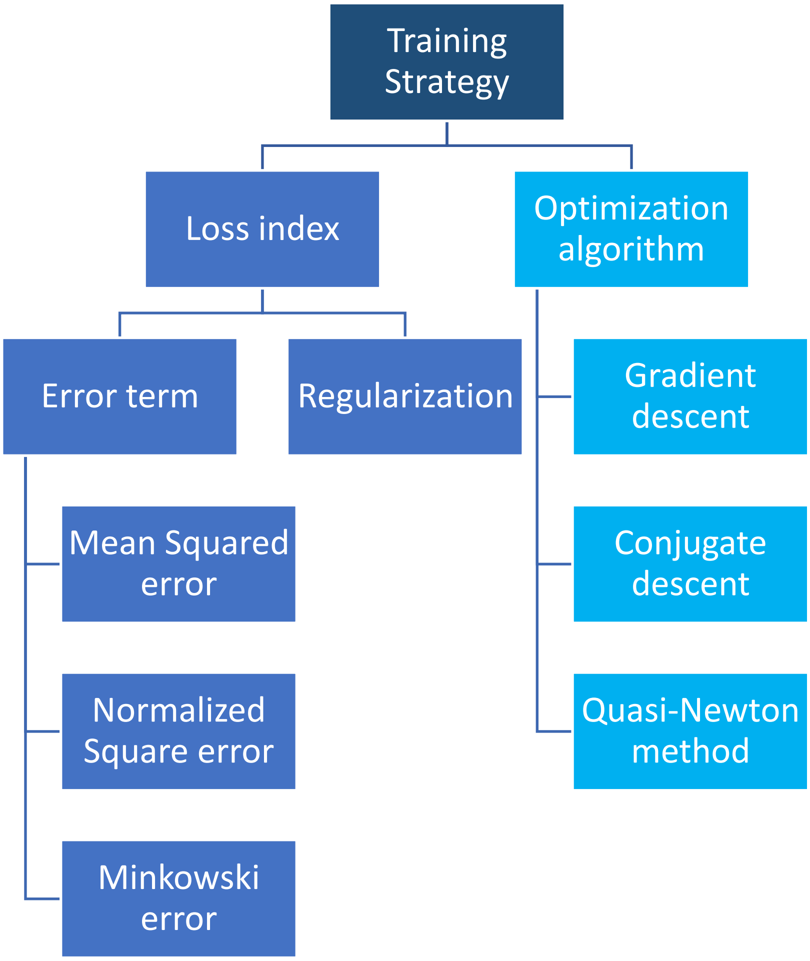


Figure 55. **Training Strategy**

4.4.4.2.1 Loss index

The loss index plays an important role in the use of a neural network. It defines the task the neural network is required to do and provides a measure of the quality of the representation that the neural network is required to learn. The choice of a suitable loss index depends on the particular application. Training an ANN can then be stated as finding a neural network function for which the loss index has a minimum value.

The loss index depends on the function represented by the neural network, and it is measured on the data set. It can be visualized as a hyper-surface with the parameters as coordinates, as illustrated in figure 56.

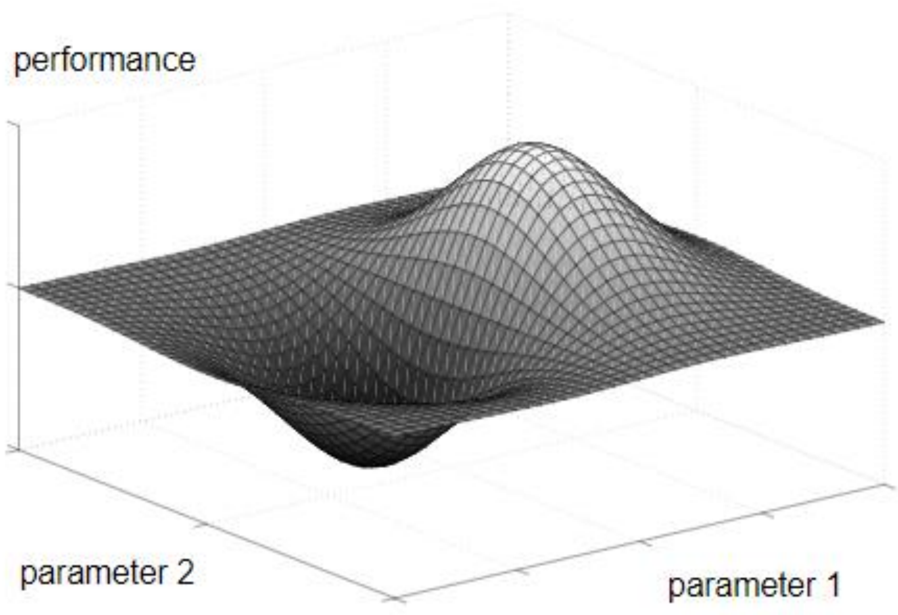


Figure 56. **Illustration of loss index**

When setting a loss index, two different terms must be chosen: an error term and a regularization term.

$$loss\ index = error\ term + regularization\ term \quad (12)$$

a. Error term

The error is the most important term in the loss expression. It measures how the neural network fits the training instances in the data set.

All that errors can be measured over different subsets of the data. In this regard, the **training error** refers to the error measured on the training instances of the data set, the **selection (testing) error** is measured on the selection instances and the validation error is measured on the validation instances. Next the most important errors used in the field of neural networks are described.

- **Mean Squared Error (MSE)**

The mean squared error calculates the average squared error between the outputs from the neural network and the targets in the data set. During the training, the weights are continuously changed until the Mean Square Error (MSE) error between the desired output and the model output is minimized. The MSE is a general indicator on the overall performance of the training (Al-Tabtabai and Alex 2000) (Albino and Garavelli 1998) and (Al-Tabtabai and Alex, 2000). Masters (1993) points out that the best measure to determine the model's reliability is the Mean Square Error.

The equation of the Mean Square Error (MSE) is as follows:

$$MSE = \frac{\sqrt{\sum_{i=1}^{n}\left(xi-E(i)\right)^{2}}}{n} \qquad (13)$$

Where: n is the number of samples to be evaluated in the training phase,

Xi is the model output related to the sample,

E(i) id the target output, i.e., the estimated time of completion of the project.

The training of all cases in a training set is called an epoch (Kalogirou 2001) (Gunaydin and Dogan 2004). In order to overcome the problem of memorizing and overfitting, the training will stop when the MSE remain the same for a certain number of epochs as illustrated in Figure 57.

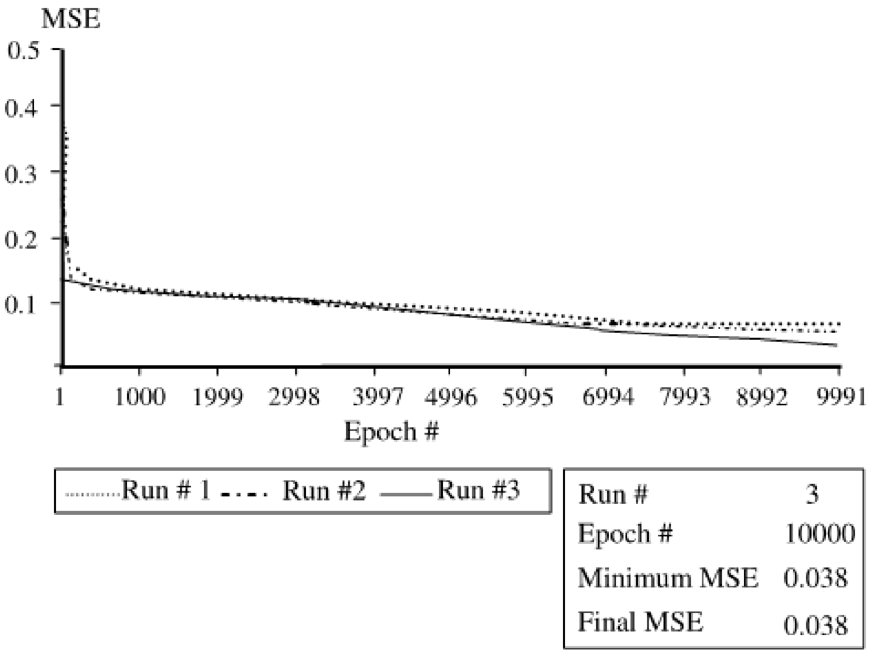


Figure 57. **Learning curve (Gunaydin and Dogan 2004)**

MSE is considered as the most suitable and used way to test the network reliability. Figure 58 shows a performance diagram illustrating the MSE calculated for training, testing and validation sets based on which the iteration where the best validation performance occurs is specified.

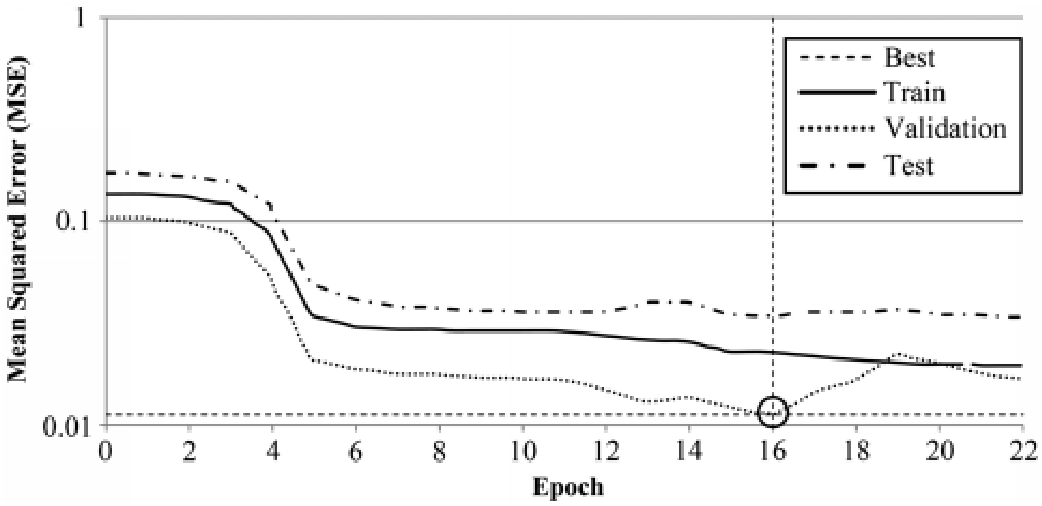


Figure 58. **Performance diagram showing the iteration at which the best network performance occurs (Heravi and Eslamdoost 2015)**

- **Normalized Squared error (NSE)**

The normalized squared error divides the squared error between the outputs from the neural network and the targets in the data set by a normalization coefficient. If the normalized squared error has a value of unity then the neural network is predicting the data 'on the mean', while a value of zero means perfect prediction of the data.

b. Regularization term

A solution is considered regular when small changes in the input variables lead to small changes in the outputs. A solution for non-regular problems is to control the effective complexity of the neural network. This can be achieved by using a regularization term into the loss index. Regularization terms usually measure the values of the parameters in the neural network. Adding that term to the error will cause the neural network to have smaller weights and biases, and this will force its response to be smoother.

4.4.4.2.2 Optimization algorithm

There is a number of optimization algorithms that can be used in ANNs, with the most popular being “the back-propagation” (Fausett 1994). Optimization algorithms are mathematical procedures used in order to automatically adjust the network´s weights and biases during training. The optimization algorithm determines the way in which the adjustment of the parameters in the neural network takes place.

The optimization algorithm stops when a specified condition is satisfied. Some stopping criteria commonly used are:

- The parameters increment norm is less than a minimum value.
- The loss improvement in one epoch is less than a set value.
- Loss has been minimized to a goal value.
- The norm of the loss index gradient falls below a goal.
- A maximum number of epochs is reached.
- A maximum amount of computing time has been exceeded.
- The error on the selection subset increases during a number of epochs.

A brief summary of the training algorithms deployed within Neural Designer ®, the software used in this research are presented below:

- **Gradient descent**

It is considered as the simplest optimization algorithm. With this method, the parameters are updated at each epoch in the direction of the negative gradient of the loss index. In other words, it is a first order optimization algorithm that moves incrementally to succesively lower points in search space until being able to locate a minimum.

$$\text{new\_parameters} = \text{parameters} - \text{loss\_gradient} * \text{learning\_ratenew\_parameters} = \text{parameters} - \text{loss\_gradient} * \text{learning\_rate}$$

- **Conjugate gradient**

It is a fast converging generic learning algorithm. The method iterates a series of line searches for global minimum in the error space.

$$\text{new\_parameters}=\text{parameters}-\text{conjugate\_gradient}\cdot\text{learning\_rate}$$

- **Quasi-Newton method**

This is also called Broyden-Fletcher-Goldfarb-Shanno (BFGS). The Newton's method uses the Hessian of the loss function, which is a matrix of second derivatives, to calculate the learning direction. Since it uses high order information, the learning direction points to the minimum of the loss function with higher accuracy. The drawback is that calculating the Hessian matrix is very computationally expensive. The quasi-Newton method is based on Newton's method, but does not require calculation of second derivatives. Instead, the quasi-Newton method computes an approximation of the inverse Hessian at each iteration of the algorithm, by only using gradient information.

$$\text{new\_parameters} = \text{parameters} - \text{inverse\_hessian\_approximation} \cdot \text{gradient} \cdot \text{learning\_}$$

The learning rate is adjusted here at each epoch using line minimization.

4.4.4.3 Model selection (Testing)

The objective of model selection is to find the network architecture with best generalization properties, that is, that which minimizes the error on the selection instances of the data set.

There are two types of model selection algorithms, order selection and inputs selection algorithms. This is illustrated in Figure 59.

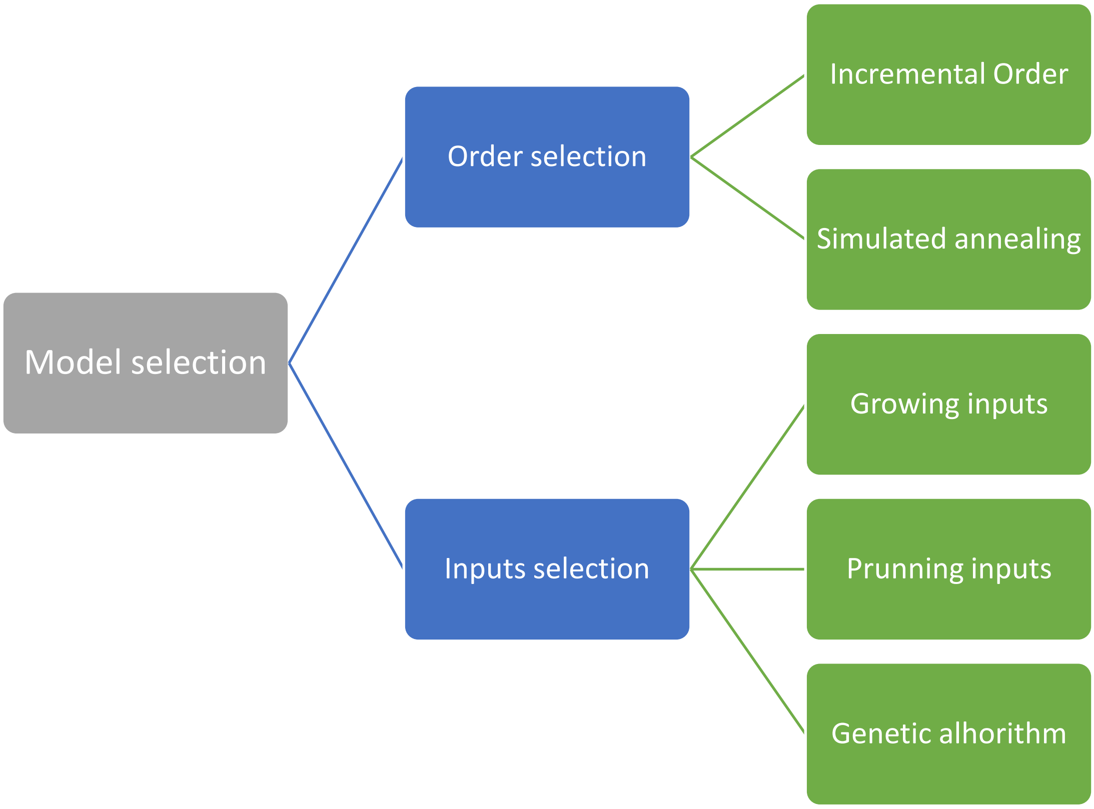


Figure 59. Model selection

a- Order selection

There are two major problems in the design of a neural network which are: underfitting and overfitting. The best generalization is achieved by using a model which complexity is the most appropriate to produce an adequate fit of the data.

Underfitting is defined as the effect of a selection error increasing due to a too simple model. Overfitting, on the other hand, is defined as the effect of a selection (testing) error increasing due to a too complex model. Over-fitted models perform very well on training and testing data but fail to generalize satisfactorily when new or "unseen" cases are used for validation of performance. Order selection algorithms are in charge of finding the complexity of the neural network which yields the best generalization properties. Two of the most used order selection algorithms are incremental order and decremental order.

- **Incremental order**

Incremental order is the simplest order selection algorithm. This method starts with a small number of neurons and increases the complexity until some stopping criteria is met. The algorithm returns the neural network with the optimal order obtained.

- **Decremental order**

A similar order selection algorithm is decremental order. It starts with a big number of neurons and decreases the complexity until a stopping criterion is reached.

b- Inputs selection

The role of the input selection algorithms is to automatically extract the features that should be used to create a sound predictive model in the data set that provide the best generalization capabilities. In order to realize this purpose, they search for the subset of inputs that minimizes the selection error. The inputs selection algorithm stops when a specified condition is satisfied. Some stopping criteria used are:

- **Growing inputs**

The growing inputs method calculates the correlation of every input with every output in the data set. Then it starts with a neural network that only contains the most correlated input and calculates the selection error for that model. It keeps adding the most correlated variables until the selection error increases. The algorithm returns the neural network with the optimal subset of inputs found.

- **Pruning inputs**

The pruning inputs method starts with all the inputs in the data set. It keeps removing those inputs with smallest correlation with the outputs until the selection error increases.

- **Genetic algorithm**

A different class of inputs selection method is the genetic algorithm. This is a stochastic method based on the mechanics of natural genetics and biological evolution. Genetic algorithms usually include fitness assignment, selection, crossover and mutation operators. The process is illustrated in the below figure:

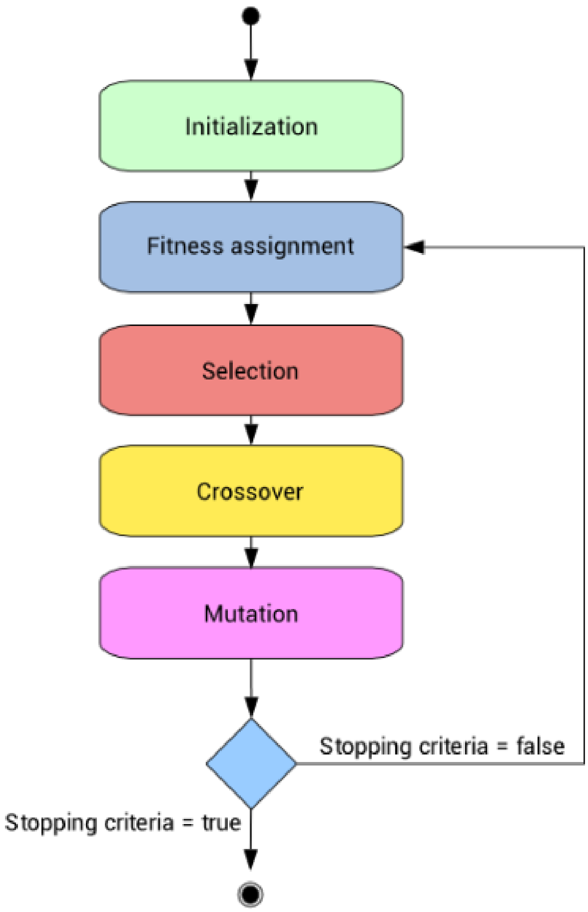


Figure 60. **Genetic algorithm process**

4.4.4.4 Training the models

This section includes the major model trials. All three activation functions in Table 40 were used with the three activation training algorithms already described (i.e. Gradient descent, conjugate gradient and Quasi-Newton). All 44 risk factors were used initially with Total Project Delay (Schedule Growth) as model output.

Early stopping was used in order to avoid model overfitting. Early stopping is simply described by halting or “stopping” training once the model error stops decreasing. The major benefit of early stopping is to overcome “memorizing” or “over-fitting. This shall improve generalization. In this case, each trial was repeatedly trained as long as testing (or selection) error was decreasing. Figure 61 shows an illustration of training a model with early stopping. In this case, the model training continues as long as the testing error decreases and is stopped once the testing error starts to increase.

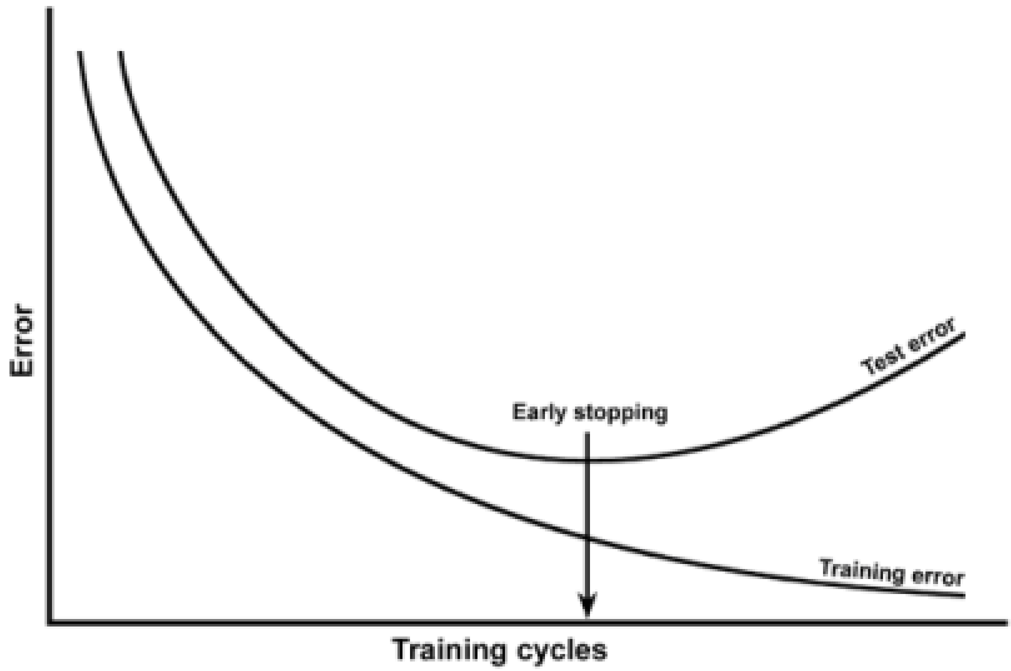


Figure 61. **Neural Network training with early stopping**

Model performance was detected using Mean Squared Error (MSE) and Normalized Squared Error (NSE) over the training, testing and validation datasets. Table 41 shows details of the ten best retained models, in no particular order of superiority.

Table 41. **Best retained models**

		Error (MSE)				Error (NSE)							
		Train		Test		Train		Test					
N.	**Architecture**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Activation function**	**optimization algorithm**	**Order selection**	**Inputs selection**
1	39-6-1	1.41001	0.00028576	1.16286	0.265803	3.38992	0.00352405	0.0571335	1.5625	Hyperbolic tangent	Quasi-Newton	Incremental	Growing inputs
2	21-2-1	0.428456	0.00283195	0.0027255	0.0027304	3.00586	0.00010956	0.0029444	0.0046979	Hyperbolic tangent	Quasi-Newton	Incremental	Genetic algorithm
3	15-1-1	39.3855	0.345018	5.34302	1.35471	11.5539	0.654893	0.914513	0.654893	Linear	Gradient descent	Simulated annealing	Genetic algorithm
4	18-2-1-1	0.06509	0.0128799	1.10045	0.73764	11.5539	0.654893	0.914513	0.654893	Logistic	Conjugate gradient	Simulated annealing	Genetic algorithm
5	15-1-1	2.49161	1.54628	1.41821	1.41821	0.92719	0.505086	1.71003	1.71003	Logistic	Gradient descent	Incremental	Genetic algorithm
6	18-2-1-1	0.492519	0.357687	1.5966	1.5966	13.9394	1.93558	0.745115	0.330551	Hyperbolic tangent	Gradient descent	Simulated annealing	Genetic algorithm
7	25-1-1	0.06509	0.0128799	1.10045	0.737464	39.3573	0.127478	11.8303	0.394828	Linear	Conjugate gradient	Simulated annealing	Pruning inputs
8	17-1-1	0.428456	0.00283195	0.0027255	0.0027304	8.28199	0	3.87898	1.06001	Linear	Quasi-Newton	Simulated annealing	Growing inputs
9	15-1-1	0.428456	0.00283195	0.0027255	0.0027304	1.87478	1.64443	0.0029444	0.0029444	Logistic	Quasi-Newton	Incremental	Growing inputs
10	39-1-1	4.85305	0.170278	2.6571	0.127035	39.3573	0.127478	11.8303	0.394828	Hyperbolic tangent	Conjugate gradient	Incremental	Pruning inputs

For each model, the MSE and NSE are calculated during training and testing and the proposed optimum network architecture is specified.

Each trial illustrated in this table is detailed in the following sub-sections.

4.4.4.4.1 Trial one

Below are the details associated with the choice of the first trial of the ANN model:

Table 42. **Details associated with the choice of the first trial of the ANN model**

Parameter	Choice
Inputs	44 Risk factors
Outputs	One (Project delay)
Activation function	Hyperbolic tangent
Optimization algorithm	Quasi-Newton method
Order selection	Incremental order
Inputs selection	Growing inputs

The following plot shows the training and selection Normalized Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection (testing) error. The training error measures the ability of the neural network to fit the data that it sees. But the selection error measures the ability of the neural network to generalize to new data. The initial value of the training error is 3.38992, and the final value after 181 epochs is 0.00352405. The initial value of the selection error is 0.0571335, and the final value after 181 epochs is 1.5625.

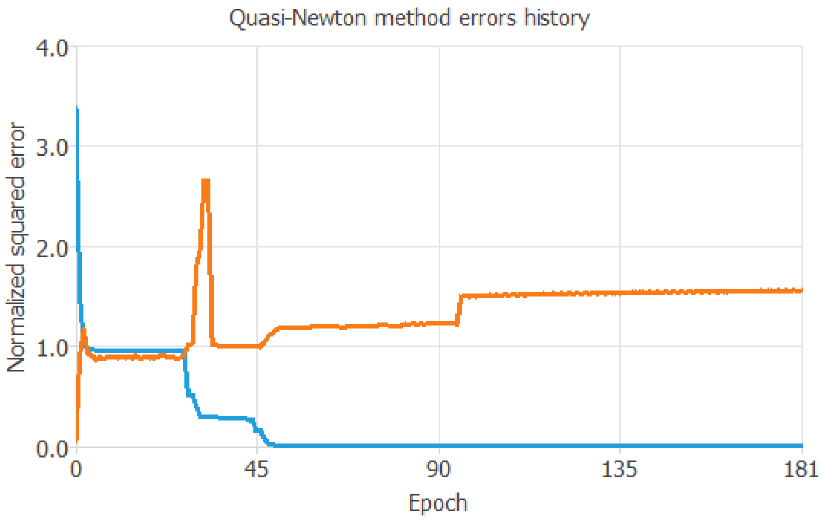


Figure 62. **Normalized square error- Quasi-Newton errors history**

The following plot extracted from the actual model shows the training and selection Mean Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection error. The higher the MSE value, the poorer the network at generalization. The initial value of the training error is 1.41001, and the final value after 109 epochs is 0.000285763. The initial value of the selection error is 1.16286, and the final value after 109 epochs is 0.265803.

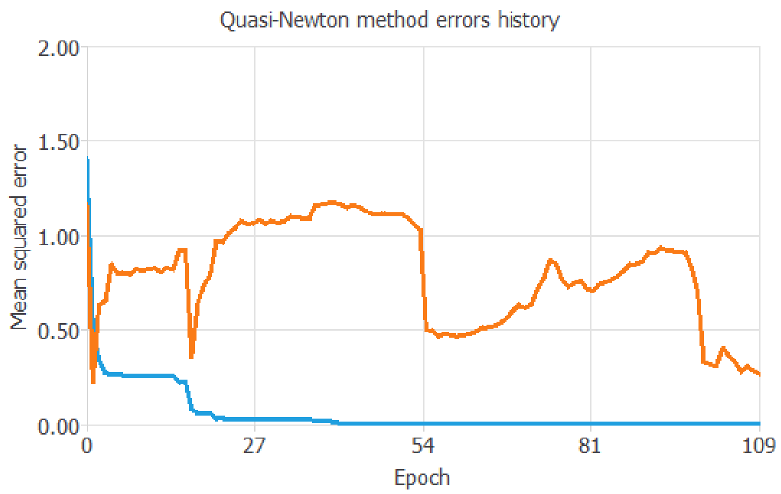


Figure 63. **Mean square error- Quasi-Newton errors history**

Table 43 provides a summary of the errors obtained from this model setup:

Table 43. **Summary of the errors obtained from the first model setup**

	Normalized-square error		Mean Square error	
	Highest value	Lowest value	Highest value	Lowest value
Training	3.38992	0.00352405	1.41001	0.000285763
Testing	0.0571335	1.5625	1.16286	0.265803

Table 44 specifies the features relative to the hidden neurons. The minimum number of hidden neurons is 1 and the maximum number is 10 with an increase of 1 hidden neuron for each iteration. The tolerance for the testing error is 0.01 while the goal value for testing error is zero.

Table 44. **Characteristics and features of the chosen optimum ANN in terms of order**

	Description	Value
Minimum order	Number of minimum hidden perceptrons to be evaluated.	1
Maximum order	Number of maximum hidden perceptrons to be evaluated.	10
Step	Number of hidden perceptrons added in each iteration.	1
Trials number	Number of trials for each neural network.	3
Tolerance	Tolerance for the selection error in the trainings of the algorithm.	0.01
Selection loss goal	Goal value for the selection error.	0
Maximum selection failures	Maximum number of iterations at which the selection error increases.	5
Maximum iterations number	Maximum number of iterations to perform the algorithm.	1000

- **Incremental Order plot**

The next chart shows the error history for the different subsets during the incremental order selection process. The blue line represents the training error and the orange line symbolizes the selection error.

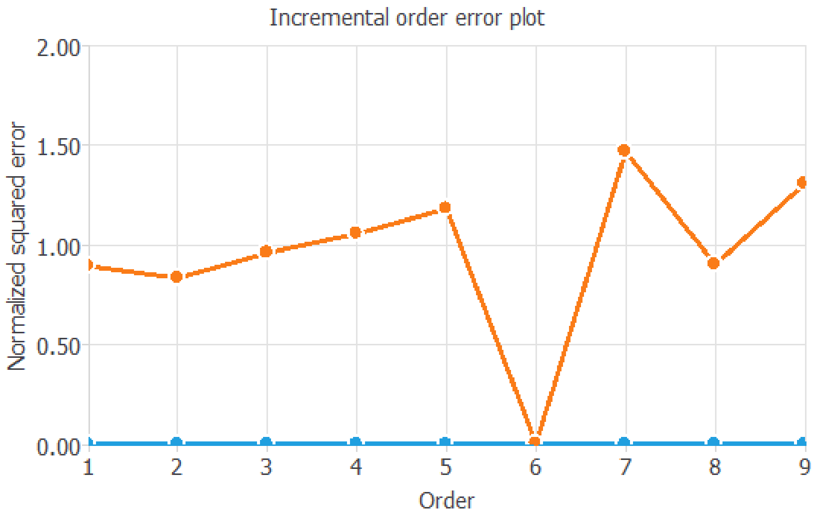


Figure 64. **Incremental order plot for the number of neurons in hidden layer**

Based on the aforementioned, it is found that based on the chosen parameters for trial one, the choice of six hidden neurons is the optimal number where the least NSE occurs in both training and testing. The NSE for training and testing are equal to zero. This was based on nine iterations.

Table 45 displays the order selection results by the incremental order algorithm. They include some final states from the neural network, the error functional and the order selection algorithm.

Table 45. **Incremental error results and optimal number of hidden neurons for trial 1**

	Value
Optimal order	6
Optimum training error	0.000105406
Optimum selection error	0.00297136
Iterations number	9
Elapsed time	00:08

After performing the testing and training and based on the ANN model´s operation, in order to obtain a testing error of zero and after doing nine iterations until the testing error increases, it was chosen for the model to have an optimum number of six hidden neurons and 39 inputs which are:

1- Delay in resolving contractual dispute
2- Lack of communication between stakeholders
3- Material availability
4- Misinterpretation of contract
5- Site availability
6- Waste of materials
7- Supporting utilities risk
8- Delay in supply
9- Labor availability
10- Geological conditions
11- Construction completion
12- Third-party reliability
13- Government reliability
14- Availability of finance
15- High finance cost
16- Inadequate PPP experience
17- Inadequate negotiation prior to initiation
18- Misunderstanding the role of stakeholders
19- Labor disputes
20- Site safety
21- Lack of coordination
22- Stakeholder management
23- Inadequate distribution of authorities
24- Inadequate distribution of responsibilities
25- Difference in working methods
26- Staff crisis
27- Third-party delays
28- Construction delays
29- Need for land acquisition
30- Insolvency of subcontractors
31- Excessive contract variation
32- Third-party tort liability

33-Subjective evaluation

34-Lack of commitment between parties

35-Cultural differences

36-Defects in construction

37-Poor quality workmanship

38-Land use

39-Lack of support from government

4.4.4.4.2 Trial two

For the second trial of the ANN model, a change was made for the testing algorithm used. This time, Genetic Algorithm was used as a testing algorithm for model selection instead of Growing Inputs method. Table 46 provides details associated with the choice of the second trial of the ANN model.

***Table 46*. Details associated with the choice of the second trial of the ANN model**

Parameter	Choice
Inputs	44 Risk factors
Outputs	One (Project delay)
Activation function	Hyperbolic tangent
Optimization algorithm	Quasi-Newton method
Order selection	Incremental order
Inputs selection	Genetic algorithm

The following plot shows the training and selection Normalized Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection (testing) error. The training error measures the ability of the neural network to fit the data that it sees. But the selection error measures the ability of the neural network to generalize to new data. The initial value of the training error is 3.00586, and the final value after 160 epochs is 0.000109559. The initial value of the selection error is 0.00294441, and the final value after 160 epochs is 0.00469793.

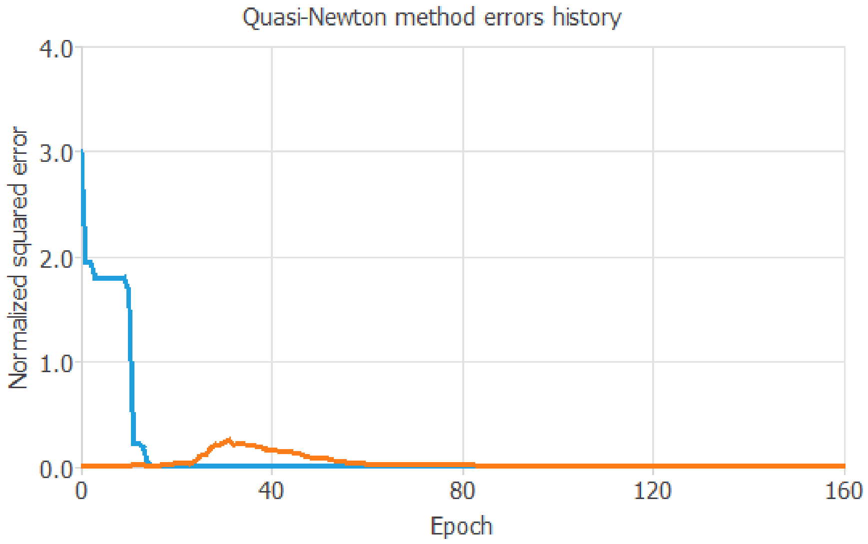


Figure 65. **Normalized square error- Quasi-Newton errors history**

The following plot extracted from the actual model shows the training and selection Mean Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection error. The higher the MSE value, the poorer the network at generalization. The initial value of the training error is 0.428456, and the final value after 192 epochs is 0.00283195. The initial value of the selection error is 0.00272551, and the final value after 192 epochs is 0.00273038.

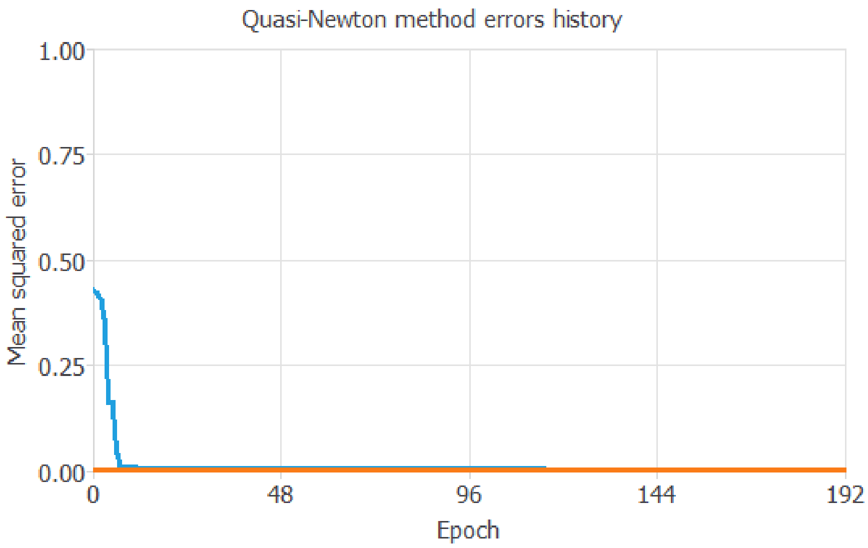


Figure 66. **Mean square error- Quasi-Newton errors history**

Displayed in table 47 is a summary of the errors obtained from this model setup:

Table 47. Summary of the errors obtained from the second model setup

	Normalized-square error		Mean Square error	
	Highest value	Lowest value	Highest value	Lowest value
Training	3.00586	0.000109559	0.428456	0.00283195
Testing	0.00294441	0.00469793	0.00272551	0.00273038

- **Genetic Algorithm error plot**

The chart in figure 67 shows the error history for the different subsets during the incremental order selection process. The blue line represents the training error, its initial value is almost zero and the final value after 100 generations is also almost zero. The orange line symbolizes the selection error its initial value is 0.299061 and the final value after 100 generations is 0.00210002.

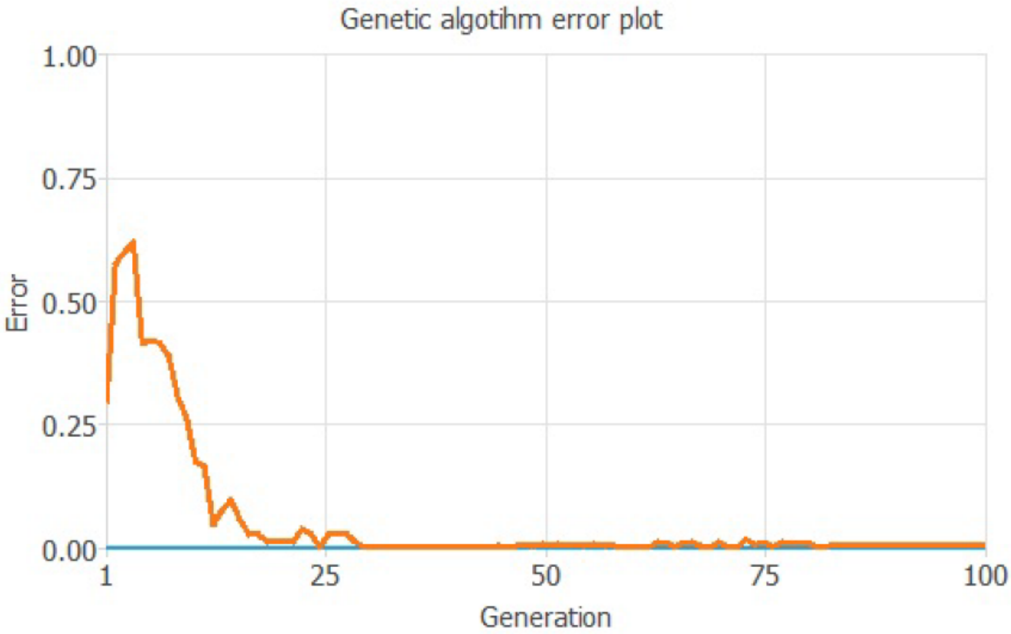


Figure 67. Genetic Algorithm error plot for the number of neurons in hidden layer

The history of the mean of the selection error in each generation during the genetic algorithm inputs selection process is illustrated in figure 68. The initial value is 1.05101, and the final value after 100 generations decreased to 0.051.

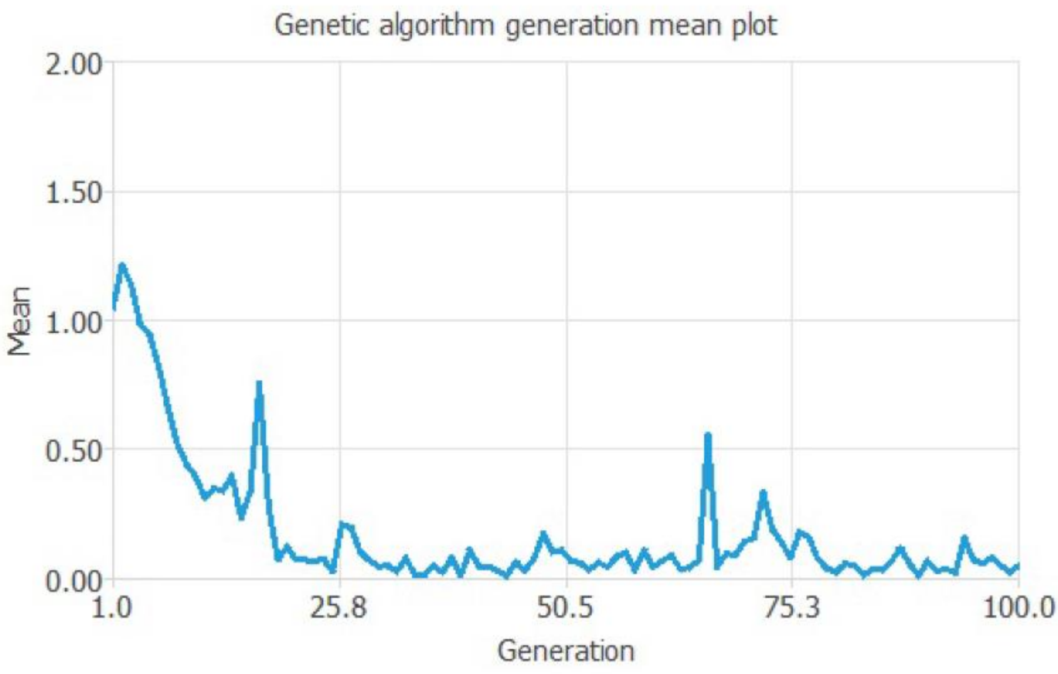


Figure 68. **Genetic Algorithm generation mean plot**

The next table (table 69) shows the order selection results by the Genetic algorithm. They include some final states from the neural network, the error functional and the order selection algorithm. Based on the second trial, the optimum number of inputs is 21 inputs.

Figure 69. **Incremental error results and optimal number of hidden neurons for trial 2**

	Value
Optimal number of inputs	21
Optimum training error	3.14535e-6
Optimum selection error	0.00210002
Generations number	100
Elapsed time	00:02

The inputs which are chosen to be selected for this trial are:

1- Public opposition
2- Lack of coordination
3- Private investor change
4- Third-party delays

5- Subjective evaluation
6- Misunderstanding the role of stakeholders
7- Misinterpretation of contract
8- Inadequate negotiation period prior to initiation
9- Material availability
10- Construction cost overrun
11- Geological conditions
12- High finance cost
13- Availability of finance
14- Construction completion
15- Insolvency of subcontractor
16- Supporting utilities risk
17- Land use
18- Third-party reliability
19- Excessive contract variation
20- Delay in supply
21- Defects in construction

- **Incremental Order plot**

Figure 70 shows the error history for the different subsets during the incremental order selection process. The blue line represents the training error and the orange line symbolizes the selection error.

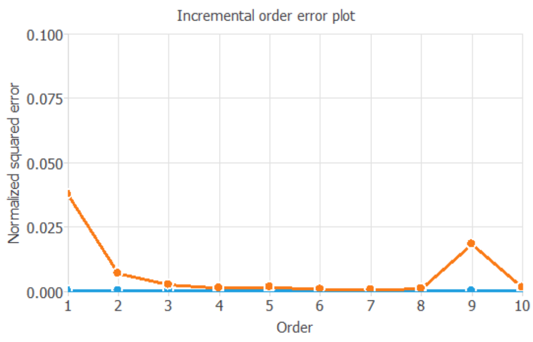


Figure 70. **Incremental order plot for the number of neurons in hidden layer**

The selected optimum number of hidden neurons in this ANN are reported in table 48.

Table 48. **Optimal number of hidden neurons- trial 2**

	Value
Optimal order	2
Optimum training error	0.000122155
Optimum selection error	0.00130343
Iterations number	9
Elapsed time	00:03

4.4.4.4.3 Trial three

Table 49 displays details associated with the choice of the third trial of the ANN model:

Table 49. **Details associated with the choice of the third trial of the ANN model**

Parameter	Choice
Inputs	44 (Risk factors)
Outputs	One (Project delay)
Activation function	Linear
Optimization algorithm	Gradient descent
Order selection	Simulated annealing
Inputs selection	Genetic algorithm

Whilst the training and selection Normalized Squared errors in each iteration for this tial ANN are shown in figure 71. The blue line represents the training error and the orange line represents the selection (testing) error. The training error measures the ability of the neural network to fit the data that it sees. But the selection error measures the ability of the neural network to generalize to new data.

The initial value of the training error is 11.5539, and the final value after one epoch is almost 0.914513. The initial value of the selection error is 0.654893, and the final value after remained almost the same after one epoch.

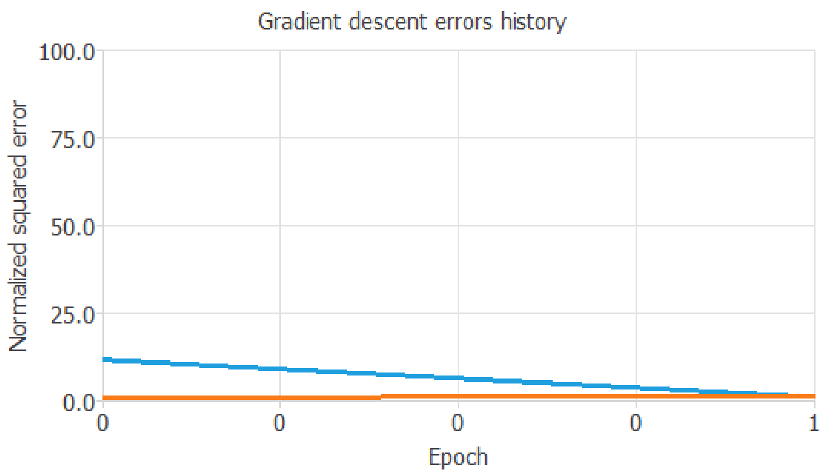


Figure 71. **Normalized square error- Gradient descent errors history**

Figure 72 is extracted from the actual model, the figure shows the training and selection Mean Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection error. The higher the MSE value, the poorer the network at generalization. In this case, the initial value of the training error is 39.3855, and the final value after one epoch is almost 0.345018. The initial value of the selection error is 5.34302, and the final value after one epoch is 1.35471.

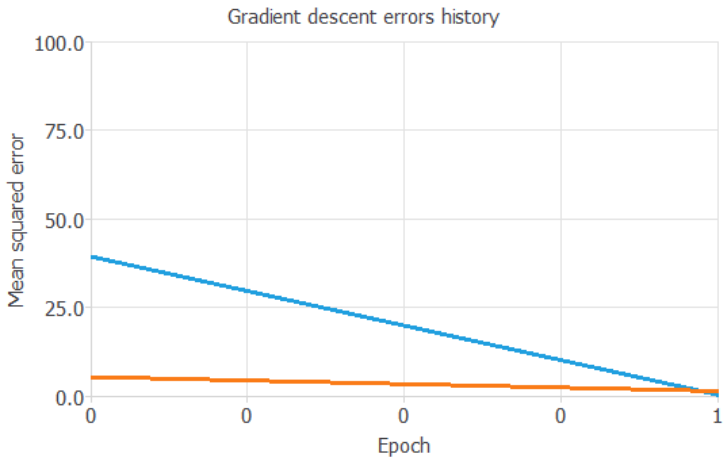


Figure 72. **Mean square error- Gradient descent history**

Provided in table 50 is a summary of the errors obtained from this model setup.

Table 50. **Summary of the errors obtained from the third model setup**

	Normalized-square error		Mean Square error	
	Highest value	Lowest value	Highest value	Lowest value
Training	11.5539	0.654893	39.3855	0.345018
Testing	0.914513	0.654893	5.34302	1.35471

- **Incremental Order plot**

The error history for the different subsets during the incremental order selection process are shown in figure 73. The blue line represents the training error and the orange line symbolizes the selection error.

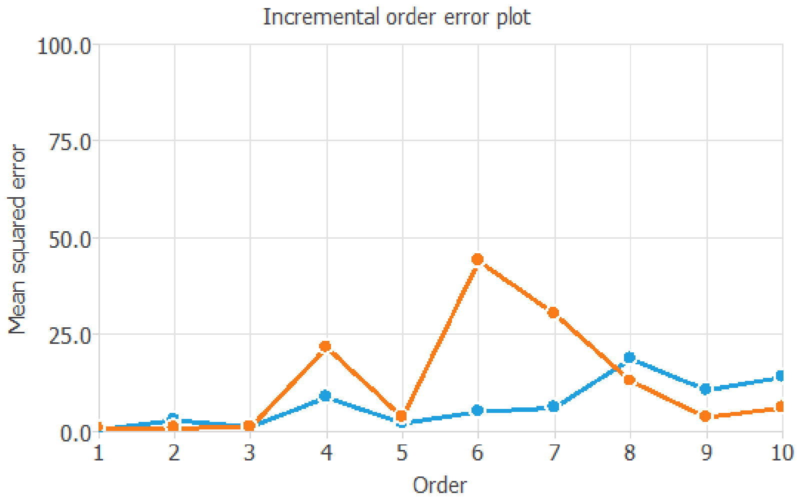


Figure 73: Incremental order plot for the number of neurons in hidden layer

Based on the aforementioned, it is found that based on the chosen parameters for trial one, one hidden neuron is the optimal number where the least MSE occurs in both training and testing. The MSE for training and testing are respectively 0.241224 and 0.596911 which are acceptably low error values. This was based on ten iterations.

Table 51 shows the order selection results by the incremental order algorithm. They include some final states from the neural network, the error functional and the order selection algorithm.

Table 51. **Incremental error results and optimal number of hidden neurons for trial 3**

	Value
Optimal order	1
Optimum training error	0.241224
Optimum selection error	0.596911
Iterations number	10
Elapsed time	00:00

The next chart (figure 74) shows the error history for the different subsets during the incremental order selection process. The blue line represents the training error, its initial value is 0.240624 and the final value after 100 generations is 0.265463. The orange line symbolizes the selection error its initial value is 0.124255 and the final value after 100 generations is 0.00478892.

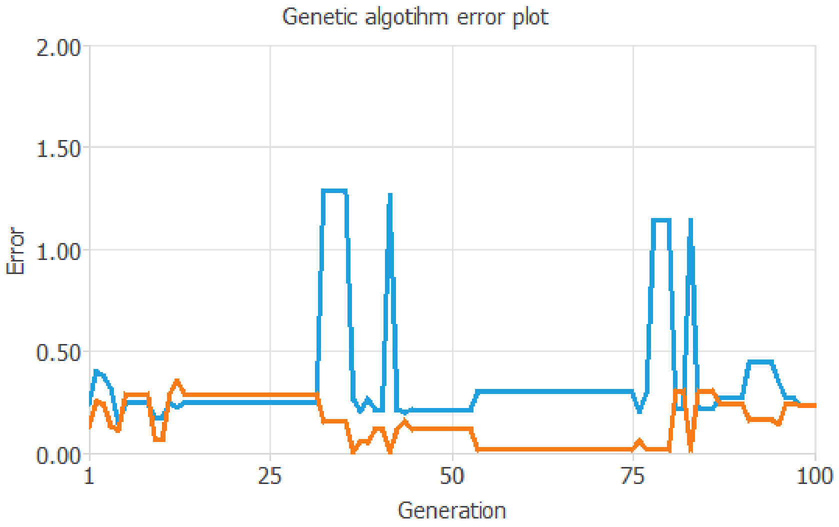


Figure 74. **Genetic Algorithm error plot for the number of neurons in hidden layer**

The history of the mean of the selection error in each generation during the genetic algorithm inputs selection process is provided in figure 75. The initial value is 0.596716, and the final value after 100 generations decreased to 0.496.

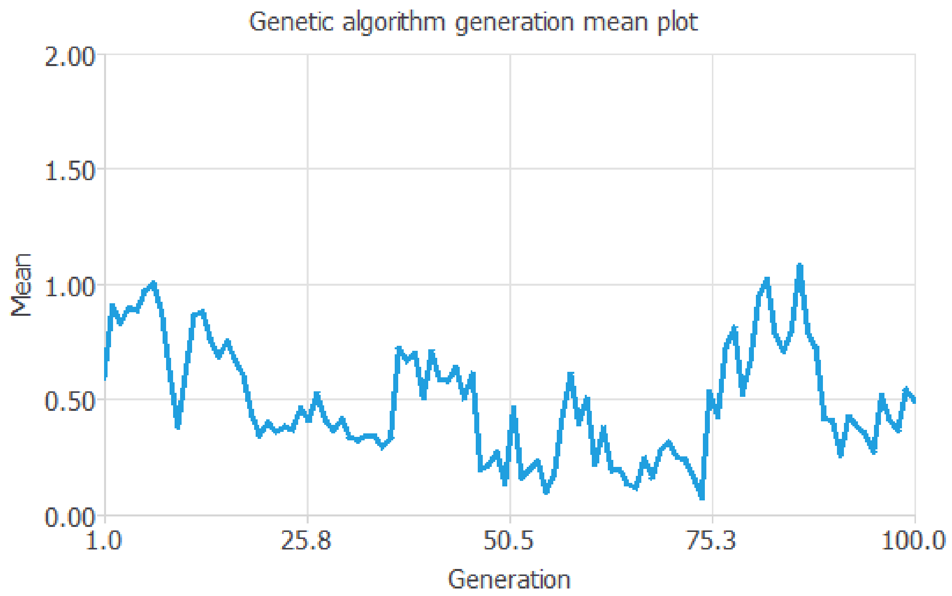


Figure 75. **Genetic Algorithm generation mean plot**

Whilst the order selection results by the Genetic algorithm are shown in table 52. They include some final states from the neural network, the error functional and the order selection algorithm. Based on the second trial, the optimum number of inputs is 21 inputs.

Table 52. **Incremental error results and optimal number of hidden neurons for trial 3**

	Value
Optimal number of inputs	15
Optimum training error	0.265463
Optimum selection error	0.00478992
Generations number	100
Elapsed time	00:00

Based on the third model trial, the proposed network architecture is illustrated in Figure 76. In this figure the optimum number of inputs is chosen to be 15 which are illustrated below.

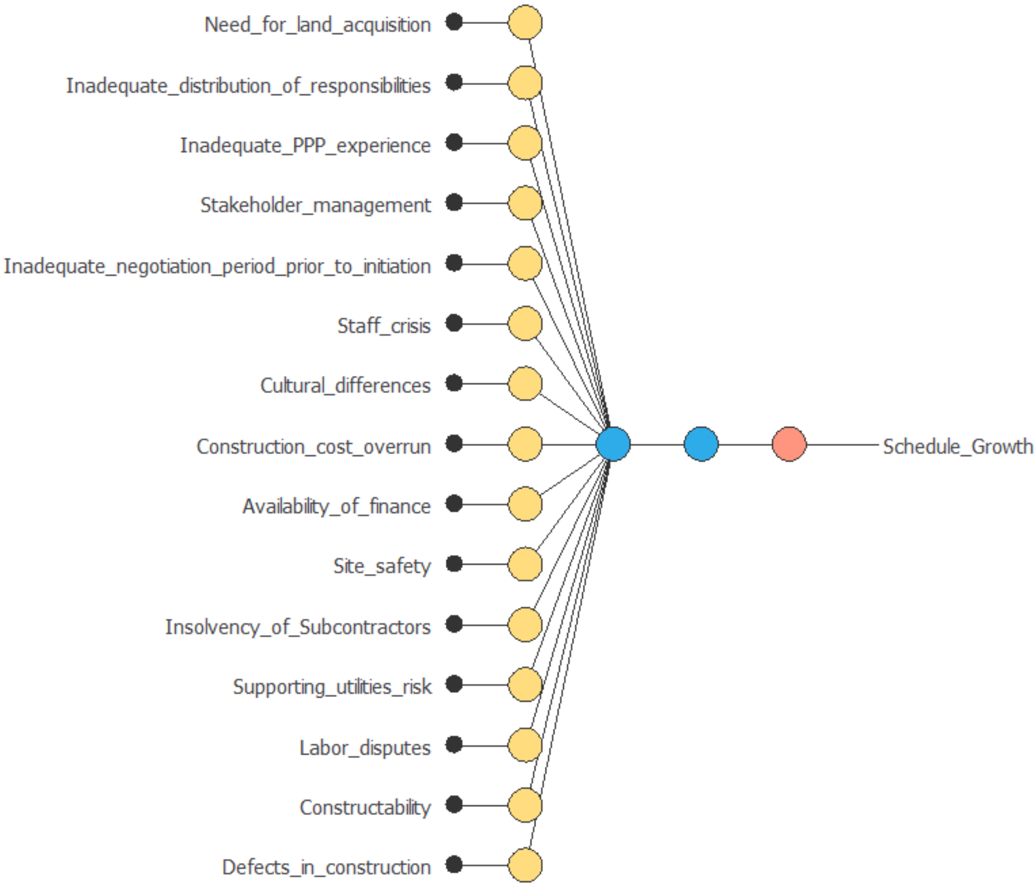


Figure 76. **Resulted deep architecture for trial 3**

4.4.4.4.4 Trial four

Below in table 53 are details associated with the choice of the fourth trial of the ANN model:

Table 53. **Details associated with the choice of the fourth trial of the ANN model**

Parameter	Choice
Inputs	44 (Risk factors)
Outputs	One (Project delay)
Activation function	Logistic
Optimization algorithm	Conjugate Gradient
Order selection	Simulated annealing
Inputs selection	Genetic algorithm

The following plot (figure 77) shows the training and selection Normalized Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection (testing) error. The training error measures the ability of the neural network to fit the data that it sees. But the selection error measures the ability of the neural network to generalize to new data.

The initial value of the training error is 0.422026, and the final value after 63 epochs is almost 0.183545. The initial value of the selection error is 1.02484, and the final value decreased to 0.766333 after 63 epochs.

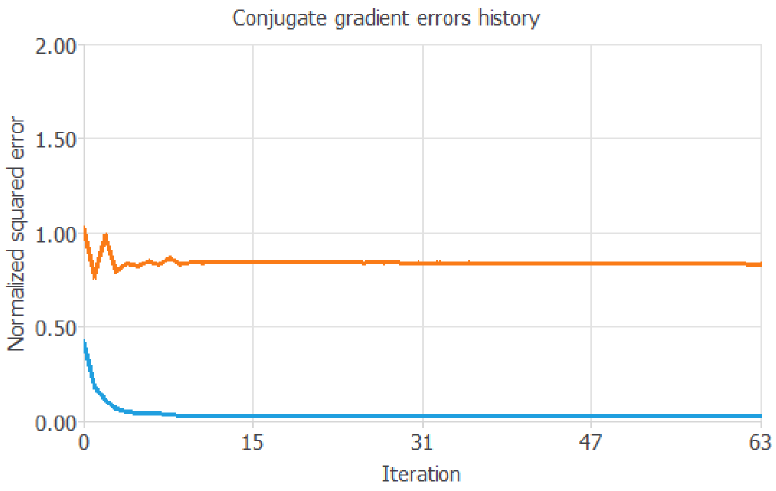


Figure 77. **Normalized square error- Conjugate Gradient errors history**

Figure 78, extracted from the actual model shows the training and selection Mean Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection error. The higher the MSE value, the poorer the network at generalization. In this case, the initial value of the training error is 0.0650897, and the final value after 206 epochs is 0.0128799. The initial value of the selection error is 1.10045, and the final value after 206 epochs is 0.73764.

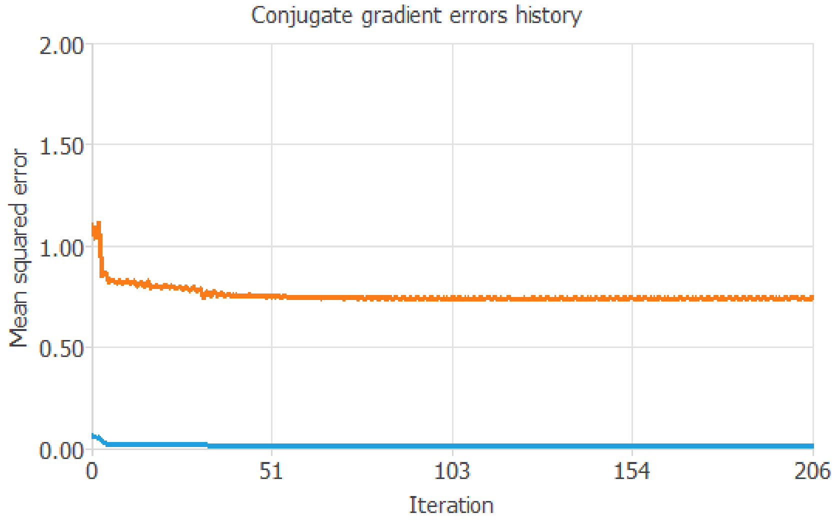


Figure 78. **Mean square error- Conjugate Gradient history**

In table 54, the reader is provided with a summary of the errors obtained from this model setup:

Table 54. **Summary of the errors obtained from the fourth model setup**

	Normalized-square error		**Mean Square error**	
	Highest value	Lowest value	Highest value	Lowest value
Training	11.5539	0.654893	0.0650897	0.0128799
Testing	0.914513	0.654893	1.10045	0.73764

- **Incremental Order plot**

Figure 79 shows the error history for the different subsets during the incremental order selection process. The blue line represents the training error and the orange line symbolizes the selection error.

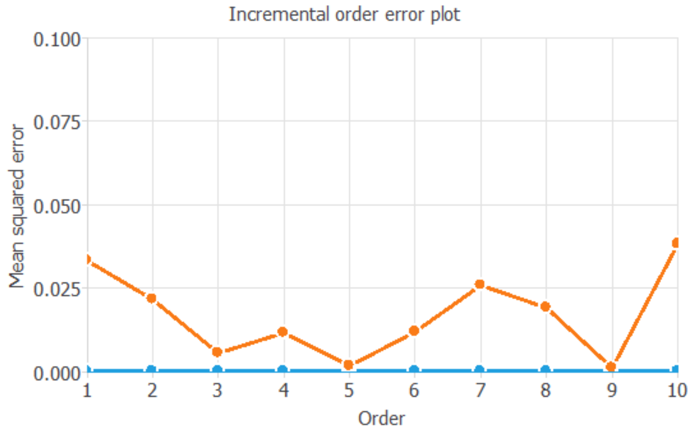


Figure 79. **Incremental order plot for the number of neurons in hidden layer**

Based on the aforementioned, it is found that based on the chosen parameters for trial one, three hidden neurons is the optimal number where the least MSE occurs in both training and testing. The MSE for training and testing are respectively zero and 0.00546449 which are acceptably low error values. This was based on ten iterations.

Figure 80 shows the order selection results by the incremental order algorithm. They include some final states from the neural network, the error functional and the order selection algorithm.

Figure 80. **Incremental error results and optimal number of hidden neurons for trial 4**

	Value
Optimal order	3
Optimum training error	3.77466e-6
Optimum selection error	0.00546449
Iterations number	10
Elapsed time	00:02

- **Genetic Algorithm error plot**

The next chart (figure 81) shows the error history for the different subsets during the incremental order selection process. The blue line represents the training error, its initial value is zero and the final value after 100 generations is also zero. The orange line symbolizes the selection error its initial value is 0.029363 and the final value after 100 generations is 0.0025417.

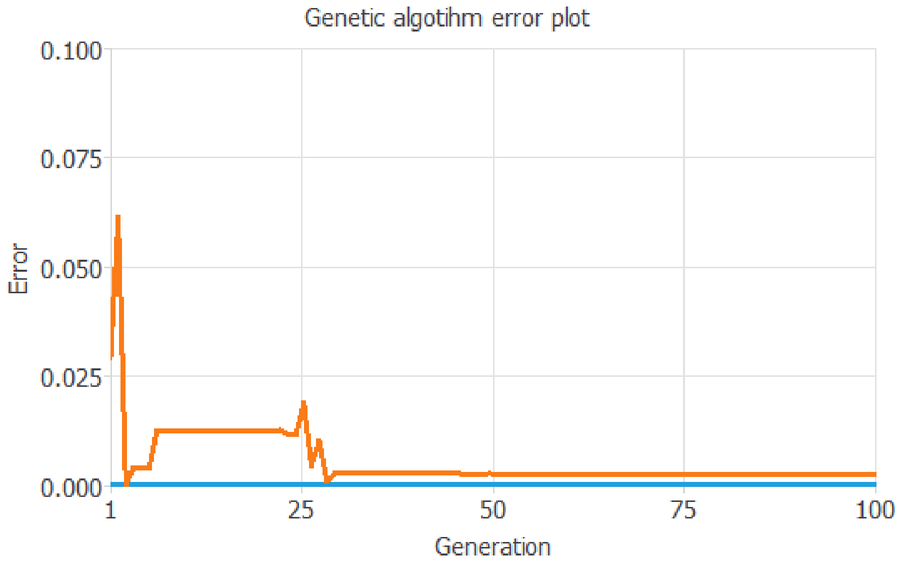


Figure 81. **Genetic Algorithm error plot for the number of neurons in hidden layer**

The history of the mean of the selection error in each generation during the genetic algorithm inputs selection process are shown in figure 82. The initial value is 0.282275, and the final value after 100 generations decreased to 0.00302.

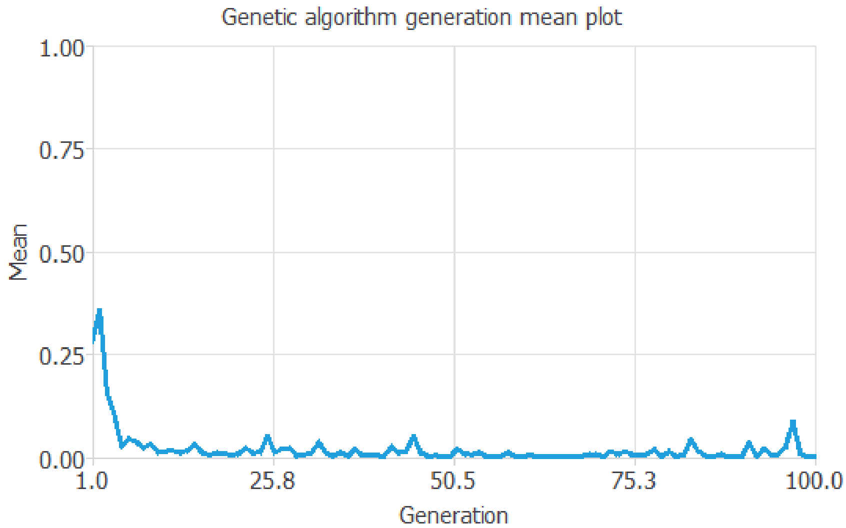


Figure 82. **Genetic Algorithm generation mean plot**

Whilst the order selection results by the Genetic algorithm are reported in table 55. They include some final states from the neural network, the error functional and the order selection algorithm. Based on the second trial, the optimum number of inputs is 18 inputs

***Table 55.* Incremental error results and optimal number of hidden neurons for trial 4**

	Value
Optimal number of inputs	18
Optimum training error	2.73667e-6
Optimum selection error	0.0024517
Generations number	100
Elapsed time	00:05

Based on the fourth model trial, the proposed network architecture is illustrated in Figure 83. In this figure the optimum number of inputs is chosen to be 18. The blue circles represent the perceptron (hidden) neurons.

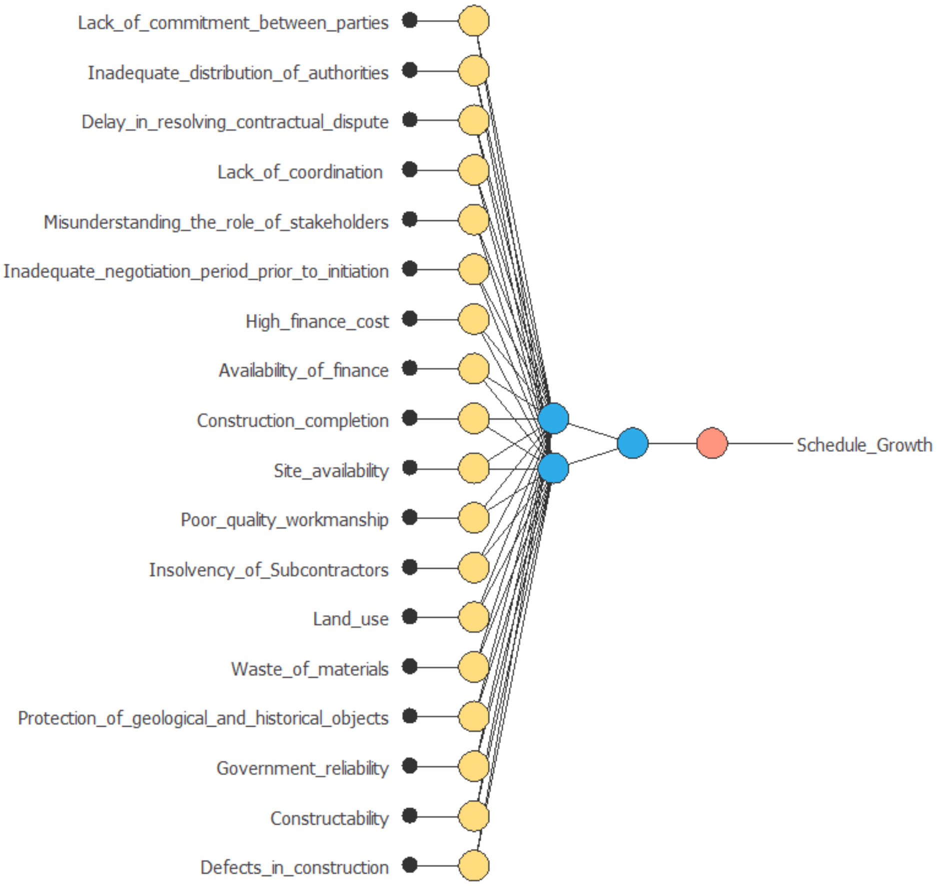


Figure 83. **Resulted deep architecture for trial 4**

4.4.4.4.5 Trial five

Details associated with the choice of the fifth trial of the ANN model are provided in table 56.

Table 56. **Details associated with the choice of the fifth trial of the ANN model**

Parameter	Choice
Inputs	44 (Risk factors)
Outputs	One (Project delay)
Activation function	Logistic
Optimization algorithm	Gradient descent
Order selection	Incremental Order
Inputs selection	Genetic algorithm

Figure 84 shows the training and selection Normalized Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection (testing) error. The training error measures the ability of the neural network to fit the data that it sees. But the selection error measures the ability of the neural network to generalize to new data.

The initial value of the training error is 2.49161, and the final value after one epoch is almost 1.54628. The initial value of the selection error is 1.41821, and the final value remained the same after one epoch.

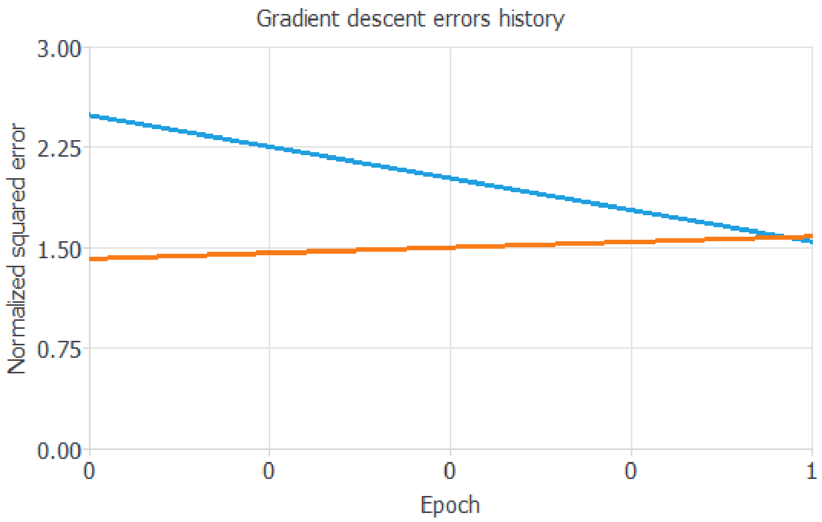


Figure 84. **Normalized square error- Gradient descent errors history**

The plot extracted from the actual model and shown in figure 85 depicts the training and selection Mean Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection error. The higher the MSE value, the poorer the network at generalization. In this case, the initial value of the training error is 0.927188, and the final value after one epoch is almost 0.505086. The initial value of the selection error is 1.71003, and the final value after one epoch is 1.71003.

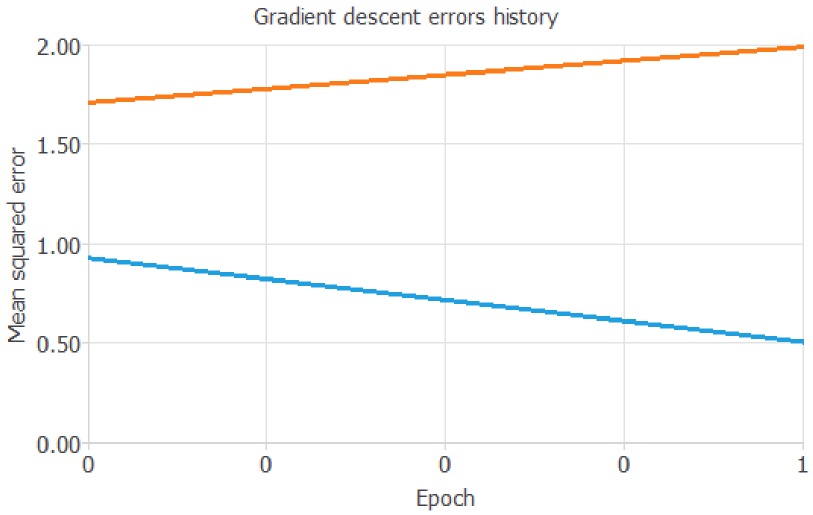


Figure 85. **Mean square error- Gradient descent history**

Table 57 provides a summary of the errors obtained from this model setup.

Table 57. **Summary of the errors obtained from the fifth model setup**

	Normalized-square error		Mean Square error	
	Highest value	**Lowest value**	**Highest value**	**Lowest value**
Training	0.927188	0.505086	2.49161	1.54628
Testing	1.71003	1.71003	1.41821	1.41821

- **Incremental Order plot**

The error history for the different subsets during the incremental order selection process is shown in figure 86. The blue line represents the training error and the orange line symbolizes the selection error.

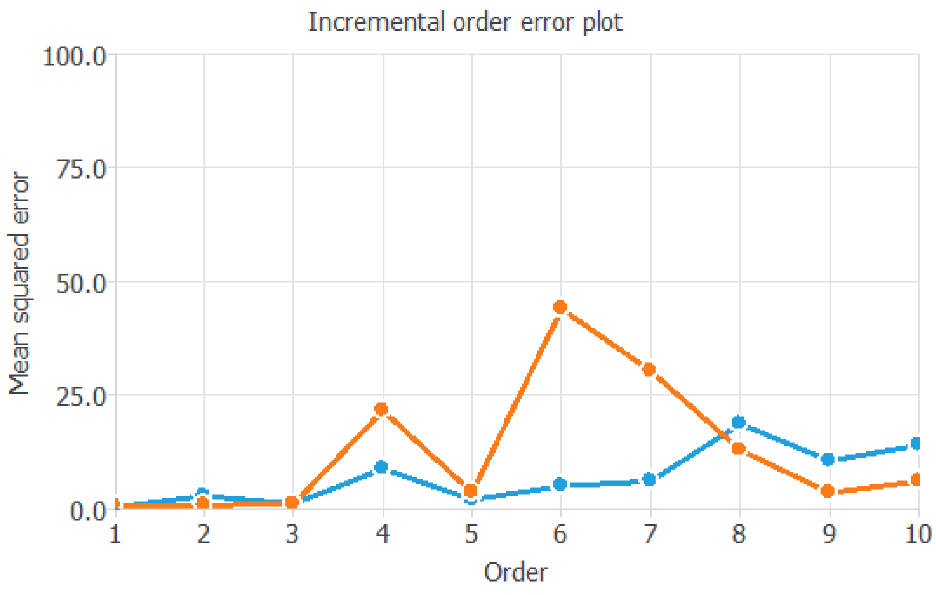


Figure 86: Incremental order plot for the number of neurons in hidden layer

Based on the aforementioned, it is found that based on the chosen parameters for trial one, one hidden neuron is the optimal number where the least MSE occurs in both training and testing. The MSE for training and testing are respectively 0.241224 and 0.596911 which are acceptably low error values. This was based on ten iterations.

Table 58 shows the order selection results by the incremental order algorithm. They include some final states from the neural network, the error functional and the order selection algorithm.

Table 58. **Incremental error results and optimal number of hidden neurons for trial 5**

	Value
Optimal order	1
Optimum training error	0.241224
Optimum selection error	0.596911
Iterations number	10
Elapsed time	00:00

Again the error history for the different subsets during the incremental order selection process are shown in figure 87. The blue line represents the training error, its initial value is 0.240624 and the final value after 100 generations is 0.265463. The orange line symbolizes the selection error its initial value is 0.124255 and the final value after 100 generations is 0.00478892.

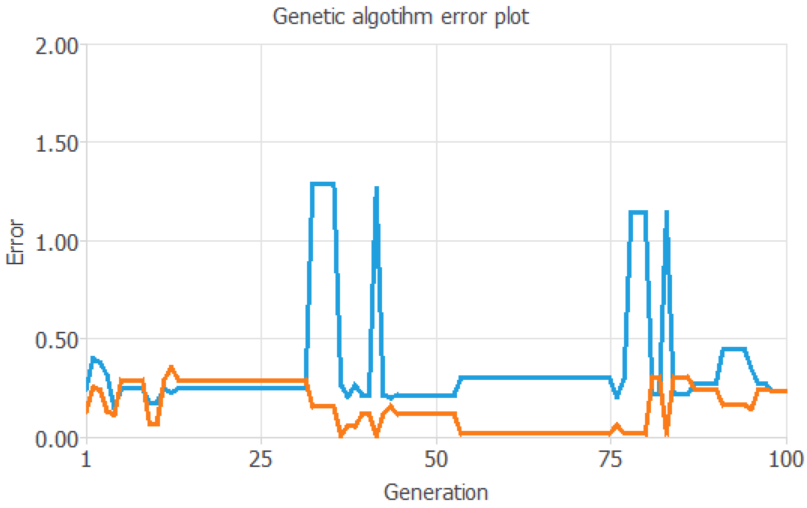


Figure 87. **Genetic Algorithm error plot for the number of neurons in hidden layer**

Figure 88 shows the history of the mean of the selection error in each generation during the genetic algorithm inputs selection process. The initial value is 0.596716, and the final value after 100 generations decreased to 0.496.

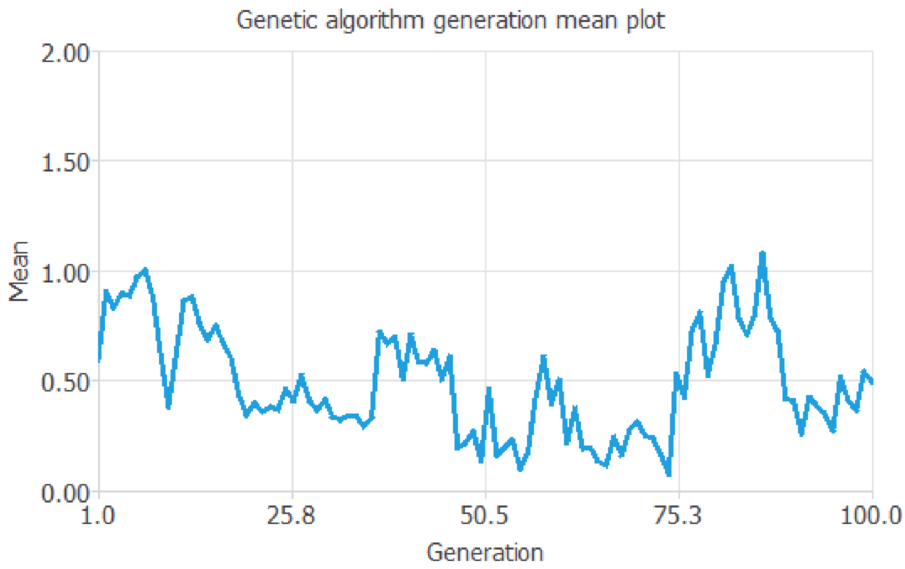


Figure 88. **Genetic Algorithm generation mean plot**

Table 59 shows the order selection results by the Genetic algorithm. They include some final states from the neural network, the error functional and the order selection algorithm. Based on the second trial, the optimum number of inputs is 21 inputs

Table 59. **Incremental error results and optimal number of hidden neurons for trial 5**

	Value
Optimal number of inputs	15
Optimum training error	0.265463
Optimum selection error	0.00478992
Generations number	100
Elapsed time	00:00

Based on the fifth model trial, the proposed network architecture is illustrated in Figure 89. In this figure the optimum number of inputs is chosen to be 15 which are illustrated below.

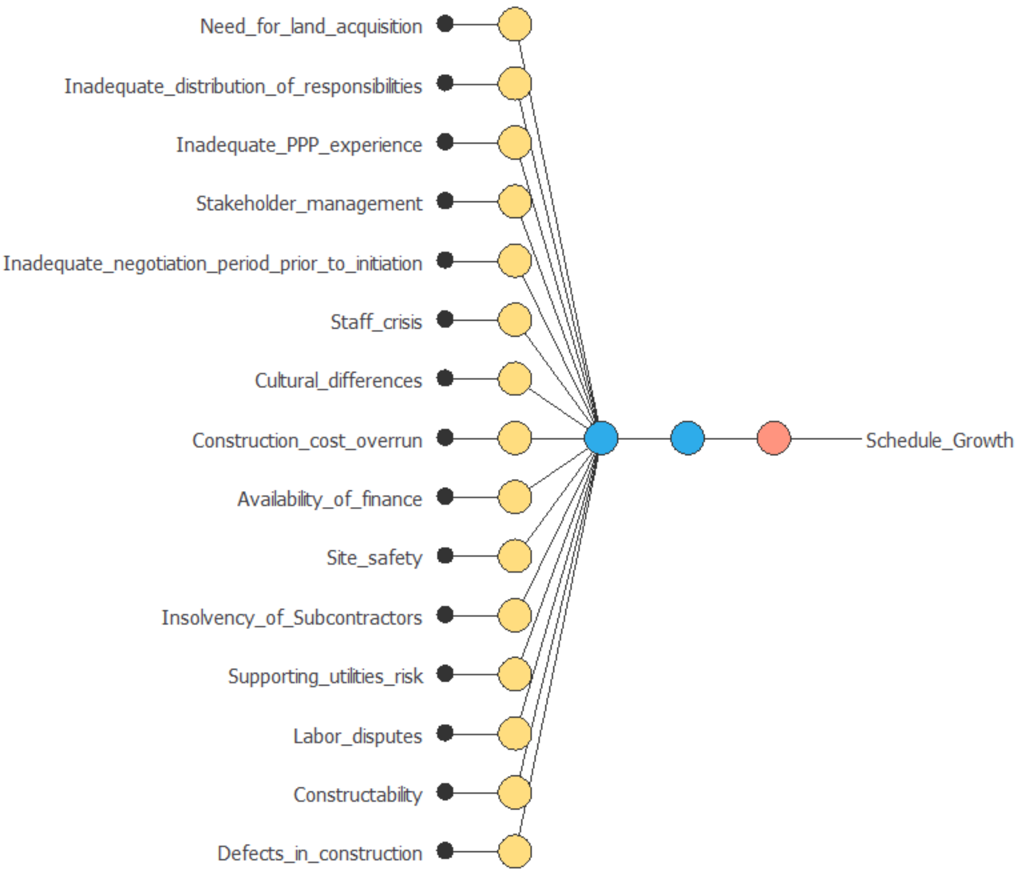


Figure 89. **Resulted deep architecture for trial 5**

4.4.4.4.6 Trial six

Table 60 provides details associated with the choice of the sixth trial of the ANN model.

***Table 60*. Details associated with the choice of the sixth trial of the ANN model**

Parameter	Choice
Inputs	44 (Risk factors)
Outputs	One (Project delay)
Activation function	Hyperbolic tangent
Optimization algorithm	Gradient descent
Order selection	Simulated annealing
Inputs selection	Genetic algorithm

Training and selection Normalized Squared errors in each iteration are provided in figure 90. The blue line represents the training error and the orange line represents the selection (testing) error. The training error measures the ability of the neural network to fit the data that it sees. But the selection error measures the ability of the neural network to generalize to new data.

The initial value of the training error is 13.9394, and the final value after one epoch is almost 1.93558. The initial value of the selection error is 0.745152, and the final value after one epoch decreased to 0.330551.

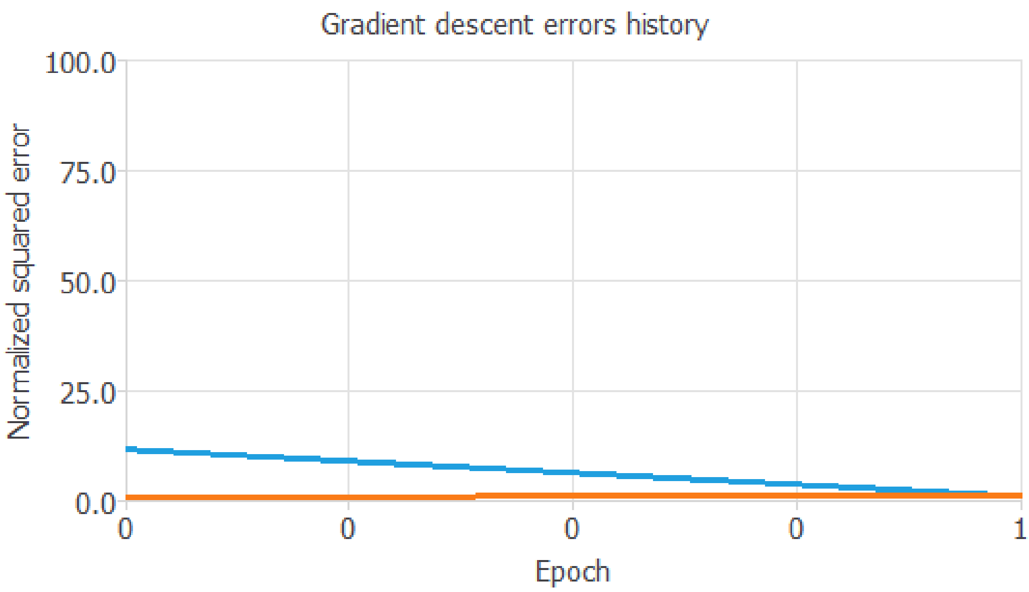


Figure 90. **Normalized square error- Gradient descent errors history**

Figure 91 shows a plot extracted from the actual model shows the training and selection Mean Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection error. The higher the MSE value, the poorer the network at generalization. In this case, the initial value of the training error is 0.492519, and the final value after one epoch is 0.357687. The initial value of the selection error is 1.5966, and the final value after one epoch remained the same.

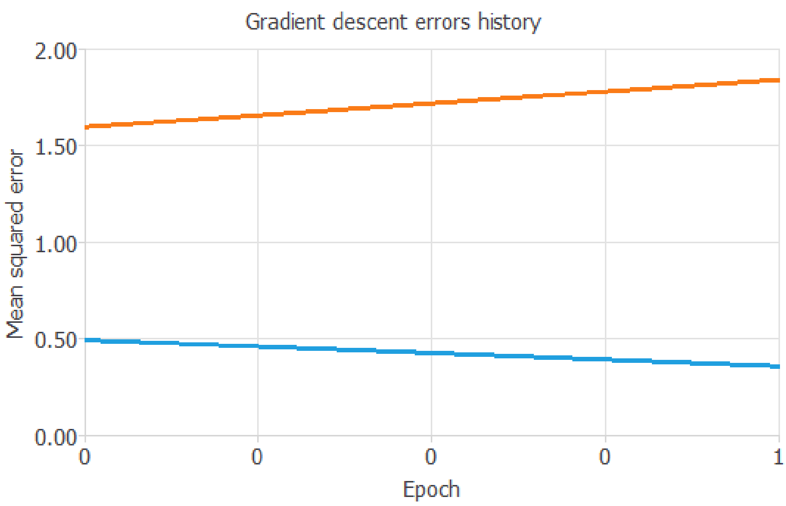


Figure 91. **Mean square error- Gradient descent history**

Table 61 is a summary of the errors obtained from this model setup:

***Table 61.* Summary of the errors obtained from the sixth model setup**

	Normalized-square error		Mean Square error	
	Highest value	**Lowest value**	**Highest value**	**Lowest value**
Training	13.9394	1.93558	0.492519	0.357687
Testing	0.745152	0.330551	1.5966	1.5966

- **Genetic Algorithm error plot**

Figure 92 shows the error history for the different subsets during the incremental order selection process. The blue line represents the training error, its initial value and its final value after 100 generations is zero. The orange line symbolizes the selection error its initial value is 0.029363 and the final value after 100 generations is 0.0024517.

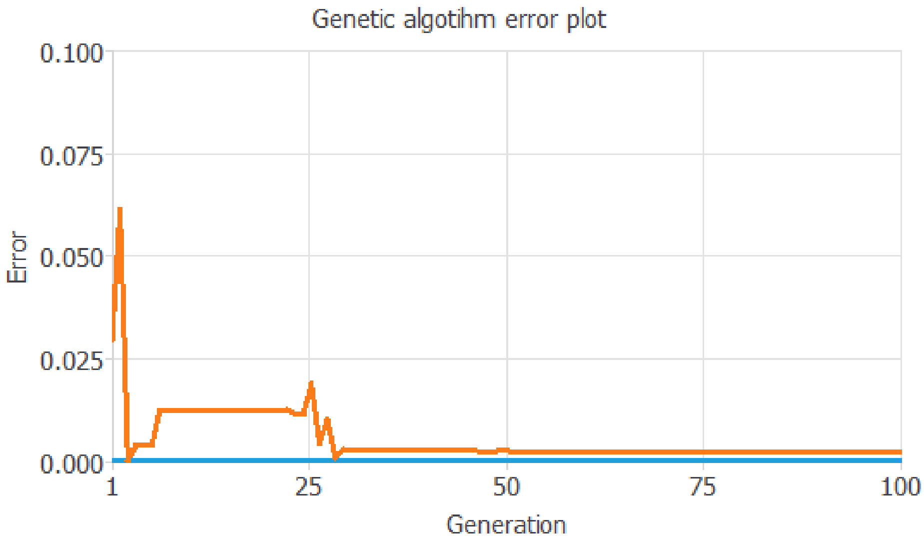


Figure 92. **Genetic Algorithm error plot for the number of neurons in hidden layer**

Figure 93 shows the history of the mean of the selection error in each generation during the genetic algorithm inputs selection process. The initial value is 0.282275, and the final value after 100 generations decreased to 0.00302.

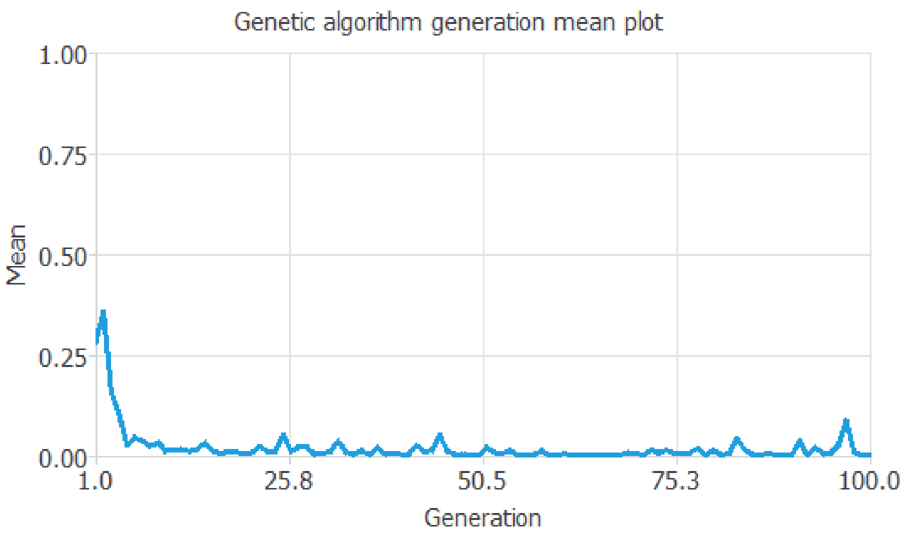


Figure 93. **Genetic Algorithm generation mean plot**

Table 62 shows the order selection results by the Genetic algorithm. They include some final states from the neural network, the error functional and the order selection algorithm. Based on the second trial, the optimum number of inputs is 18 inputs

Table 62. **Incremental error results and optimal number of hidden neurons for trial 6**

	Value
Optimal number of inputs	18
Optimum training error	2.73667e-6
Optimum selection error	0.0024517
Generations number	100
Elapsed time	00:05

Based on the sixth model trial, the proposed network architecture is illustrated in Figure 94. In this figure the optimum number of inputs is chosen to be 18 which are illustrated below.

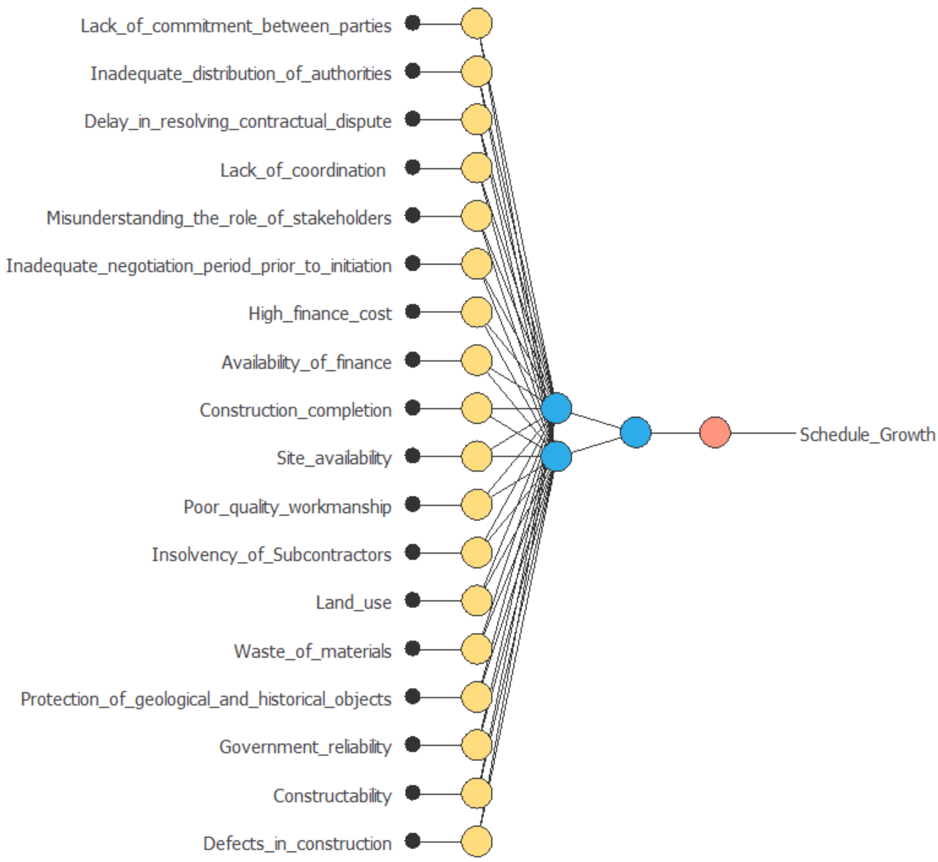


Figure 94: Resulted deep architecture for trial 6

4.4.4.4.7 Trial seven

Table 63 provides details associated with the choice of the seventh trial of the ANN model:

Table 63. **Details associated with the choice of the seventh trial of the ANN model**

Parameter	Choice
Inputs	44 (Risk factors)
Outputs	One (Project delay)
Activation function	Linear
Optimization algorithm	Conjugate Gradient
Order selection	Simulated annealing
Inputs selection	Pruning inputs

The following plot (figure 95) shows the training and selection Normalized Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection (testing) error. The training error measures the ability of the neural network to fit the data that it sees. But the selection error measures the ability of the neural network to generalize to new data.

The initial value of the training error is 39.3573, and the final value after 151 epochs is almost 0.127478. The initial value of the selection error is 11.8303, and the final value after 151 epochs became 0.394828.

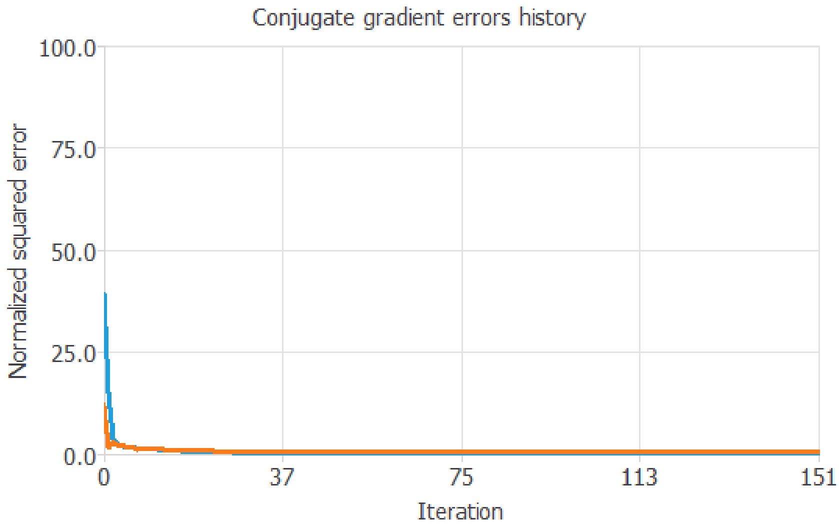


Figure 95: Normalized square error- Conjugate Gradient errors history

The following plot extracted from the actual model shows the training and selection Mean Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection error. The higher the MSE value, the poorer the network at generalization. In this case, the initial value of the training error is 0.0650897, and the final value after 206 epochs is 0.0128799. The initial value of the selection error is 1.10045, and the final value after 206 epochs is 0.737464.

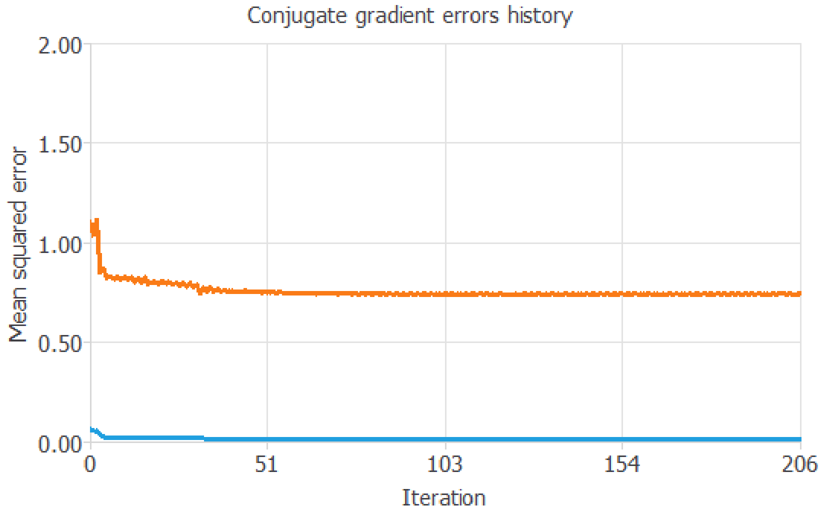


Figure 96: Mean square error- Conjugate Gradient history

Below in table 64 is a summary of the errors obtained from this model setup.

***Table 64.* Summary of the errors obtained from the seventh model setup**

	Normalized-square error		Mean Square error	
	Highest value	**Lowest value**	**Highest value**	**Lowest value**
Training	39.3573	0.127478	0.0650897	0.0128799
Testing	11.8303	11.8303	1.10045	0.737464

Based on the seventh model trial, concerning the proposed network, the optimum number of inputs is chosen to be 25 which are:

1- Lack of communication between stakeholders
2- Third party tort liability
3- Lack of support from government
4- Inadequate distribution of responsibilities
5- Inadequate PPP experience
6- Lack of commitment between parties
7- Delay in resolving contractual dispute
8- Lack of coordination
9- Private investor change
10-Third-party delays

11-Subjective evaluation

12-Misunderstanding the role of stakeholders

13-Inadequate negotiation period prior to initiation

14-Construction cost overrun

15-Geological conditions

16-Construction completion

17-Poor quality workmanship

18-Labor availability

19-Insolvency of subcontractors

20-Construction delays

21-Labor disputes

22-Land use

23-Government reliability

24-Excessive contract variation

25-Constructability

4.4.4.4.8 Trial eight

Table 65 provides are the details associated with the choice of the eighth trial of the ANN model.

***Table 65.* Details associated with the choice of the eight trial of the ANN model**

Parameter	Choice
Inputs	44 (Risk factors)
Outputs	One (Project delay)
Activation function	Linear
Optimization algorithm	Quasi-Newton
Order selection	Simulated annealing
Inputs selection	Growing inputs

Training and selection Normalized Squared errors in each iteration are shown in figure 97. The blue line represents the training error and the orange line represents the selection (testing) error. The training error measures the ability of the neural network to fit the data that it sees. But the selection error measures the ability of the neural network to generalize to new data.

The initial value of the training error is 8.28199, and the final value after 198 epochs is almost zero. The initial value of the selection error is 3.87898, and the final value after 198 epochs is 1.06001.

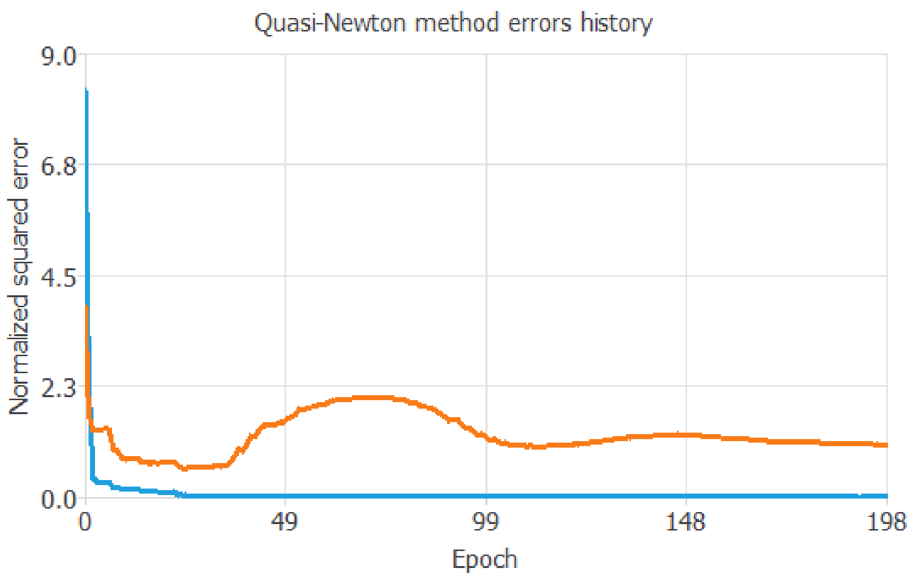


Figure 97. **Normalized square error- Quasi-Newton method**

Training and selection Mean Squared errors in each iteration are provided in figure 98. The blue line represents the training error and the orange line represents the selection error. The initial value of the training error is 0.428456, and the final value after 192 epochs is 0.00283195. The initial value of the selection error is 0.00272551, and the final value after 192 epochs is 0.00273038.

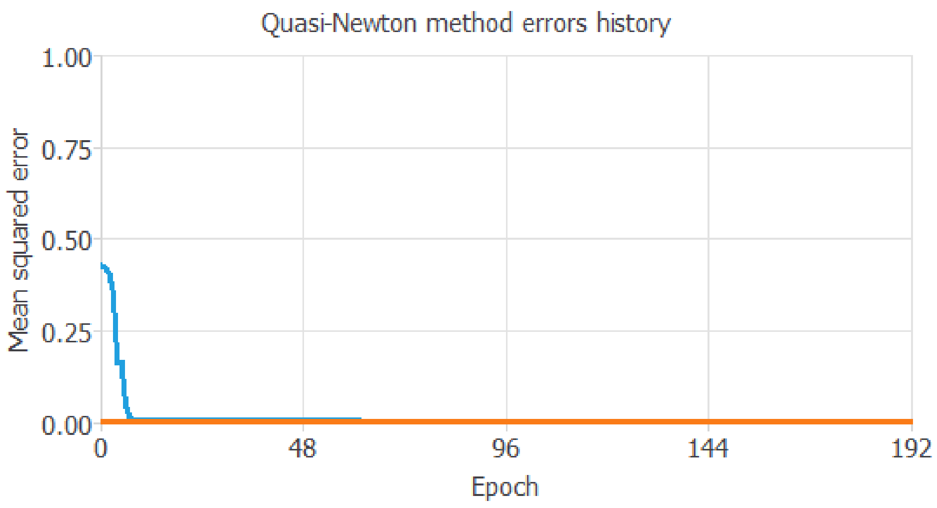


Figure 98. Mean square error- Quasi-Newton method

Below in table 66 is a summary of the errors obtained from this model setup.

Table 66. Summary of the errors obtained from the eight-model setup

	Normalized-square error		Mean Square error	
	Highest value	**Lowest value**	**Highest value**	**Lowest value**
Training	8.28199	0	0.428456	0.00283195
Testing	3.87898	1.06001	0.0027255	0.0027304

- **Simulated annealing error plot**

The next chart (figure 99) shows the error history for the different subsets during the simulated annealing order selection process. The blue line represents the training error and the orange line symbolizes the selection error.

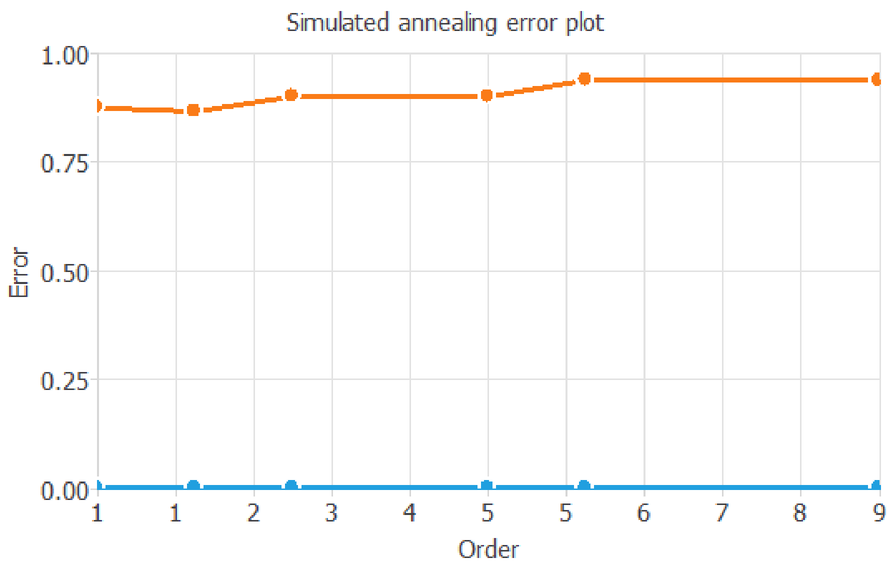


Figure 99: Incremental order plot for the number of neurons in hidden layer

Based on the eight-model trial, the proposed network architecture is consisting from 17 input nodes and one hidden node.

4.4.4.4.9 Trial nine

Below (table 67) are the details associated with the choice of the ninth trial of the ANN model.

Table 67. **Details associated with the choice of the ninth trial of the ANN model**

Parameter	Choice
Inputs	44 (Risk factors)
Outputs	One (Project delay)
Activation function	Logistic
Optimization algorithm	Quasi-Newton
Order selection	Incremental
Inputs selection	Growing inputs

The plot shown in figure 100 shows the training and selection Normalized Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection (testing) error. The training error measures the ability of the neural network to fit the data that it sees. But the selection error measures the ability of the neural network to generalize to new data. The following plot shows the training and selection errors in each iteration. The blue line represents the training error and the orange line represents the selection error. The initial value of the training error is 1.84748, and the final value after 4 epochs is 1.64443. The initial value of the selection error is 0.00294441, and the final value after 4 epochs is 0.00294441.

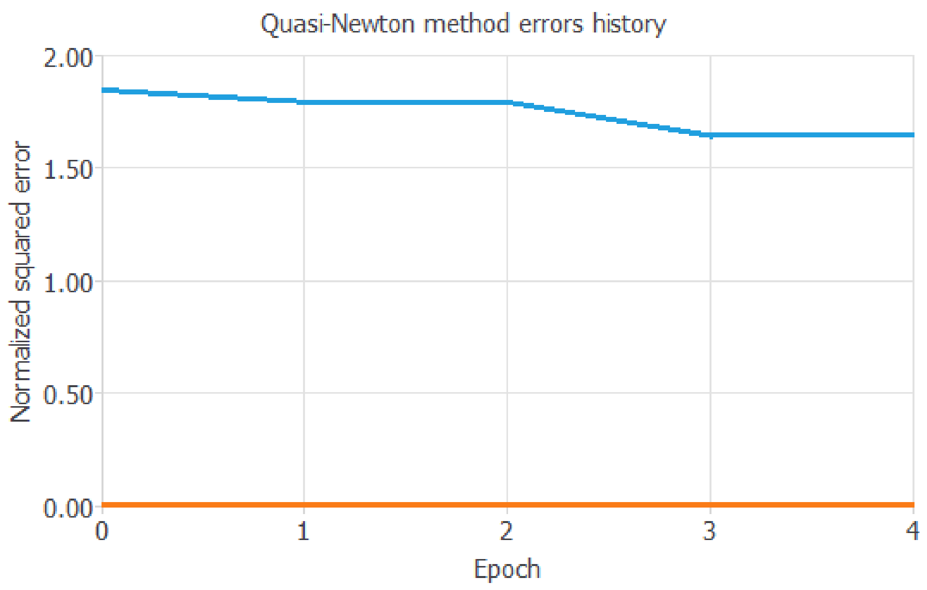


Figure 100. **Normalized square error- Quasi-Newton method**

The following plot (figure 101) shows the training and selection errors in each iteration. The blue line represents the training error and the orange line represents the selection error. The initial value of the training error is 0.428456, and the final value after 192 epochs is 0.00283195. The initial value of the selection error is 0.00272551, and the final value after 192 epochs is 0.00273038.

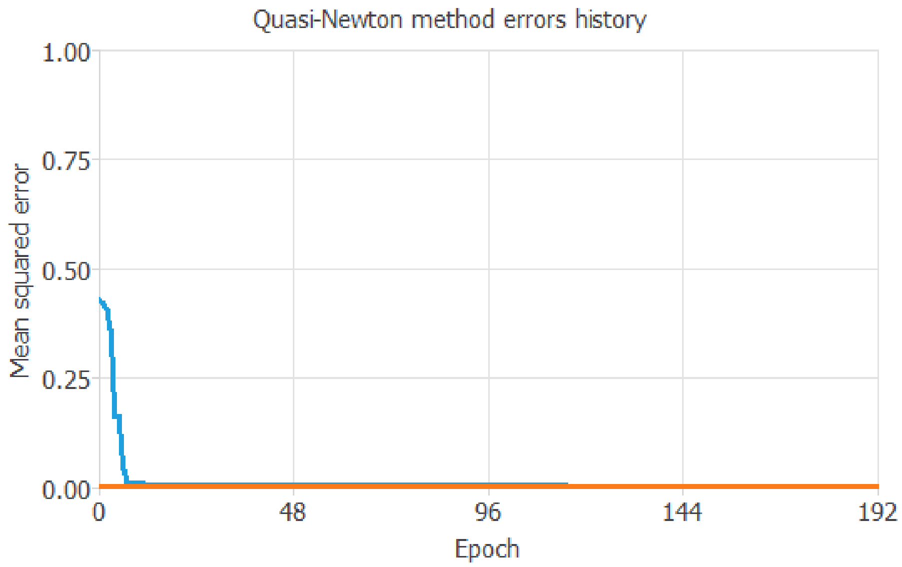


Figure 101. **Mean square error- Quasi-Newton method**

Below in table 68 is a summary of the errors obtained from this model setup.

Table 68. **Summary of the errors obtained from the ninth model setup**

	Normalized-square error		**Mean Square error**	
	Highest value	**Lowest value**	**Highest value**	**Lowest value**
Training	1.87478	1.64443	0.428456	0.00283195
Testing	0.0029444	0.0029444	0.0027255	0.0027304

Based on the ninth model trial, the proposed network architecture is illustrated in Figure 102. In this figure the optimum number of inputs is chosen to be 15 with one hidden neuron.

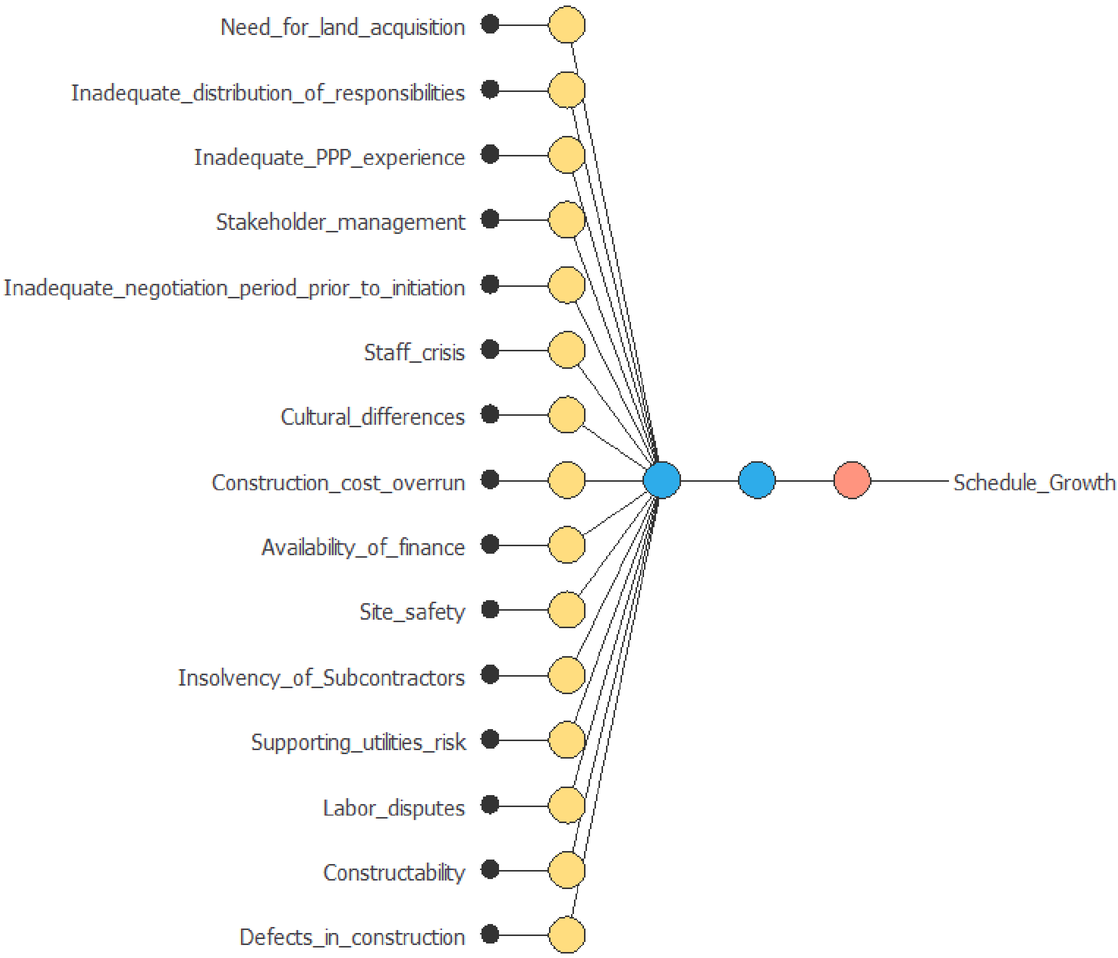


Figure 102. **Resulted deep architecture for trial 9**

4.4.4.4.10 Trial ten

Below (table 69) are the details associated with the choice of the tenth trial of the ANN model.

***Table 69*. Details associated with the choice of the tenth trial of the ANN model**

Parameter	Choice
Inputs	44 (Risk factors)
Outputs	One (Project delay)
Activation function	Hyperbolic tangent
Optimization algorithm	Conjugate Gradient
Order selection	Incremental
Inputs selection	Pruning inputs

Figure 103 shows the training and selection Normalized Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection (testing) error. The training error measures the ability of the neural network to fit the data that it sees. But the selection error measures the ability of the neural network to generalize to new data.

Figure 103 also shows the training and selection errors in each iteration. The initial value of the training error is 39.3573, and the final value after 151 epochs is 0.127478. The initial value of the selection error is 11.8303, and the final value after 151 epochs is 0.394828.

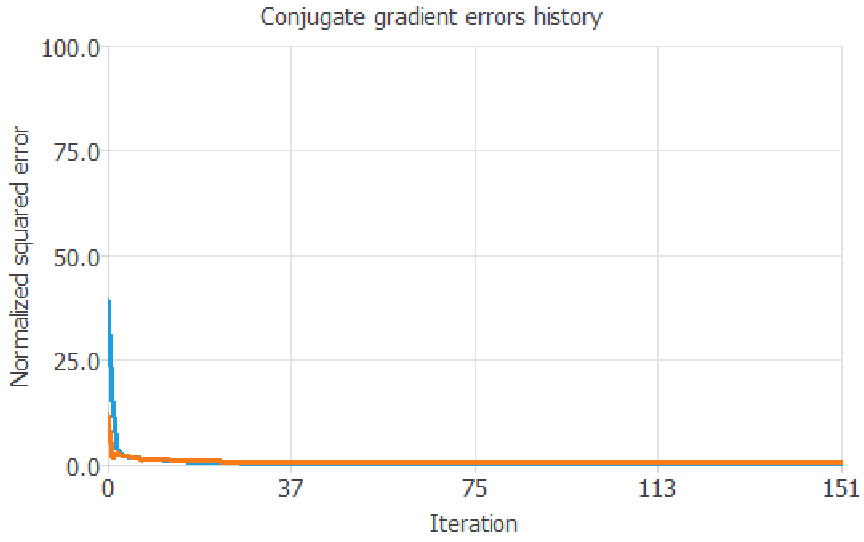


Figure 103. **Normalized square error- Conjugate Gradient errors history**

The following plot extracted from the actual model shows the training and selection Mean Squared errors in each iteration. The blue line represents the training error and the orange line represents the selection error. The higher the MSE value, the poorer the network at generalization. The following plot shows the training and selection errors in each iteration. The initial value of the training error is 4.85305, and the final value after 211 epochs is 0.170278. The initial value of the selection error is 2.6571, and the final value after 211 epochs is 0.127035.

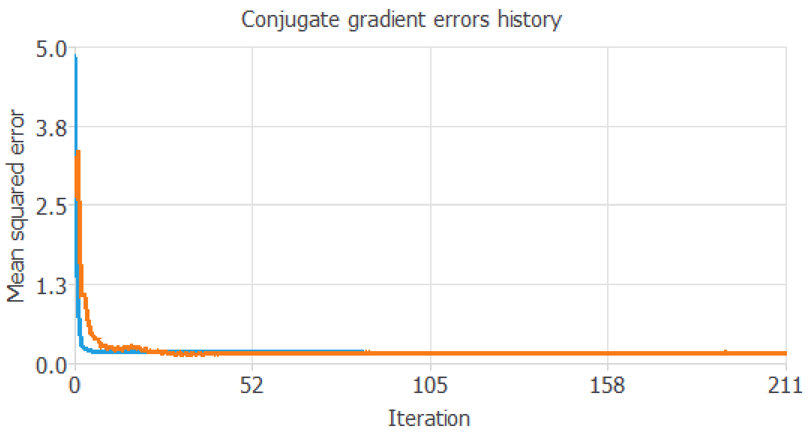


Figure 104. **Mean square error- Conjugate Gradient history**

Below in table 70 is a summary of the errors obtained from this model setup.

Table 70. **Summary of the errors obtained from the tenth model setup**

	Normalized-square error		Mean Square error	
	Highest value	Lowest value	Highest value	Lowest value
Training	4.85305	0.170278	39.3573	0.127478
Testing	2.6571	0.127035	11.8303	0.394828

Based on the tenth model trial, the proposed network architecture is chosen to be with 39 input nodes and one hidden node.

4.4.4.5 Conclusions and observations based on models ´performance

Table 41 (this can be seen on p. 196 of this thesis) includes a summary of the best models and their performance which were detailed in the previous section. Based on the different trials output, it is concluded that Model 4 delivers the smallest range of error (MSE and NSE) for training and testing. The architecture of this particular model is: 18 input nodes, three hidden neurons on two layers and one output. It was trained using a logistic function. The training was set to continue until there is no more improvement in test error over 10 cycles to prevent model over-fitting. The optimum model architecture is illustrated in figure 83 (this can be seen on p. 220 of this thesis) showing which risk factors to include.

The next best model delivering the smallest errors is trial N. 6 (with the architecture 18-2-1-1). For this specific model, the activation function was chosen to be the hyperbolic tangent, the optimization algorithm is the gradient descent, simulated annealing is used for order selection and genetic algorithm is used for inputs selection. Trials one and two delivered also results with relatively low error ranges for both training and testing. For both models, hyperbolic tangent was the activation function used, quasi-newton was used as the optimization algorithm and the order selection was incremental. The only difference lies in the input's selection where growing inputs and genetic algorithm were respectively used for trial one and two. Nevertheless, the optimum architecture for both models differed where for the first trial the optimum architecture was to have 39 input nodes, 6 hidden nodes in one layer and one output. On the other hand, the second trial's architecture was 21 nodes in the input layer, two hidden nodes on one layer and one output node.

Accordingly, based on the performance of the model in the different trials, some observations can be drawn which are:

1- As previously stated in the literature review, the hidden nodes' role is crucial in extracting and memorizing the useful features from the input layers in order to determine the values of the output layer.
2- In this particular research, with the application of "early stopping" to avoid over-fitting, the number of hidden nodes was ranging between one and 6.
3- In this particular research, it is noticed that having the hidden perceptron on two layers improved the model's performance significantly and decreased errors for both training and testing.
4- After performing training and testing of all models, and in all trials, it was noticed that the error decreased considerably by decreasing the number of input nodes.
5- Using the hyperbolic tangent activation function delivered relatively low errors compared to linear and logistic.

In addition to the MSE calculation proposed in almost all sources in the literature implementing ANN models (Gulcicek, *et al.* 2013, Gunaydin and Dogan 2004, Boussabaine 1996, Lhee *et al.* 2012, Heravi and Eslamdoost 2015), there are other ways to test the validity of the ANN such as:

1- Consistency: Checked when the executions are repeated several times with the same data and checking the results. If the same data delivers the same results each time, then the network is consistent.
2- Accuracy: This done by comparing the known data with the model's predictions.
3- Sensitivity analysis: It consists of varying each parameter, while holding all other parameters constant and observing how changing each parameter alone affects the output result. It will be explained in more details in the next sub-sub-section.

4.4.5 Performing sensitivity analysis

Patel and Jha (2014) points out that the aim of sensitivity analysis is to determine the cause and effect relationship between inputs and outputs of the ANN model.

According to Gunaydin and Dogan (2004), sensitivity analysis helps in determining the effect of each of the network inputs on the network output. This determines which input parameters are the most significant to the model's output. It is important to disable the network learning during the sensitivity analysis.

Sonmez and Rowings (1998) explain the procedure necessary to perform the sensitivity analysis in a simple yet clear way. The value of each factor will be varied will the values of all other factors will be fixed. Lhee *et al.* (2012) points out that performing the sensitivity analysis will help in ranking the variables based on their significance. This will help in determining how the output vary as a function of a single input. In this case, sensitivity analysis was performed on the input factors used in each of the best retained models from the previous stage. Table 71 shows the relative influence of the various risks on the predictive performance of the models. The variables (risks) are then arranged in order of contribution to the total project delay.

Table 71. Sensitivity Analysis results

Risks		ANN-39-6-1	ANN-21-2-1	ANN-15-1-1	ANN-18-2-1-1	ANN-15-1-1	ANN-18-2-1-1	ANN-25-1-1	ANN-17-1-1	ANN-15-1-1	ANN-39-1-1	Avg
1	Lack of coordination	11.93	8.19727	0	6.08333	0	6.08333	6.08333	6.08333	0	11.93	5.639
2	Delay in resolving contractual dispute	8.195	0	0	11.7233	0	6.08333	6.08333	11.7233	0	8.195	5.200
3	Availability of finance	7.75667	11.7233	7.75667	0	7.75667	0	0	0	7.75667	7.75667	5.051
4	Need for land acquisition	9.5375	0	9.5375	0	9.5375	0	0	0	9.5375	9.5375	4.769
5	Excessive contract variation	11.7233	11.7233	0	0	0	11.7233	0	0	0	11.7233	4.689
6	Construction completion	16.6667	1.25	0	0	0	6.08333	6.08333	0	0	16.6667	4.675
7	Government reliability	7.75667	0	0	7.75667	0	7.75667	7.75667	7.75667	0	7.75667	4.654
8	Geological conditions	3.31833	1.25	0	6.08333	0	11.7233	11.7233	6.08333	0	3.31833	4.350
9	Inadequate PPP experience	5.13833	0	5.13833	6.08333	5.13833	1.25	1.25	6.08333	5.13833	5.13833	4.036
10	Construction delays	6.685	0	0	6.685	0	6.685	6.685	6.685	0	6.685	4.011
11	Inadequate negotiation period prior to initiation	3.61083	0.324167	3.61083	7.75667	3.61083	2.49917	2.49917	7.75667	3.61083	3.61083	3.889
12	Lack of commitment between parties	1.38917	0	0	11.7233	0	6.08333	6.08333	11.7233	0	1.38917	3.839
13	Defects in construction	6.08333	6.08333	6.08333	0	6.08333	0	0	0	6.08333	6.08333	3.650
14	Private investor change	0	11.7233	0	11.7233	0	0	0	11.7233	0	0	3.517

Risks		ANN-39-6-1	ANN-21-2-1	ANN-15-1-1	ANN-18-2-1-1	ANN-15-1-1	ANN-18-2-1-1	ANN-25-1-1	ANN-17-1-1	ANN-15-1-1	ANN-39-1-1	Avg
15	Lack of support from government	11.1267	0	0	0	0	6.08333	6.08333	0	0	11.1267	3.442
16	Third-party tort liability	7.51417	0	0	6.685	0	1.25	1.25	6.685	0	7.51417	3.090
17	Construction cost overrun	0	11.7233	0	0	0	7.75667	7.75667	0	0	0	2.724
18	Misunderstanding the role of stakeholders	3.61083	11.7233	0	0	0	0	6.08333	0	0	3.61083	2.503
19	Third-party reliability	8.19727	8.19727	0	0	0	0	0	0	0	8.19727	2.459
20	Site availability	6.20417	0	0	11.7233	0	0	0	0.2775	0	6.20417	2.441
21	Poor quality workmanship	6.08333	0	0	0	0	6.08333	6.08333	0	0	6.08333	2.433
22	Insolvency of subcontractors	2.49917	2.49917	2	2.49917	2	2.49917	2.49917	2.49917	2.49917	2.49917	2.399
23	Third-party delays	7.3475	1.25	0	0	0	0	6.08333	0	0	7.3475	2.203
24	Lack of communication between stakeholders	2.25	0	0	2.49917	0	6.08333	6.08333	2.49917	0	2.25	2.167
25	High finance cost	7.75667	6.08333	0	0	0	0	0	0	0	7.75667	2.160
26	Land use	4.16667	4.16667	0	0	0	4.16667	4.16667	0	0	4.16667	2.083
27	Inadequate distribution of responsibilities	3.37917	0	3.37917	0.2775	3.37917	1.25	1.25	0.2775	3.37917	3.37917	1.995
28	Stakeholder management	3.37917	0	3.37917	0	3.37917	0	0	0	3.37917	3.37917	1.690
29	Subjective evaluation	0.833333	1.25	0	0	0	6.08333	6.08333	0	0	0.833333	1.508

	Risks	ANN-39-6-1	ANN-21-2-1	ANN-15-1-1	ANN-18-2-1-1	ANN-15-1-1	ANN-18-2-1-1	ANN-25-1-1	ANN-17-1-1	ANN-15-1-1	ANN-39-1-1	Avg
30	Cultural differences	2.36083	0	2.36083	0	2.36083	0	0	0	2.36083	2.36083	1.180
31	Material availability	0.666667	8.19727	0	0	0	0	0	0	0	0.666667	0.953
32	waste of materials	4.0275	0	0	0	0	0	0	0	0	4.0275	0.806
33	Inadequate distribution of authorities	3.37917	0	0	0	0	0	0	0	0	3.37917	0.676
34	Delay in supply	1.25	1.25	0	1.25	0	0	0	1.25	0	1.25	0.625
35	Public opposition	0	6.08333	0	0	0	0	0	0	0	0	0.608
36	Staff crisis	1.08083	0	1.08083	0	1.08083	0	0	0	1.08083	1.08083	0.540
37	Labor disputes	0.555833	0	0.555833	0	0.555833	0.555833	0.555833	0	0.555833	0.555833	0.389
38	Misinterpretation of contract	0.944167	1.25	0	0	0	0	0	0	0	0.944167	0.314
39	Site safety	0.555833	0	0.555833	0	0.555833	0	0	0	0.555833	0.555833	0.278
40	Supporting utilities risk	0.324167	0.324167	0.324167	0.324167	0.324167	0	0	0.324167	0.324167	0.324167	0.259
41	Differences in working methods	0.833333	0	0	0	0	0	0	0	0	0.833333	0.167
42	Labor availability	0.2775	0	0	0.2775	0	0.2775	0.2775	0	0	0.2775	0.139
43	Constructability	0	0	0	0	0	0	0	0	0	0	0.000
44	Protection of geological and historical objects	0	0	0	0	0	0	0	0	0	0	0.000

It is noticed, based on this table that the most significant risk factor is “the lack of coordination” as it is the most important contributor to the model´s ability to predict total project´s delay. On the other hand, the least significant risk factor in this case is the “constructability” and the “protection of geological and historical objects”. The results of this sensitivity analysis and its comparison to the outcomes of the risk ranking based on the literature review are further discussed in section 4.5.

4.5 Final validation of the Artificial Neural Network model

4.5.1 Automated verification of the performance of the model after training

After the sensitivity analysis will be performed in order to determine the effect of each one of the 44 risks on the project’s completion time, a new risk ranking will be developed based on the outcomes of the model.

Based on the model´s outcomes, the below table shows the value of the correlations between all input and target variables ranked in descending order based on the best model out of the ten models. The maximum correlation (0.803336) is yield between the input variable “Delay in resolving contractual dispute” and the target variable “Schedule growth”. 37 risk factors out of the 44 have a high correlation factor (more than 0.1) with the total project´s delay.

The following factors have “zero” correlation with the overall project delay:

- Constructability
- Protection of geological and historical objects
- Construction cost overrun
- Private investor change
- Public opposition

Despite the fact that “zero” correlation in fact means that the input and output variables are independent from each other, this is not true for this particular research. The reason for these variables having the value of zero is that these risk factors were not present in the projects forming Dataset 1 and Dataset 2 from the data collection phase. The absence of occurrence of these risks is the main reason that they showed “no correlation” with the output variable.

Table 72. **Schedule Growth correlation table**

Risk number	Risk name	Correlation value
1	Delay in resolving contractual dispute	0.803336
2	Lack of communication between stakeholders	0.550436
3	Material availability	0.52233
4	Misinterpretation of contract	0.52233
5	Site availability	0.473285
6	waste of materials	0.468641
7	supporting utilities risk	0.440892
8	Delay in supply	0.440886
9	Labor availability	0.440884
10	Geological conditions	0.431428
11	Construction completion	0.410046
12	Third-party reliability	0.356261
13	Government reliability	0.331109
14	Availability of finance	0.331109
15	High finance cost	0.331109
16	Inadequate PPP experience	0.320319
17	Inadequate negotiation period prior to initiation	0.303625
18	Misunderstanding the role of stakeholders	0.303625
19	Labor disputes	0.260199
20	Site safety	0.260198
21	Lack of coordination	0.259285
22	Stakeholder management	0.258581
23	Inadequate distribution of authorities	0.258581
24	Inadequate distribution of responsibilities	0,258581
25	Differences in working methods	0.224261
26	Staff crisis	0.20182
27	Third-party delays	0.186922
28	Construction delays	0.182161
29	Need for land acquisition	0.180697
30	Insolvency of subcontractors	0.175718
31	Excessive contract variation	0.160275
32	Third-party tort liability	0.150971
33	Subjective evaluation	0.148367
34	Lack of commitment between parties	0.148352
35	Cultural differences	0.121717
36	Defects in construction	0.117501
37	Poor quality workmanship	0.117501
38	Land use	0.062796

Risk number	Risk name	Correlation value
39	Lack of support from government	0.003338
40	Constructability	0
41	Protection of geological and historical objects	0
42	Construction cost overrun	0
43	Private investor change	0
44	Public opposition	0

The correlation between each input variable (the percentage of contribution of each risk factor) to the output value (overall project delay) is illustrated in the graph shown in figure 105.

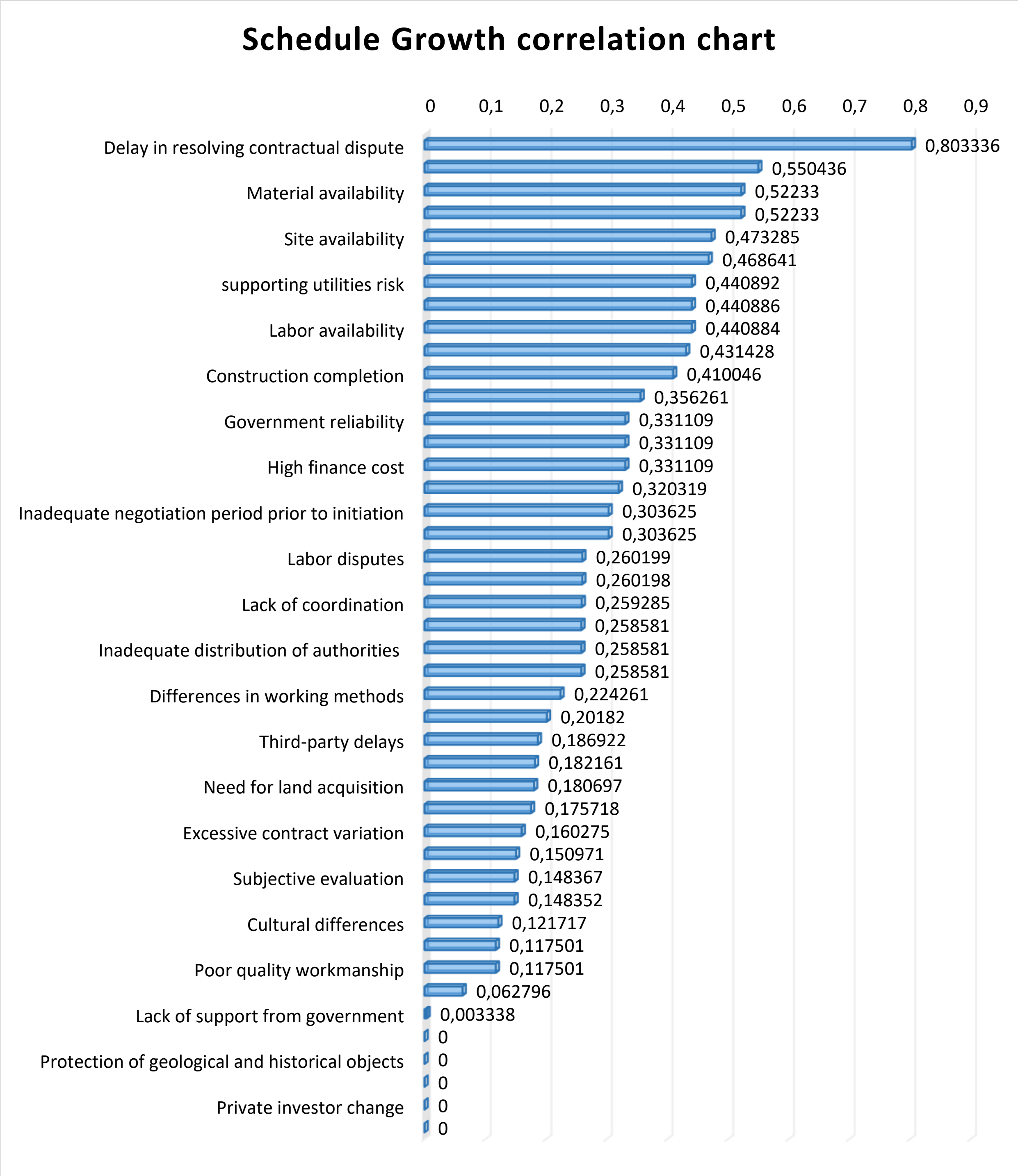


Figure 105: Schedule growth correlation chart

At this stage, a comparison will be established between this new ranking and the ranking previously obtained from the literature review based on content analysis and on the ranking obtained from the sensitivity analysis in section 4.4.5. Comments and recommendations will be drawn. The three different rankings are detailed in Table 73.

Table 73. **Comparison between the new ranking, the ranking from the literature and the ranking obtained from the sensitivity analysis**

#	List of risks	Ranking based on literature review	Ranking based on sensitivity analysis	Ranking based on correlation to delay
1	Public opposition	2	35	44
2	Lack of communication between stakeholders	12	24	2
3	Third party tort liability	14	16	32
4	Need for land acquisition	15	4	29
5	Lack of support from government	16	15	39
6	Inadequate distribution of responsibilities	19	27	24
7	Inadequate PPP experience	27	9	16
8	Lack of commitment between parties	28	12	34
9	Inadequate distribution of authorities	29	33	23
10	Differences in working methods/Knowhow between parties	30	41	25
11	Delay in resolving contractual dispute	31	2	1
12	Lack of coordination	32	1	21
13	Private investor change	33	14	43
14	Third party delays	34	23	27
15	Subjective evaluation	36	29	33
16	Misunderstanding the role of stakeholders	39	18	18
17	Misinterpretation of contract	40	38	4

#	List of risks	Ranking based on literature review	Ranking based on sensitivity analysis	Ranking based on correlation to delay
18	Stakeholder management	41	28	22
19	Inadequate negotiation period prior to initiation	42	11	17
20	Staff crisis	43	36	26
21	Cultural differences between main stakeholders	44	30	35
22	Material availability	1	31	3
23	Construction cost overrun	3	17	42
24	Geological conditions	4	8	10
25	High finance cost	5	25	15
26	Availability of finance	6	3	14
27	Construction completion	7	6	11
28	Site availability	8	20	5
29	Poor quality workmanship	9	21	37
30	Labor availability	10	42	9
31	Site safety and security	11	39	20
32	Insolvency of Subcontractors	13	22	30
33	Construction delays	17	10	28
34	Supporting utilities risk	18	40	7
35	Labor disputes/strikes	20	37	19
36	Land use	21	26	38
37	Waste of materials	22	32	6
38	Protection of geological and historical objects	23	44	41
39	Government reliability	24	7	13
40	Third-party reliability	25	19	12
41	Excessive contract variation	26	5	31
42	Delay in supply	35	34	8
43	Constructability	37	43	40

#	List of risks	Ranking based on literature review	Ranking based on sensitivity analysis	Ranking based on correlation to delay
44	Defects in construction	38	13	36

Based on the data provided in table 73, the following observations can be drawn:

- Based on the literature review, the material availability risk occupies the first position in terms of the most critical risks. This ranking is similar to a great extent to its ranking based on the correlation calculations according to which this risk occupies the third position. On the other hand, the ranking of this same risk is 31 based on the sensitivity analysis in terms of its effect and contribution to the total project delay.

- The "Delay in resolving contractual dispute" occupies the highest rank in terms of correlation with the total project delay based on the ANN model's outputs. This ranking is also similar to the results of the sensitivity analysis where it occupies the second position in terms of the risks having the highest contribution to the total project's delay. On the other hand, the same risk is ranked 31st based on the results of the analysis of the literature review. Since the ANN model was based on real case projects, it makes more sense that this particular risk can be of detrimental effect to the project's completion time. The same goes for the risk "Inadequate negotiation period prior to initiation". This risk, based on the model's deliverables, is ranking 11th and 17th in sensitivity analysis and correlation to the total project's delay while, based on the literature review, is ranking 42nd out of 44.

- The "Public opposition" risk is one of the most severe risks facing PPP projects based on the literature review as it occupies the second position based on the various sources taken into account. Nevertheless, based on the sensitivity analysis and on the correlation analysis, this risk occupies the 35th and 44th positions respectively. This difference in ranking can be caused by the relatively small sample size of PPP projects studied in this research. The dataset studied was not encompassing such risk as it was not faced in the projects that were analyzed. However, this does not mean that this risk is not significant especially for PPP projects. As it was previously discussed in section 2.3.8 the general public has a considerable power especially when it comes to PPP projects. The same goes for "poor quality workmanship" risk which ranks 9th based on the literature review and has less contribution to the total project's delay based on the sensitivity and correlation analysis where it occupies 21st and 37th positions respectively.

- For other risks such as "Constructability", "staff crisis" and "subjective evaluation", the literature review and the model deliverables produced very close results.

4.5.2. Manual validation of the model through interviews

After the model development was performed, as a second way to test the model's reliability, ease of use and clarity of outcomes, the model was circulated among 25 experts in the domain of construction engineering. As there was no predetermined written format for the interview questions and in order to obtain the proper and unified response to the interview from the various experts, the following strategy was followed:

1- Individual meetings were held with each one of the experts in order to provide detailed information and background about the purpose and objectives of the research.
2- The list of risks (construction and stakeholders risks) were handed to the experts.
3- Further explanation was provided regarding artificial intelligence and Artificial Neural Network models development.
4- The use of Artificial Neural Network to develop the model was explained with a special emphasis on the major aim of the model which is to determine the effects of stakeholders and construction risks on the total project delay in a comparison between PPP projects and traditional projects.
5- The operation principles of the software were explained.

6- After all clarifications needed by the experts were provided, each expert was invited to use and test the pre-developed model and visualize the outcomes of the model.

7- The experts were also invited and guided on how to change the different parameters such as the activation function, the order selection and the optimization algorithm and monitor the contributions of such parameters on the training and testing errors, on the number of hidden nodes and on the risk factors contributing to the project´s delay.

For all of the aforementioned steps, the experts were closely guided by the researcher. The following sections provide some information regarding the respondents to the interview.

4.5.2.1 Background information of the interviewees

Among the respondents, 72 % (18 respondents out of 25) have a more than 10 year experience in the domain of Construction Engineering: 36% of the respondents have more than 15 years of experience in the domain of Construction Engineering and 36 % of the respondents have an experience in the domain of Construction Engineering ranging from 10 to 15 years. 28% of the respondents have an experience ranging from 0 to 10 years. This is illustrated in figure 106:

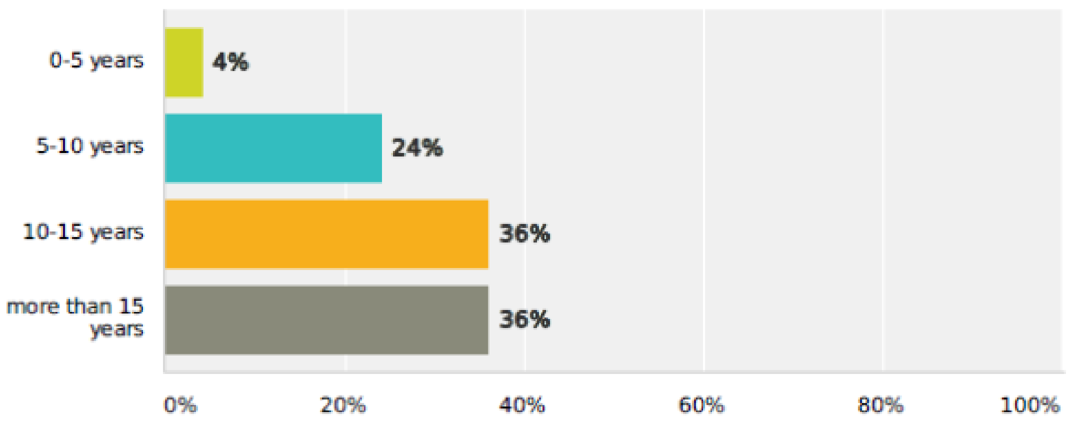


Figure 106. **Experience of the respondents in the domain of Construction Engineering**

Concerning the domain of work of the respondents, 92 % of them have worked or are working in the private sector. 20 % of them have worked in the public sector and 20 % have worked in the Academic sector as illustrated in figure 107 below:

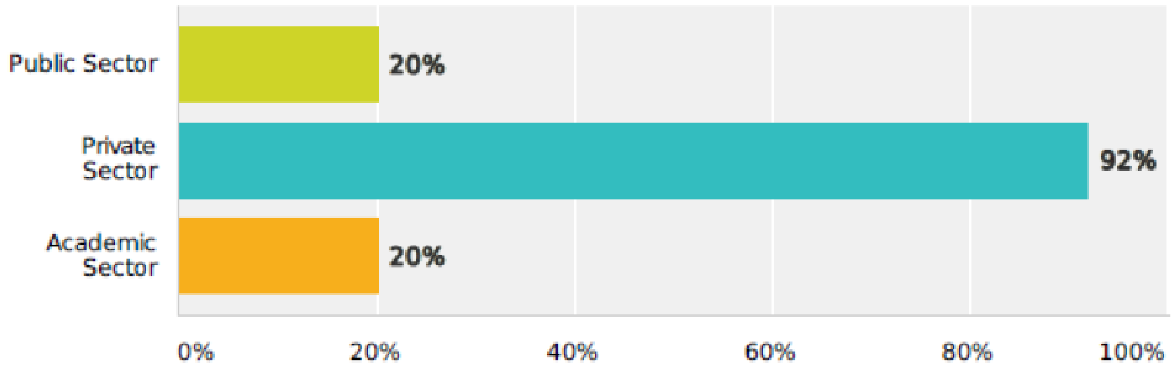


Figure 107. **Domain of work of the respondents**

All the respondents to the interview have worked and are currently working in Egypt as shown in the table 74 and figure108.

Table 74. **Work location of the respondents**

Work location and background of the respondent		
Answer Options	Response Percent	Response Count
Egypt	100.0%	25
Other		10
	Total Number	25

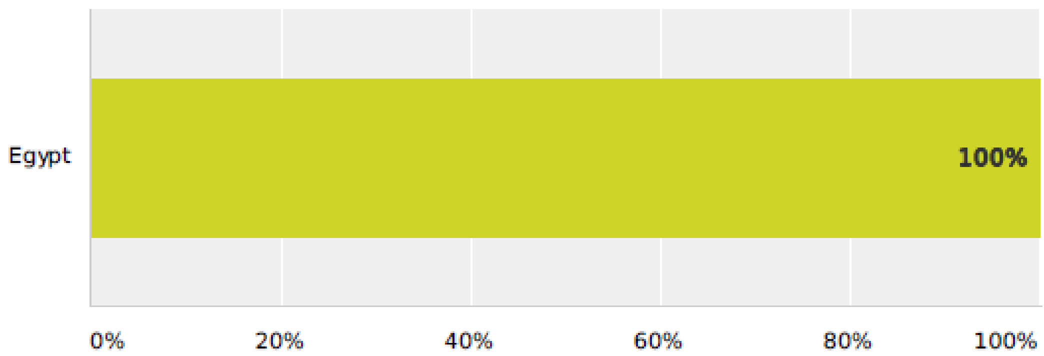


Figure 108. **Work location and background of the respondents**

However, 10 out of the 25 respondents have worked in other countries such as Australia, Saudi Arabia, Algeria, United States, The United Kingdom, Canada, Africa, etc. as shown in table 75.

Table 75. **Other countries in which the respondents have worked**

Number	Other countries in which the respondents have worked
1	United Kingdom
2	Saudi
3	International
4	previous experience at the states of Qatar and Kuwait
5	Algeria, USA
6	Canada
7	Africa
8	Australia, Algeria, UAE
9	Gulf
10	Regional

Concerning the experience of the respondents in PPP projects, 44% of the respondents (11 respondents out of 25) have an experience in PPP projects ranging from 2 to 4 years. 12% of the respondents have more than 6 years of experience in PPP projects. 8% of the survey respondents have an experience ranging from 4 to 6 years while 36% of the respondents (9 respondents out of 25) have a recent experience in PPP projects which is ranging from 0 to 2 years.

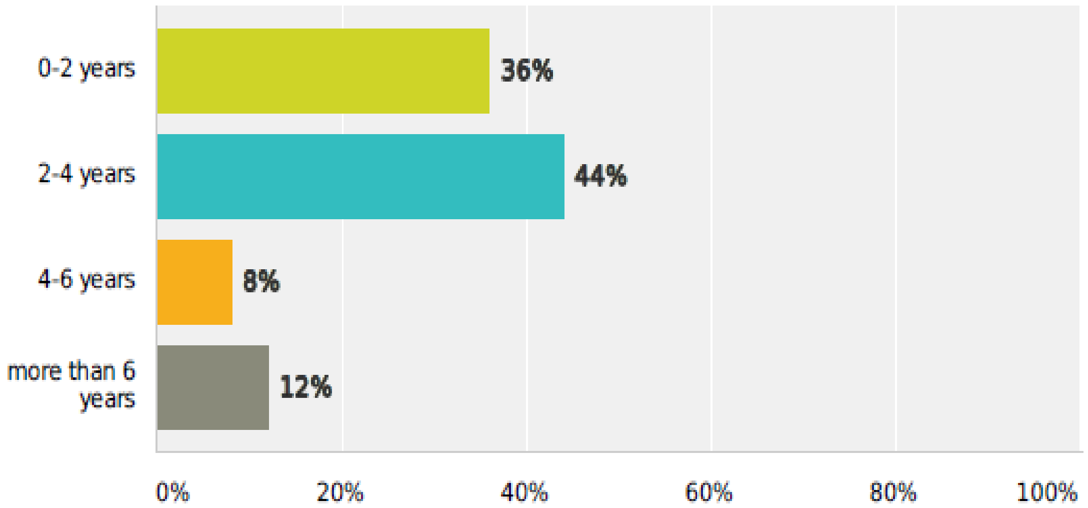


Figure 109. **PPP experience of the interview respondent**

The respondents have worked in different types of PPP projects such as educational, transportation, health, wastewater treatment, housing, power, etc. Approximately, 80 % of the respondents have worked in transportation PPP projects, 56 % of the respondents have worked in health PPP projects and 45% of the respondents have worked in educational projects as it is shown in figure 110:

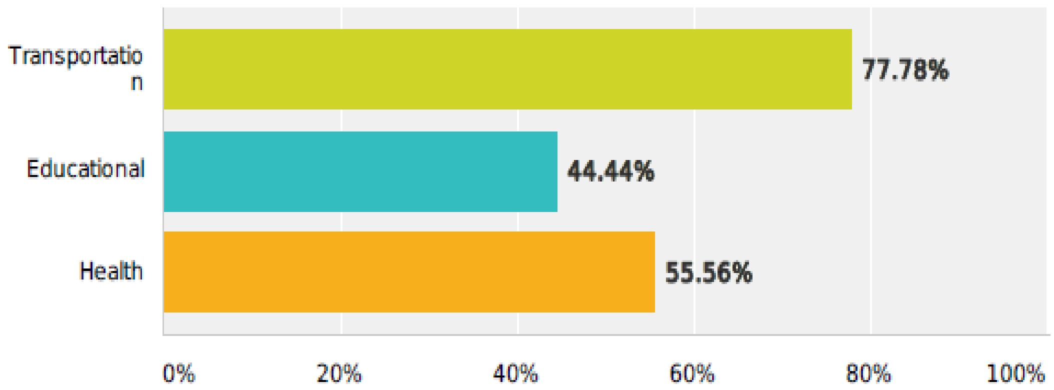


Figure 110. **Types of PPP projects that the respondents have worked in**

On the other hand, 20 respondents out of the 25 have worked in other PPP project types than the above-mentioned transportation, educational and health projects as shown in table 76:

Table 76. **Other PPP project types that the respondents have been involved with**

Number	Other PPP project types
1	Water Treatment
2	Water Treatment
3	Wastewater
4	Sewage Treatment
5	Sewage Treatment Plant
6	Water Treatment Projects
7	Infrastructure-Waste Water Treatment
8	Water
9	Wastewater Treatment
10	Infrastructure
11	Infrastructure (wastewater Treatment Plant)
12	Sewage treatment Plant
13	Waste Water Treatment
14	Waste Water
15	Waste and Airports
16	Housing
17	Residential
18	Affordable Housing project
19	Utilities
20	Utilities and power

All the respondents have been involved in PPP projects in Egypt while 5 respondents have been involved in PPP projects in other countries such as Canada, Australia, Saudi Arabia and Malaysia. This is illustrated in table 77:

Table 77. **Other countries in which the respondents have worked in the domain of PPP**

Number	Other
1	Canada
2	Australia
3	Saudi Arabia
4	Malaysia (Conference)
5	Regional

4.5.2.2 Observations of the interviewees regarding the ANN model

After the ANN model and its deliverables were discussed with each one of the interviewees as explained in the previous section, the following observations were provided by the interviewees:

1- The software Neural Designer ® is a user-friendly software which does not require any programming knowledge. This will be encouraging for different users to try inserting the different risks for any given new project in order to determine the contribution of each risk to the total project delay.

2- 100% of the interviewees confirmed that this model will be more beneficial if it is possible to provide a cost-modelling as well.

3- Regarding the risk ranking based on sensitivity analysis and input-output correlation, the ranking of some risks is in line with real life such as Delay in resolving contractual dispute, lack of coordination, availability of finance. However, in other cases, and due to the size of the dataset, the ranking of some risks is not in line with real life. For instance, the need for land acquisition and public opposition are severe risks which have great implications on the project's time for completion. Their ranking based on the ANN model does not truly reflect their importance in real-case projects.

4.6 Chapter Summary

A lot of project time and cost information are usually available on any particular construction project. If proper document control is performed over time, a vast database of valuable and retrievable asset can result. This can be converted into useful models and decision-support systems that can, in the future, help construction practitioners and decision-makers during the lifetime of the project.

This chapter presents a practical means of transforming information embedded in existing construction projects into data-modelling information for more reliable delay analysis. Using Artificial Neural Networks, and using data extracted from traditional projects, the model was developed determining the effects of construction and stakeholders risks on the project completion time. Then, in order to test the model's performance, the same concept was applied on PPP projects. Ten trials have been presented and the model that was delivering the smallest range of errors shall be retained for future research.

In order to validate the model's performance, sensitivity analysis helped in determining the effect of each of the network inputs on the network output. Furthermore, based on the model´s outcomes, the value of the correlations between all input and target variables ranked in descending order based on the best model out of the ten models was determined.

As another way to test the model's reliability, ease of use and clarity of outcomes, the model was circulated among 25 experts in the domain of construction engineering.

The results from the models show significant promise for future work on construction data mining, thereby potentially producing more reliable and realistic estimates. The model will be particularly useful in the construction stage of the project. The method and approach adopted to develop the models can be extended to even more detailed and holistic estimation including the "cost" aspect as well as long as relevant and reliable data can be acquired.

Chapter 5 – Conclusions and Recommendations

5.1 Chapter Introduction

There has been a continuous increase in the demand for public services and infrastructure all over the world especially in developing countries. Accordingly, the attention towards the PPP scheme increased as it is a way for the public authorities to improve their infrastructure and provide better services to the end users with the help and expertise of the private sector. However, due to the complexity of such scheme, it has not always been successful. It has been noticed that in several cases, the "failure" of such scheme was due to underestimation of stakeholders' effects on the project. Consequently, proper risk management in PPP projects necessitates a clear understanding and thorough study especially when it comes to stakeholders and construction risks occurring during the whole project's lifecycle especially during construction period.

This Chapter illustrates the key findings and results of the study by tying the results reached to the aims and objectives in the introductory chapter. Also, in this chapter, the research questions shall be answered to identify the theoretical and practical implications of the study.

5.2 Review of original aims and objectives

Based on the research conducted in Chapter Two, Three and Four, the following conclusions were reached regarding the objectives previously stated in Chapter One.

1- *Develop a mathematical approach modelling the expected total effect of risks associated with poor stakeholder management during the construction phase on PPP projects' schedule based on historical details of previous PPP projects in a comparative study with traditional construction projects using ANNs.*

The main aim of the research has been achieved. The model was developed using Neural Designer ® Software. This software was used in particular as it is a powerful user-friendly interface able to make complex operations and build predictive models in an intuitive way with a graphical user interface.

To build the model, the following parameters were used:

1- The 44 risk factors used as input variables
2- Schedule Growth (or total project delay) used as target variables

The dataset contains 12 instances (or 12 projects) and was divided into:

d. Training comprising 66.7% of the projects (8 traditional projects)
e. Selection (testing) comprising 16.7% of the projects (2 traditional projects)
f. Validation comprising 16.7 of the projects (2 PPP projects)

Once all the dataset information has been set, some analytics were performed in order to check the quality of the data.

During the training phase, as it was previously explained, the neuron calculates the sum of the weighed inputs, subtracts its threshold from the sum and transfers the results by a transformation function or “activation function”. Early stopping was used in order to avoid model overfitting. Early stopping is simply described by halting or “stopping” training once the model error stops decreasing. The major benefit of early stopping is to overcome “memorizing” or “over-fitting.
Model performance was detected using Mean Squared Error (MSE) and Normalized Squared Error (NSE) over the training, testing and validation datasets.

Ten trials of the ANN model were performed using different training and testing strategies in order to be able choose the optimum model that has the best learning capabilities and delivering the least possible errors during the training and testing without falling in the trap of “overfitting” or “underfitting”.

Based on the different trials output, it is concluded that Model 4 delivers the smallest range of error (MSE and NSE) for training and testing. The architecture of this particular model is: 18 input nodes, three hidden neurons on two layers and one output. It was trained using a logistic function. The training was set to continue until there is no more improvement in test error over 10 cycles to prevent model over-fitting.

it is noticed that having the hidden perceptron on two layers improved the model's performance significantly and decreased errors for both training and testing. After performing training and testing of all models, and in all trials, it was noticed that the error decreased considerably by decreasing the number of input nodes.
Using the hyperbolic tangent activation function delivered relatively low errors compared to linear and logistic.

2- *Provide a better conceptual understanding of the PPP scheme and different types of PPP.*

The PPP model is complex model involving long-term relationships. PPPs are categorized into contractual and institutionalized PPPs. Also, there are different degrees of partnership between the public and the private partner based on the role of the private partner. The degrees range from the design Build contract until reaching the privatization. Nevertheless, in all cases, PPP projects involve bringing two different milieus to operate in a single project organization. The extreme challenge facing PPP project is the paradox between the concepts of "public", concerned about the community as a whole, and "private" concerned about the Value for Money, the profit and the market competitiveness.

3- *In light of the PPP history, study, evaluate previous failure and success stories in different countries that used PPP delivery method and critically appraise existing international literatures relating to PPP to identify the common key success factors and major causes of failure of PPP projects.*

Some countries such as the United Kingdom, Canada and the European Union have a strong and well established PPP scheme. Other countries, such as the Middle East countries, Turkey and China are taking serious steps by establishing PPP laws and PPP central units affiliated to its governments to study PPP projects. From the literature, it has been found that in general the critical success factors are:

- Adequate risk identification and allocation

- Good stakeholder management
- Paying attention to the role of the general public (the 4th P)

4. *Provide a better conceptual understanding of “Risk Management” and “Stakeholder Management” and ascertain, through a critical review of the literature, how both concepts are related.*

The quality of the relationship between public and private sector on one side and the end users on the other side has been shown to be a key contributor to the success of a PPP project. In fact, the real case projects that were discussed can be considered as clear evidence to support the following statement “Many of the risks affecting PPP projects arise due to poor management of stakeholders”. Therefore, minimizing the risks caused by inadequate management of stakeholders is a way of mitigation of a significant number of risks affecting PPP projects which is step towards better Risk Management for PPP projects.

5. *Develop from existing literature a comprehensive list including all the risks affecting PPP projects and determine to which risk group each individual risk is associated (For instance: economic, political, etc.), map each identified risk to its root cause and establish a cross-country comparison between different risks.*

In this research and in order to develop “the risks checklist”, an extensive literature review of 30 sources was thoroughly studied in order to develop the list of the risks affecting PPP projects. To properly develop a comprehensive list of risks, the journal papers, research and publications that were studied covered the time span between 1998 and 2018. Furthermore, the literature review performed for the sake of developing the risk factors was encompassing different countries. Some researches were studying the risk factors worldwide and others were dedicated to specifically study the risks associated with countries such as: the United Kingdom, Hong Kong, Scotland, China, Australia, India, Indonesia, Singapore, Iran, Malysia, Thailand, Portugal and South Africa. These countries were chosen to encompass different levels of PPP experience as previously explained in Chapter Two (Section 2.1.6: PPP around the world: success and failure stories). For instance, the Unites

Kingdom is an experienced country with a long history in PPPs, China and India are considered countries with limited PPP experience while Portugal is considered a country with moderate PPP experience. The risks extracted from this literature review are the outcomes of previous research, interviews and questionnaires. Accordingly, a comprehensive list of 118 risks was developed. The 118 identified risks were classified into various categories based on the source of each risk and on lifecycle perspective (Li and Zou 2012). Based on the research, the risks affecting PPP projects are classified into 16 different categories. Among the 16 categories, six categories are related to the life-cycle of the PPP project which are: feasibility study, financing, design, construction, operation and commissioning. In this research, the specific stage in the lifecycle of the project where the risk appears is specified. However, some risks should be managed throughout the lifecycle of the project from the start till the end such as legal, political and stakeholders' related risks.

In addition to the ranking and classification of risks into various risks categories, each one of the identified risks was mapped to its corresponding country. The purpose of this step is to know the critical risks that the literature identified for each country in order to establish a cross-country comparison. From this mapping, it is found that most of the risks affecting PPP projects around the world are political, legal, stakeholder and construction risks. The inadequate PPP experience, lack of support from government, force majeure and permits delays are affecting PPP projects in all the countries included in this research. It is also noticed that risks affecting developed countries such as Hong Kong, China and UK are of similar nature to the risks affecting developing countries.

6. *Develop a ranking for the identified risks based on the literature review with a special emphasis on risks related to construction and poor stakeholder management.*

From this ranking regarding the stakeholders related risks, it was found that the public opposition risk, which has the highest ranking among the stakeholders related risks also occupies ranking # 7 among the overall risk ranking. Based on the assessment technique used in this research, the top five risks related to stakeholders' issues and affecting PPP projects are: the public opposition, lack of communication between stakeholders, third party tort liability, need for land acquisition and lack of support from government.

From this ranking regarding the construction risks, it was found that the material availability risk, which has the highest ranking among the construction risks also occupies ranking # 5 among the overall risk ranking. Based on the assessment technique used in this research, the top 5 risks related to construction and affecting PPP projects are: material availability, construction cost overrun, geological conditions, high finance cost/availability of finance and construction completion risks.

7. *Using data collected from real case projects, design the Neural Network approach modelling the effect of construction risks and poor stakeholder management risks (previously identified in step (4)) on the project's schedule and time for completion. The data will be collected for both traditional and PPP projects.*

This objective has also been achieved. Several ANN models were trained for this research using different activation functions (i.e. Gradient descent, conjugate gradient and Quasi-Newton). All 44 risk factors were used initially with Total Project Delay (Schedule Growth) as model output. Early stopping was used in order to avoid model overfitting. Model performance was detected using Mean Squared Error (MSE) and Normalized Squared Error (NSE) over the training, testing and validation datasets.

8. *Determine, based on the model's outputs, a new ranking for the risks affecting the project's time for the completion.*

The aim of sensitivity analysis is to determine the cause and effect relationship between inputs and outputs of the ANN model. In this case, sensitivity analysis was performed on the input factors used in each of the best retained models from the previous stage. It is noticed, based on this table that the most significant risk factor is "the lack of coordination" as it is the most important contributor to the model´s ability to predict total project´s delay. On the other hand, the least significant risk factor in this case is the “constructability” and the “protection of geological and historical objects”. The results of this sensitivity analysis and its comparison to the outcomes of the risk ranking based on the literature review are further discussed in section 4.5.

9. *Compare the risk ranking generated through the Neural Network model to the risk ranking previously developed though the literature review in step (7).*

At this stage, a comparison was established between this new ranking and the ranking previously obtained from the literature review based on content analysis and on the ranking obtained from the sensitivity analysis. The following observations can be drawn:

- Based on the literature review, the material availability risk occupies the first position in terms of the most critical risks. This ranking is similar to a great extent to its ranking based on the correlation calculations according to which this risk occupies the third position. On the other hand, the ranking of this same risk is 31 based on the sensitivity analysis in terms of its effect and contribution to the total project delay.

- The “Delay in resolving contractual dispute” occupies the highest rank in terms of correlation with the total project delay based on the ANN model’s outputs. This ranking is also similar to the results of the sensitivity analysis where it occupies the second position in terms of the risks having the highest contribution to the total project’s delay. On the other hand, the same risk is ranked 31st based on the results of the analysis of the literature review. Since the ANN model was based on real case projects, it makes more sense that this particular risk can be of detrimental effect to the project’s completion time. The same goes for the risk “Inadequate negotiation period prior to initiation”. This risk, based on the model’s deliverables, is ranking 11th and 17th in sensitivity analysis and correlation to the total project’s delay while, based on the literature review, is ranking 42nd out of 44.

- The "Public opposition" risk is one of the most severe risks facing PPP projects based on the literature review as it occupies the second position based on the various sources taken into account. Nevertheless, based on the sensitivity analysis and on the correlation analysis, this risk occupies the 35th and 44th positions respectively. This difference in ranking can be caused by the relatively small sample size of PPP projects studied in this research. The dataset studied was not encompassing such risk as it was not faced in the projects that were analyzed. However, this does not mean that this risk is not significant especially for PPP projects. As it was previously discussed in section 2.3.8 the general public has a considerable power especially when it comes to PPP projects. The same goes for "poor quality workmanship" risk which ranks 9th based on the literature review and has less contribution to the total project's delay based on the sensitivity and correlation analysis where it occupies 21st and 37th positions respectively.

- For other risks such as "Constructability", "staff crisis" and "subjective evaluation", the literature review and the model deliverables produced very close results.

10. *Critically evaluate the mathematical model's performance based on:*

    i. *The percentage error the model will deliver*

Based on the different trials output, it is concluded that Model 4 delivers the smallest range of error (MSE and NSE) for training and testing. The architecture of this particular model is: 18 input nodes, three hidden neurons on two layers and one output. It was trained using a logistic function. The training was set to continue until there is no more improvement in test error over 10 cycles to prevent model over-fitting.

    ii. *The discrepancies in the risk ranking between the model and the literature review.*

Based on the literature review, the material availability risk occupies the first position in terms of the most critical risks. This ranking is similar to a great extent to its ranking based on the correlation calculations according to which this risk occupies the third position. On the other hand, the ranking of this same risk is 31 based on the sensitivity analysis in terms of its effect and contribution to the total project delay. The “Delay in resolving contractual dispute” occupies the highest rank in terms of correlation with the total project delay based on the ANN model’s outputs. This ranking is also similar to the results of the sensitivity analysis where it occupies the second position in terms of the risks having the highest contribution to the total project’s delay. The “Public opposition” risk is one of the most severe risks facing PPP projects based on the literature review as it occupies the second position based on the various sources taken into account. Nevertheless, based on the sensitivity analysis and on the correlation analysis, this risk occupies the 35th and 44th positions respectively.

5.3 Limitations of study

1. This research is mainly focusing only on the contribution of construction and stakeholders’ risks to the total project’s delay during the construction period without taking into account other risk groups.
2. This research is mainly concerned with the impact of construction and poor stakeholder management related risks on PPP projects in comparison to traditional projects with a special emphasis on developing nations. Despite the benefits of PPP projects for developing countries in particular, the number of PPP projects achieved and/or under construction is limited. Accordingly, the dataset was not very large to encompass various projects. Nevertheless, future expansions can occur to enhance the model when the number of projects is larger. This will help in creating a larger database that will be of help in the future.
3. This research is studying the impacts of the risks only during the construction period. It is true that the construction period is when most of the risks occur. However, being able to study the PPP project and the associated risks during the pre-construction and operation phase will be also beneficial.
4. The ANN models that were developed are totally dependent on the data extracted from the projects time schedule. Fake or manipulated schedules may lead to either earlier than estimated or delayed than expected results.

5. In order to determine the various sources of delays in different projects during data collection, the delay analysis used for the projects in the datasets were not the same. For example, in some projects Time Impact Analysis was used, in other projects, impacted-as-planned was the tool determining the delays. This may cause some discrepancies in the collected data as the delay analysis tools were not the same.
6. The success of the models depends heavily on the availability of project data which should be stored in retrievable manner. For many construction companies, relevant data is not stored in an organized way, making the access to useful data practically difficult, or sometimes, impossible. The poor warehousing and protection of data is expected to be one of the major limitations of using such data and developing models in practice.
7. When developing the ANN model, there are no set rules on the nature of the network architecture or the number of neurons or layers to use. Each problem should be treated separately using a trial and error approach until optimum network performance is reached. This means that if the current model is expanded or if a similar model will be built, there will be no rules to follow. This can be challenging in some cases.

5.4 Recommendations for Future research

1. **Expanding the risk groups studied**

This research is mainly focusing on the contribution of construction and stakeholders' risks to the total project's delay. The ANN model can be expanded to include other types of risks such as: economic and financing, operation, market, political, legal, etc.

2. **Studying other periods during the project's lifecycle**

This research is studying the risks that are born during the construction period. It is true that the construction period is pivotal during the project's lifetime. However, in order to ensure the success of a project, the whole project's lifecycle should be studied. Accordingly, this research can be expanded to cover other phases such as the feasibility study, financing stage, design stage, operation and transfer stages.

3. **Taking Risk allocation into account**

Risk allocation was briefly discussed in this research in section 2.2.2 and was included in the data analysis and integration steps in Chapter 4 in order to determine which party is responsible for each risk. Nevertheless, risk allocation was not included in the actual model. Risk allocation is a crucial topic playing a major role in reducing disputes during the whole lifespan of the project, if studied properly. Several studies proved that most of the claims and disputes occurring in the construction industry are caused by improper risk allocation. Moreover, allocating the risk to the wrong party can cause the contractors to add high contingency (risk premium) to their bids or deliver low quality of work. The key is to find the "optimum level of risk allocation". Including risk allocation in a future expansion of the model can be an asset of a great importance.

4. **Validation in practice**

In this research, the different model trials that were produced have gone through the validation process using a sample data that was kept aside for this purpose (PPP projects used for validation). A further stage of validating the models would be to test them against a new project that has not been undertaken yet.

5. **Developing a stakeholder management framework**

Using the model's outcomes to develop a framework for adequate management of stakeholders throughout the lifetime of the PPP project.

6. **Modelling the "cost-related" aspect of the projects**

This research is mainly concerned with the time aspect of the project as the project delays are directly related to the cost's overruns. Nevertheless, there are other causes for cost overruns such as inflation, legal changes, etc. Building another mathematical approach modelling the impacts of the risks on PPP projects' "cost" can be a considerable addition to this study.

7. **Data warehousing is crucial**

The real value of the data lies in being able to extract it and use it when needed. A proper and sound document control and data warehousing systems should be established in construction companies. This will help in improving the learning curve and avoiding, as much as possible, previous mistakes by mitigating already known risks.

8. Decision Support System

The ultimate aim of this research and a future destination for this study is to provide, in addition to the ANN model determining the contribution of the risks to the overall project delay, a tool assisting the public sector to choose and determine whether the PPP scheme in a particular project is the optimum scheme to use or not. This can be achieved at a later stage after building a more robust database using a large sample size (which can consist of PPP projects performed in other countries). This Decision Support System can be built using a software like “Crystal Ball” which can be easier to use as it is integrated to Microsoft Excel.

A broad image of this Decision Support System suggests depending on two concepts: the first one is the “Experts Opinion” which is the Opinion that was obtained through the ANN model (or through surveys). The second one is the “End user’s opinion” which is the opinion of the user who is going to use the Decision Support System. The idea of the Decision Support System is based on the fact that the end user starts by selecting the weighing of his opinion with respect to the expert’s (or database) opinion. If the end user has a considerable background about risk management and about investment in PPP projects, then, he/she can assign a large weight to his/her opinions. On the other hand, if the end user does not have an experience about risk management or cannot determine the probability and the impacts of the risks, therefore, he/she should depend more on the experts’ opinion.

Figure 111 shows a screen shot showing an example for the drop-down menu including the experts’ opinion weight. Based on the weight assigned to the experts, the end user’s opinion will be automatically updated.

Experts Opinion Weight	100			
Risk Factor 1: Macroecon	30 40 50 60 70 80 90 100	ancial Risks		
Item		I	S	Normalized Severity
Interest Rate Fluctuation		3.28	10.10	0.20
Inflation	3.88	3.8	14.74	0.80
Foreign Exchange Fluctuation	4.04	4.04	16.32	1.00
Price Change	3.48	3.16	11.00	0.31
Operation Cost Overrun	3	3.12	9.36	0.10
Revenue Risk	2.84	3.64	10.34	0.23

Figure 111. **Drop-down menu including the experts' opinion weight**

User Opinion Weight	0			
Risk Factor 1: Macroeconomic and Financial Risks				
Item	P	I	S	Normalized Severity
Interest Rate Fluctuation			0.00	#DIV/0!
Inflation			0.00	#DIV/0!
Foreign Exchange Fluctuation			0.00	#DIV/0!
Price Change			0.00	#DIV/0!

Figure 112. **View of a potential DSS for future research**

Moreover, experts' opinions can regularly be updated if the conditions change in the country through the development of new surveys or through distributing a second round of questionnaires or through the establishment of new projects. Figure 112 and 113 provide another screen shot for the model, with the area required to be filled by the end user:

RDSS-[PPP] Risk Decision Support System for PPP projects

There are 3 steps to run this model, they are highlighted throughout the model:

1- Please Enter the desired experts opinion weight with the respect to the end user's opinion weight

Experts Opinion Weight	90	User Opinion Weight	10

This section is already filled according to the previous survey results and is not to be filled by the end user

Risk Factor 1: Macroeconomic and Financial Risks				
Item	P	I	S	Normalized Severity
Interest Rate Fluctuation	3.08	3.28	10.10	0.20
Inflation	3.88	3.8	14.74	0.80
Foreign Exchange Fluctuation	4.04	4.04	16.32	1.00
Price Change	3.48	3.16	11.00	0.31
Operation Cost Overrun	3	3.12	9.36	0.10
Revenue Risk	2.84	3.64	10.34	0.23

Risk Factor 2: Commercial and Market Environmental Risks				
				Normaliz

2- Please fill the probability and the impact of the following risks (Risk definitions are provided in the second Sheet)

Risk Factor 1: Macroeconomic and Financial Risks				
Item	P	I	S	Normalized Severity
Interest Rate Fluctuation	4	4	16.00	0.63
Inflation	5	5	25.00	1.00
Foreign Exchange Fluctuation	5	5	25.00	1.00
Price Change	3	3	9.00	0.33
Operation Cost Overrun	3	3	9.00	0.33
Revenue Risk	3	3	9.00	0.33

Risk Factor 2: Commercial and Market Environmental Risks				
				Norma

Figure 113. **Screen shot for the model**

In this case, the severity of the project is obtained through the model, by getting an end user acquainted with the project's conditions fill the part related to the end user as it is shown in figure 114 extracted from the model:

2- Please fill the probability and the impact of the following risks (Risk definitions are provided in the second Sheet)

Risk Factor 1: Macroeconomic and Financial Risks				
Item	P	I	S	Normalized Severity
Interest Rate Fluctuation	4	4	16.00	0.63
Inflation	5	5	25.00	1.00
Foreign Exchange Fluctuation	5	5	25.00	1.00
Price Change	3	3	9.00	0.33
Operation Cost Overrun	3	3	9.00	0.33
Revenue Risk	3	3	9.00	0.33

Risk Factor 2: Commercial and Market Environmental Risks				
Item	P	I	S	Normalized Severity
Supply and Demand	4	4	16	0.63
Public Credit	4	4	16.00	0.63

Figure 114. **Extract from the Decision Support System-end user's opinion**

The Decision Support System's output can be the following:

- The overall risk level for the whole project
- The Contingency percentage for the whole project based on the most critical risks included in the questionnaire and based on the severity obtained.

Based on the severity of the project and based on the contingency percentage associated with the risks in this specific project, the end user can decide whether this specific project should be accepted under the PPP scheme or not. The flowchart in figure 114 shows the steps that can be followed in order to develop the DSS.

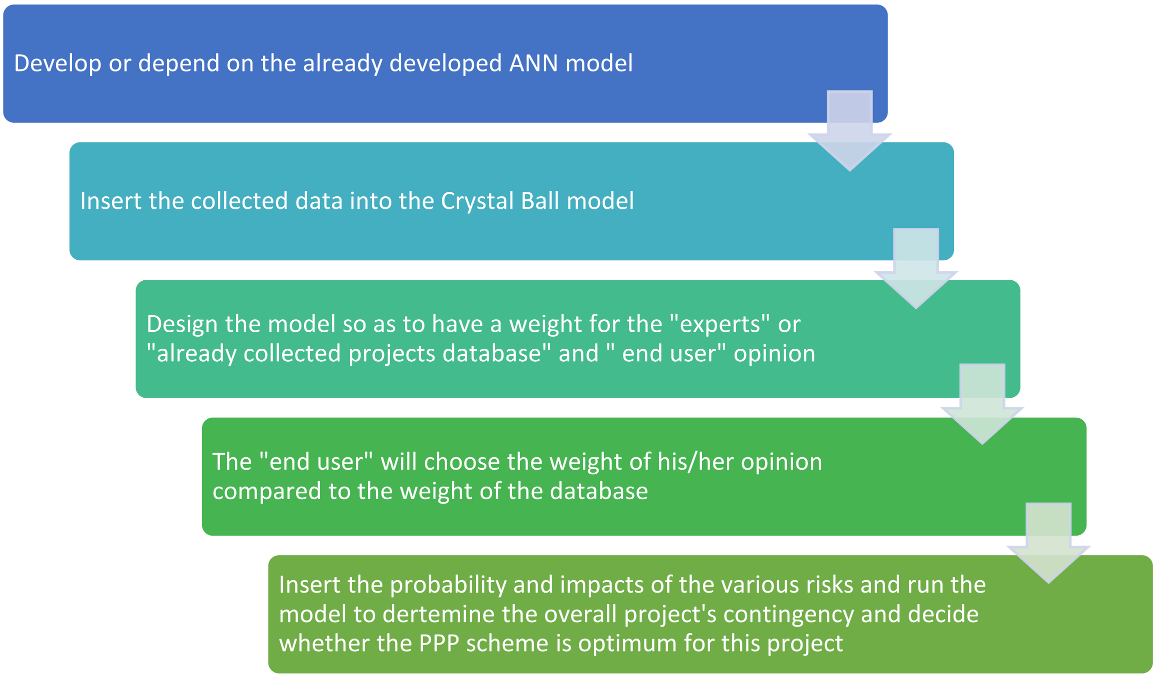


Figure 115. **Steps that can be followed in order to develop the DSS**

5.5 Making sense of the research contribution to knowledge

The aims and objectives have been achieved and research questions have been answered. However, it is also crucial to place this research within the wider spectrum of construction management and practice.

Primary contribution:

> *A mathematical Artificial Neural Network approach modelling the impact of construction and stakeholders related risks on the project's schedule and completion time based on a comparative analysis between traditional projects and PPP projects in developing nations.*

This research attempts to highlight the importance of risks affecting traditional and PPP projects during the construction period especially stakeholders and construction-related risks. In order to build the ANN models, data was collected from real case projects and not on questionnaire results in order to add a "practical" perspective to the research which will make the developed model "closer" to the end user as it is based on real-case problems faced in actual projects. Adding the comparative aspect between traditional and PPP projects proved the similarity between the two project types especially during the construction period and proved that applying the traditional models' outcomes on PPP projects is doable. This can make the end users more comfortable to use this model especially the ones who are less familiar with the PPP scheme. The presentation of a neural network model for solving schedule-related problems in terms of risks affecting the projects can be viewed as a contribution of the study to practice. Also, the use of ANN models has been demonstrated as a possible opportunity for converting existing data within construction firms into decision support tools, especially where information is lacking or inadequate. The use of such models can help the public owners, contractors and project managers to:

- Be proactive in predicting the contribution of various risks to the project's delay
- Enhance early identification of potential problems on a project
- Minimize disputes, delays and additional costs
- Help in having better contract management and better relationship among parties
- Enhance the learning curve especially in the domain of PPP

Secondary contributions:

A comprehensive definition of Stakeholder Management and Stakeholder Involvement (including the importance of the "People" (general public/end users) as a major PPP project stakeholder)

In order to ensure the success of the PPP projects, the public sector, the private sector and the public should be involved. Stakeholder engagement means involving and building relationships with different stakeholders as early as possible in the project's lifetime. Getting early feedback from the stakeholders can help avoiding doing many changes afterwards during the project's lifetime which can reduce cost overruns and poor VFM. It was also proved that PPP projects that paid attention to public needs resulted in less changes during operation.

In light of the complex nature of PPP projects and with the disputes that may arise between the private and public, people will act as the "cementing agent" or "the link" connecting the public to the private partner. It will be in the project's benefit to engage the general public as early as possible in the project in order to unify the goals, objectives and benefits of all the stakeholders as marginalizing the general public could lead to detrimental results.

Understanding of the relationship between Risk Management and Stakeholder Management

As it has been shown, the quality of the relationship between public and private sector on one side and the end users on the other side has been shown to be a key contributor to the success of a PPP project. In fact, the real case projects that were discussed can be considered as clear evidence to support the following statement "Many of the risks affecting PPP projects arise due to poor management of stakeholders". Therefore, analyzing the risks caused by inadequate management of stakeholders and determining their effect on PPP projects compared to their effect on traditional projects is a way of mitigation of a significant number of risks affecting PPP projects which is step towards better Risk Management for PPP projects.

5.6 Final thoughts

The problem of delays in construction projects (traditional and PPP projects) occurs irrespective of the size or type of project, its location, procurement method or duration.

It is not expected that the public sector will be able to adequately deal with the problem of project delays right away especially when it comes to choosing whether the traditional method or the PPP scheme is the most suitable scheme for this particular project. The only way to improve the decision-support tools to help the public sector in developing countries is fresh thinking and continuous work in both academia and industry. The contribution of this research lies in its ability to provide a way of practically linking the contribution of construction and stakeholders' risks to the total project delay for both traditional and PPP projects.

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APPENDIX A: RISK IDENTIFICATION IN THE LITERATURE AND RISK GROUPS

Risk identification in PPP projects

#	Risk factors	References																														Total	% of times cited	Risk group
		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	A1	B1	C1	C2			
1	Lack of support from government		*				*		*	*	*	*									*											7	24.14	Stakeholders' issue
2	Unstable government			*					*			*	*	*	*	*	*	*	*													10	34.48	Political
3	Strong political interference	*		*	*	*		*			*	*																				7	24.14	Political
4	Corruption and bribery	*		*					*		*	*								*												6	20.69	Political
5	Nationalization/Expropriation	*		*		*	*	*			*	*	*	*	*	*	*	*		*												14	48.28	Political
6	Poor financial market			*					*			*								*					*	*			*	*		8	27.59	Economic and Financing
7	Inflation	*		*	*		*		*		*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*		24	82.76	Economic and Financing
8	Interest rate	*		*		*	*	*	*		*	*	*	*	*	*	*	*	*	*	*			*	*	*	*	*	*	*		24	82.76	Economic and Financing
9	Lack of legal/regulatory framework				*			*			*	*																				4	13.79	Legal
10	Inconsistent legal framework	*	*	*	*	*	*				*	*																				8	27.59	Legal
11	Change in tax regulation	*		*		*	*	*			*	*								*	*			*	*	*	*	*	*	*		16	55.17	Economic and Financing
12	Public opposition		*	*			*		*		*	*	*	*	*	*	*	*	*		*				*			*	*	*		18	62.07	Stakeholders' issue
13	Environment		*	*							*	*							*	*					*	*	*	*	*	*		12	41.38	Natural
14	Force Majeure	*	*	*		*	*				*	*	*	*	*	*	*	*	*	*	*				*		*	*		*		20	68.97	Natural
15	Weather			*		*					*	*	*	*	*	*	*	*	*	*					*			*		*		15	51.72	Natural
16	Geological conditions			*		*					*	*	*	*	*	*	*	*		*	*							*		*		14	48.28	Construction
17	Construction delays			*		*	*			*	*	*							*													7	24.14	Construction
18	Site safety and security			*					*			*	*	*	*	*	*	*														9	31.03	Construction
19	Poor quality workmanship			*								*	*	*	*	*	*	*										*	*	*		11	37.93	Construction
20	Construction cost overrun			*						*		*	*	*	*	*	*	*	*						*	*	*	*	*	*		16	55.17	Construction
21	Excessive contract variation			*								*																*	*	*		5	17.24	Construction
22	Material availability	*		*	*	*	*				*	*	*	*	*	*	*	*	*		*		*			*		*		*		19	65.52	Construction
23	Availability of finance			*	*				*	*	*	*	*	*	*	*	*	*			*											13	44.83	Construction
24	High finance cost			*				*				*	*	*	*	*	*	*								*	*	*	*	*		14	48.28	Construction
25	Financial attraction of project to investors			*								*																				2	6.90	Economic and financing
26	Delay in approval and permits			*	*	*					*	*	*	*	*	*	*	*		*	*				*	*		*	*	*		18	62.07	Political
27	Design deficiency			*	*			*	*			*	*	*	*	*	*	*	*		*		*		*	*	*		*	*		19	65.52	Design
28	Scope variation		*		*						*	*									*											5	17.24	Design
29	Unproven engineering techniques			*		*	*				*	*	*	*	*	*	*	*									*			*		13	44.83	Construction and design
30	Level of demand for project	*	*	*			*	*	*	*	*	*													*				*	*		12	41.38	Feasibility study
31	Site availibility			*			*			*	*	*	*	*	*	*	*	*	*													12	41.38	Construction
32	Operation cost overrun		*	*		*	*					*	*	*	*	*	*	*	*	*				*	*	*	*	*	*	*		20	68.97	Operation
33	Low operation productivity			*								*	*	*	*	*	*	*	*			*		*								11	37.93	Operation
34	Maintenance cost higher than expected			*								*	*	*	*	*	*	*			*			*								10	34.48	Operation
35	Maintenance more frequent than expected			*								*	*	*	*	*	*	*			*			*								10	34.48	Operation
36	Residual asset risk			*		*					*	*	*	*	*	*	*	*		*				*								12	41.38	Operation
37	Indequate PPP experience			*	*							*																			*	4	13.79	Stakeholders' issue
38	Lack of communication between stakeholders			*	*	*					*	*							*	*	*		*									9	31.03	Stakeholders' issue
39	Inadequate distribution of responsibilities			*	*	*		*				*																			*	6	20.69	Stakeholders' issue
40	Inadequate distribution of authorities			*	*							*																				3	10.34	Stakeholders' issue
41	Lack of commitment between parties	*		*								*																			*	4	13.79	Stakeholders' issue
42	Differences in working methods/Knowhow between parties			*								*																			*	3	10.34	Stakeholders' issue
43	Termination of concession by government												*	*	*	*	*	*	*													7	24.14	Political
44	Change in law												*	*	*	*	*	*	*	*	*			*	*	*	*	*	*	*		16	55.17	Political/Legal/Financial
45	Influential economic events												*	*	*	*	*	*			*											7	24.14	Political

Risk identification in PPP projects

#	Risk factors	References																														Total	% of times cited	Risk group
46	Change in industrial code of practice												*	*	*	*	*	*														6	20.69	Political and construction
47	Insolvency of Subcontractors												*	*	*	*	*	*										*	*	*		9	31.03	Construction
48	Labor availability												*	*	*	*	*	*	*				*			*		*		*		11	37.93	Construction
49	Construction/design changes												*	*	*	*	*	*		*	*	*			*	*	*		*	*		14	48.28	Construction/Design
50	Labor disputes/strikes												*	*	*	*	*	*														6	20.69	Construction
51	Land use												*	*	*	*	*	*														6	20.69	Construction
52	Waste of materials												*	*	*	*	*	*														6	20.69	Construction
53	Construction completion												*	*	*	*	*	*		*					*	*	*	*	*	*		13	44.83	Construction
54	Supporting utilities risk												*	*	*	*	*	*		*												7	24.14	Construction
55	Protection of geological and historical objects												*	*	*	*	*	*														6	20.69	Construction
56	Operator default												*	*	*	*	*	*	*					*								8	27.59	Operation
57	Quality of operation												*	*	*	*	*	*						*								7	24.14	Operation
58	Condition of facility												*	*	*	*	*	*						*								7	24.14	Operation
59	Contractual risk												*	*	*	*	*	*						*								7	24.14	Legal
60	Third party tort liability												*	*	*	*	*	*						*							*	8	27.59	Stakeholders' issue
61	Ownership assets												*	*	*	*	*	*	*					*								8	27.59	Legal
62	Insolvency of Concession company												*	*	*	*	*	*			*			*								8	27.59	Legal
63	Insufficient income												*	*	*	*	*	*	*													7	24.14	Market
64	Fluctuation of material cost (by government)												*	*	*	*	*	*														6	20.69	Market
65	Fluctuation of material cost (by private sector)												*	*	*	*	*	*														6	20.69	Market
66	Tariff change												*	*	*	*	*	*		*												7	24.14	Market
67	Market demand change/Demand below anticipation												*	*	*	*	*	*	*	*	*				*	*	*	*	*	*		15	51.72	Market/Operation
68	Exclusivity												*	*	*	*	*	*							*	*			*	*		10	34.48	Market
69	Foreign currency exchange												*	*	*	*	*	*	*	*				*								9	31.03	Economic
70	Residual risk												*	*	*	*	*	*			*					*			*	*		10	34.48	Operation
71	Changes in value of granted land due to development																		*					*								2	6.90	Economic
72	Changes in value of granted land due to inflation																		*					*								2	6.90	Economic
73	Financial problems due to environmental protection																		*					*								2	6.90	Economic
74	Need for land appraisal																		*					*								2	6.90	Economic
75	Limited capital																		*					*								2	6.90	Economic
76	Delay in resolving contractual dispute																		*		*											2	6.90	Stakeholders' issue
77	Inadequate study and unsufficient data																		*					*								2	6.90	Legal
78	Lack of standard model for PPP agreements																		*					*								2	6.90	Legal
79	Need for land acquisition																		*	*	*				*	*		*	*	*		8	27.59	Stakeholders' issue
80	Delay in resolving litigation or arbitration dispute																		*		*			*								3	10.34	Legal
81	Influencial economic events																		*													1	3.45	Political
82	Poor public decision making process																		*	*							*			*		4	13.79	Political/Feasibility study
83	Sanction																		*													1	3.45	Political
84	Arbitrary definition of tariff of services by government																		*													1	3.45	Market
85	Competition																		*	*	*											3	10.34	Market
86	Operating revenues below expectation																		*		*				*	*	*	*	*	*		8	27.59	Market/Operation
87	Lack of coordination and commitment																		*												*	2	6.90	Stakeholders' issue
88	Need for environmental approval																		*					*								2	6.90	Legal
89	Third party delays																		*													1	3.45	Stakeholders' issue
90	Government intervention																			*												1	3.45	Political
91	Government reliability																			*					*		*	*	*	*		6	20.69	Construction

Risk identification in PPP projects

#	Risk factors	References																														Total	% of times cited	Risk group
92	Third-party reliability																		*					*		*	*	*	*		6	20.69	Construction
93	Immature juristic system																		*												1	3.45	Legal
94	Improper contract																		*												1	3.45	Legal
95	Delay in supply																		*												1	3.45	Construction
96	Technological risk																		*					*		*	*	*	*		6	20.69	Operation
97	Payment risk																		*												1	3.45	Economic and financing
98	Uncompetetive tender																		*												1	3.45	Political
99	Consortium inability																		*					*			*	*	*		5	17.24	Operation
100	Private investor change																		*	*											2	6.90	Stakeholders' issue
101	Subjective evaluation																		*												1	3.45	Stakeholders' issue
102	Insufficient financial audit																		*												1	3.45	Economic and financing
103	Change in output specification																			*											1	3.45	Design
104	Innovative design																			*											1	3.45	Design
105	Design complexity																			*											1	3.45	Design
106	Constructability																			*											1	3.45	Construction
107	Defects in construction																			*											1	3.45	Construction
108	Delay in operation																			*			*								2	6.90	Operation
109	Excessive maintenance and refurbishment																			*			*								2	6.90	Operation
110	Filre/delay in commissioning test																			*											1	3.45	Commissioning risks
111	Technical obsolescence																			*											1	3.45	Market
112	Misunderstanding the role of stakeholders																			*											1	3.45	Stakeholders' issue
113	Misinterpretation of contract																			*											1	3.45	Stakeholders' issue
114	Stakeholder management																					*									1	3.45	Stakeholders' issue
115	Low financial attraction of project to investors																							*	*	*		*	*		5	17.24	Economic and Financing
116	Inadequate negotiation period prior to initiation																													*	1	3.45	Stakeholders' issue
117	Staff crisis																													*	1	3.45	Stakeholders' issue
118	Cultural differences between main stakeholders																													*	1	3.45	Stakeholders' issue

APPENDIX B: RISK RANKING

Ranking of all risks

#	Risk factors	Total	% of times cited	Risk group
1	Inflation	24	82.76	Economic and Financing
2	Interest rate	24	82.76	Economic and Financing
3	Force Majeure	20	68.97	Natural
4	Operation cost overrun	20	68.97	Operation
5	Material availability	19	65.52	Construction
6	Design deficiency	19	65.52	Design
7	Public opposition	18	62.07	Stakeholders' issue
8	Delay in approval and permits	18	62.07	Political
9	Change in tax regulation	16	55.17	Economic and Financing
10	Construction cost overrun	16	55.17	Construction
11	Change in law	16	55.17	Political/Legal/Financial
12	Weather	15	51.72	Natural
13	Market demand change/Demand below anticipation	15	51.72	Market/Operation
14	Nationalization/Expropriation	14	48.28	Political
15	Geological conditions	14	48.28	Construction
16	High finance cost	14	48.28	Construction
17	Construction/design changes	14	48.28	Construction/Design
18	Availability of finance	13	44.83	Construction
19	Unproven engineering techniques	13	44.83	Construction and design
20	Construction completion	13	44.83	Construction
21	Environment	12	41.38	Natural
22	Level of demand for project	12	41.38	Feasibility study
23	Site availibility	12	41.38	Construction
24	Residual asset risk	12	41.38	Operation
25	Poor quality workmanship	11	37.93	Construction
26	Low operation productivity	11	37.93	Operation
27	Labor availability	11	37.93	Construction
28	Unstable government	10	34.48	Political
29	Maintenance cost higher than expected	10	34.48	Operation
30	Maintenance more frequent than expected	10	34.48	Operation
31	Exclusivity	10	34.48	Market
32	Residual risk	10	34.48	Operation
33	Site safety and security	9	31.03	Construction
34	Lack of communication between stakeholders	9	31.03	Stakeholders' issue
35	Insolvency of Subcontractors	9	31.03	Construction
36	Foreign currency exchange	9	31.03	Economic
37	Poor financial market	8	27.59	Economic and Financing
38	Inconsistent legal framework	8	27.59	Legal
39	Operator default	8	27.59	Operation
40	Third party tort liability	8	27.59	Stakeholders' issue
41	Ownership assets	8	27.59	Legal
42	Insolvency of Concession company	8	27.59	Legal
43	Need for land acquisition	8	27.59	Stakeholders' issue
44	Operating revenues below expectation	8	27.59	Market/Operation
45	Lack of support from government	7	24.14	Stakeholders' issue
46	Strong political interference	7	24.14	Political
47	Construction delays	7	24.14	Construction
48	Termination of concession by government	7	24.14	Political
49	Influential economic events	7	24.14	Political
50	Supporting utilities risk	7	24.14	Construction
51	Quality of operation	7	24.14	Operation
52	Condition of facility	7	24.14	Operation

Ranking of all risks

#	Risk factors	Total	% of times cited	Risk group
53	Contractual risk	7	24.14	Legal
54	Insufficient income	7	24.14	Market
55	Tariff change	7	24.14	Market
56	Corruption and bribery	6	20.69	Political
57	Inadequate distribution of responsibilities	6	20.69	Stakeholders' issue
58	Change in industrial code of practice	6	20.69	Political and construction
59	Labor disputes/strikes	6	20.69	Construction
60	Land use	6	20.69	Construction
61	Waste of materials	6	20.69	Construction
62	Protection of geological and historical objects	6	20.69	Construction
63	Fluctuation of material cost (by government)	6	20.69	Market
64	Fluctuation of material cost (by private sector)	6	20.69	Market
65	Government reliability	6	20.69	Construction
66	Third-party reliability	6	20.69	Construction
67	Technological risk	6	20.69	Operation
68	Excessive contract variation	5	17.24	Construction
69	Scope variation	5	17.24	Design
70	Consortium inability	5	17.24	Operation
71	Low financial attraction of project to investors	5	17.24	Economic and Financing
72	Lack of legal/regulatory framework	4	13.79	Legal
73	Indequate PPP experience	4	13.79	Stakeholders' issue
74	Lack of commitment between parties	4	13.79	Stakeholders' issue
75	Poor public decision making process	4	13.79	Political/Feasibility study
76	Inadequate distribution of authorities	3	10.34	Stakeholders' issue
77	Differences in working methods/Knowhow between parties	3	10.34	Stakeholders' issue
78	Delay in resolving litigation or arbitration dispute	3	10.34	Legal
79	Competition	3	10.34	Market
80	Financial attraction of project to investors	2	6.90	Economic and financing
81	Changes in value of granted land due to development	2	6.90	Economic
82	Changes in value of granted land due to inflation	2	6.90	Economic
83	Financial problems due to environmental protection	2	6.90	Economic
84	Need for land appraisal	2	6.90	Economic
85	Limited capital	2	6.90	Economic
86	Delay in resolving contractual dispute	2	6.90	Stakeholders' issue
87	Inadequate study and unsufficient data	2	6.90	Legal
88	Lack of standard model for PPP agreements	2	6.90	Legal
89	Lack of coordination and commitment	2	6.90	Stakeholders' issue
90	Need for environmental approval	2	6.90	Legal
91	Private investor change	2	6.90	Stakeholders' issue
92	Delay in operation	2	6.90	Operation
93	Excessive maintenance and refurbishment	2	6.90	Operation
94	Influencial economic events	1	3.45	Political
95	Sanction	1	3.45	Political
96	Arbitrary definition of tariff of services by government	1	3.45	Market
97	Third party delays	1	3.45	Stakeholders' issue
98	Government intervention	1	3.45	Political
99	Immature juristic system	1	3.45	Legal
100	Improper contract	1	3.45	Legal
101	Delay in supply	1	3.45	Construction
102	Payment risk	1	3.45	Economic and financing
103	Uncompetetive tender	1	3.45	Political
104	Subjective evaluation	1	3.45	Stakeholders' issue

Ranking of all risks

#	Risk factors	Total	% of times cited	Risk group
105	Insufficient financial audit	1	3.45	Economic and financing
106	Change in output specification	1	3.45	Design
107	Innovative design	1	3.45	Design
108	Design complexity	1	3.45	Design
109	Constructability	1	3.45	Construction
110	Defects in construction	1	3.45	Construction
111	Filre/delay in commissioning test	1	3.45	Commissioning risks
112	Technical obsolescence	1	3.45	Market
113	Misunderstanding the role of stakeholders	1	3.45	Stakeholders' issue
114	Misinterpretation of contract	1	3.45	Stakeholders' issue
115	Stakeholder management	1	3.45	Stakeholders' issue
116	Inadequate negotiation period prior to initiation	1	3.45	Stakeholders' issue
117	Staff crisis	1	3.45	Stakeholders' issue
118	Cultural differences between main stakeholders	1	3.45	Stakeholders' issue

APPENDIX C: RISK SOURCES FROM THE LITERATURE REVIEW

List of 30 sources

#	Reference letter	Reference name	Reference year	Country
1	A	Kumaraswamy and Zhang	2001	Hong Kong
2	B	Grimsey and Lewis	2002	Scotland
3	C	Li et al.	2005	United Kingdom
4	D	Shen et al.	2006	Hong Kong
5	E	Ng and Loosemore	2007	Australia
6	F	Estache et al.	2007	Worldwide
7	G	Medda	2007	Worldwide
8	H	Zou et al.	2008	China and Australia
9	I	Thomas et al.	2003	India
10	J	Xu et al.	2010	China
11	K	Hwang et al.	2012	Singapore
12	L	Ke et al.	2009	China
13	M	Lam et al.	2007	Hong Kong
14	N	Arndt	1998	Australia
15	O	Wang and Tiong	2000	China
16	P	NTSA	2004	South Africa
17	Q	VDTF	2001	Australia
18	R	Valipour et al.	2016	Iran
19	S	Ke et al.	2011	China
20	T	Doloi	2012	Australia
21	U	Kaming et al.	1997	Indonesia
22	V	Sambasivan and Soon	2007	Malysia
23	W	Ghosh and Jintanapakanout	2004	Thailand
24	X	Singh et al.	2006	India
25	Y	Lemos et al.	2004	Portugal
26	Z	Grimsey et al.	2002	United Kingdom
27	A1	Wang et al.	2000	China
28	B1	Akintoye et al.	1998	United Kingdom
29	C1	Li and Zou	2012	Worldwide
30	C2	Badala et al.	2018	Worldwide

APPENDIX D: RISK DEFINITIONS

Definition of risks

#	Risk factors	Definition	Risk group
4	Corruption and bribery	Happens in the case the local government is corrupt and asks for bribes or unjust rewards	Political
5	Nationalization/Expropriation	Happens when the public partner unreasonably takes over the facility operated by the private partner without giving the latter the proper compensation	Political
6	Poor financial market	This happens in the case of unavailability of financial instrument resulting in difficulty in financing the project	Economic and Financing
7	Inflation	Happens in case the local economic and banking system in the country is immature which leads to an unexpected local inflation rate	Economic and Financing
8	Interest rate	Happens in case the local economic and banking system in the country is immature which leads to an unexpected fluctuation in the interest rate	Economic and Financing
11	Change in tax regulation	Happens in cxase the government applies tax regulations in an inconsistent way.	Economic and Financing
12	Public opposition	Objection from the public	Stakeholders' issue
13	Environment	Stringent regulations regarding the environment which will have an impact on construction.	Natural
14	Force Majeure	Unforeseen adverse conditions out of the control of both parties such as flood, fires, hurricanes, storms, epidemic diseases, wars and hostilities	Natural
15	Weather	Unforeseen adverse weather conditions	Natural
16	Geological conditions	Unforeseen ground conditions	Construction
26	Delay in approval and permits	This happens when any of the project's approvals or permits are delayed	Political
32	Operation cost overrun	This happens as a result of inadequate planning, low efficiency or improper measurement	Operation
36	Residual asset risk	This happens at the end of the concession period in case the project transferred from the private partner to the public partner is not running properly	Operation
38	Lack of communication between stakeholders	Poor communication or organization among stakeholders leading to increased disputes causing parties to incur additional cost and/or time	Stakeholders' issue
44	Change in law	Happens when the government applies, in an inconsistent way, new laws and regulations	Political/Legal/Financial
49	Construction/design changes	This happens in case of changes and/or errors in the design/construction due to poor study of the project	Construction/Design
53	Construction completion	This happens when the construction period exceeds the planned period, exceeds the planned budget or is performed below the required quality	Construction
54	Supporting utilities risk	This happens when the supporting utilities such as: water, electricity used in the construction and/or operation are not timely available or are available at a higher rate that anticipated.	Construction
66	Tariff change	Happens in case of unsufficient project income leading to a change in tariff as it was originally not adequately designed.	Market
67	Market demand change/Demand below anticipation	Happens when the demand for the project changes for various factors except the exclusive right	Market/Operation
68	Exclusivity	The presence of another "competitive" project	Market
69	Foreign currency exchange	Happens in the case of currency exchange fluctuation	Economic
79	Need for land acquisition	This happens when the project land is unavailable or cannot be occupied at the required time	Stakeholders' issue
82	Poor public decision making process	This happens when the government lacks a long term view and lacks adequate PPP experience or makes decisions based on personal interests	Political/Feasibility study
83	Sanction	A type of damages that can be applied by one party over the other in case of non-compliance with contract terms and conditions	Political
85	Competition	This happens when the government does not offer the "exclusive right" or does not honor its commitment and build another competitive project.	Market
90	Government intervention	Means the unjustified intervention of the government in the matters of the private facility	Political
91	Government reliability	Means the credibility that the government will honor their responsibilities in the future	Construction
92	Third-party reliability	Means the credibility that a third party will honor their responsibilities in the future	Construction
93	Immature juristic system	Happens in case the PPP law is absent or recent	Legal
94	Improper contract	This happens when the contract's terms and conditions are not drafted in a proper way, stakeholders are not defined, risks are not adequately allocated between projects stakehodlers	Legal
95	Delay in supply	This happens when the suppliers and subcontractors are unable to supply work on time	Construction
96	Technological risk	This happens when the technology used is inadequate to the project or not good enough	Operation
97	Payment risk	This happens when the end user/consumer or even the government is not willing to pay due to several reasons (economic, social, etc.)	Economic and financing
98	Uncompetetive tender	The absence of a standardized transparent model for tender to PPP projects in each country	Political
99	Consortium inability	The project company is unable to fulfill its obligations set for in the PPP terms and conditions	Operation
100	Private investor change	This happens when one or more of the investors exit the consortium and the projects due to disputes, poor relationship among the stakeholders or due to any other reason.	Stakeholders' issue
101	Subjective evaluation	Subjective evaluation and design of the concession period, market demand, tariff structure, etc.	Stakeholders' issue
102	Insufficient financial audit	The government is doing the necessary monitoring over the financial aspect of the project company throughout the project's lifetime	Economic and financing

APPENDIX E: RISKS MAPPED TO THEIR CORRESPONDING COUNTRIES

Risks mapped to their corresponding countries

	Risk factors	Hong Kong	Hong Kong	Hong Kong	Hong Kong	Scotland	UK	UK	UK	Australia	Australia	Australia	Australia	China & Australia	China	China	China	China	China	India	India	Singapore	South Africa	Iran	Indonesia	Malysia	Thailand	Portugal	Worldwide	Worldwide	Worldwide	Worldwide	Risk Group
1	Lack of support from government					*						*		*		*					*	*							*				Stakeholders' issue
2	Unstable government			*					*	*	*			*			*	*				*	*	*									Political
3	Strong political interference	*			*				*				*			*						*								*			Political
4	Corruption and bribery	*							*					*	*	*						*											Political
5	Nationalization/Expropriation	*		*					*	*	*		*		*	*	*	*				*	*						*	*			Political
6	Poor financial market						*		*					*	*					*		*						*			*		Economic and Financing
7	Inflation	*		*	*		*	*	*	*	*	*		*	*	*	*	*	*	*		*	*	*	*		*	*	*		*		Economic and Financing
8	Interest rate	*		*			*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*			*	*	*	*	*		Economic and Financing
9	Lack of legal/regulatory framework				*											*						*								*			Legal
10	Inconsistent legal framework	*			*	*			*				*			*						*							*				Legal
11	Change in tax regulation	*					*	*	*			*	*		*	*			*	*		*					*	*	*	*	*		Economic and Financing
12	Public opposition			*		*	*		*	*	*	*		*		*	*	*	*	*		*	*	*					*		*		Stakeholders' issue
13	Environment					*	*	*	*						*	*			*	*		*		*				*			*		Natural
14	Force Majeure	*		*		*		*	*	*	*	*	*		*	*	*	*	*	*		*	*	*					*		*		Natural
15	Weather			*					*	*	*		*		*	*	*	*	*	*		*	*	*							*		Natural
16	Geological conditions			*					*	*	*	*	*		*	*	*	*	*			*	*								*		Construction
17	Construction delays								*				*			*					*	*		*					*				Construction
18	Site safety and security			*					*	*	*			*			*	*				*	*										Construction
19	Poor quality workmanship			*			*		*	*	*						*	*	*			*	*								*		Construction
20	Construction cost overrun			*			*	*	*	*	*						*	*	*	*	*	*	*	*				*			*		Construction
21	Excessive contract variation						*		*										*			*									*		Construction
22	Material availability	*		*	*				*	*	*	*	*			*	*	*	*			*	*	*		*		*	*		*		Construction
23	Availability of finance			*	*				*	*	*	*		*		*	*	*			*	*	*										Construction
24	High finance cost			*			*	*	*	*	*						*	*	*			*	*					*		*	*		Construction
25	Financial attraction of project to investors								*													*											Economic and financing
26	Delay in approval and permits			*	*		*		*	*	*	*	*		*	*	*	*	*	*		*	*					*			*		Political
27	Design deficiency			*	*		*	*	*	*	*	*		*			*	*		*		*	*	*		*		*		*	*		Design
28	Scope variation				*	*						*				*						*											Design
29	Unproven engineering techniques			*				*	*	*	*		*			*	*	*				*	*						*		*		Construction and design
30	Level of demand for project	*				*	*		*					*		*					*	*						*	*	*	*		Feasibility study
31	Site availibility			*					*	*	*					*	*	*			*	*	*	*					*				Construction
32	Operation cost overrun			*		*	*	*	*	*	*		*		*		*	*	*	*		*	*	*			*	*	*		*		Operation
33	Low operation productivity			*					*	*	*						*	*				*	*	*	*		*						Operation
34	Maintenance cost higher than expected			*					*	*	*	*					*	*				*	*				*						Operation
35	Maintenance more frequent than expected			*					*	*	*	*					*	*				*	*				*						Operation
36	Residual asset risk			*					*	*	*		*		*	*	*	*				*	*				*						Operation
37	Indequate PPP experience				*				*													*										*	Stakeholders' issue
38	Lack of communication between stakeholders				*				*			*	*		*	*						*		*		*							Stakeholders' issue
39	Inadequate distribution of responsibilities				*				*				*									*								*		*	Stakeholders' issue
40	Inadequate distribution of authorities				*				*													*											Stakeholders' issue
41	Lack of commitment between parties	*							*													*										*	Stakeholders' issue
42	Differences in working methods								*													*										*	Stakeholders' issue
43	Termination of concession by government			*						*	*						*	*					*	*									Political
44	Change in law			*			*	*		*	*	*			*		*	*	*	*			*	*			*	*			*		Political/Legal/Financial
45	Influential economic events			*						*	*	*					*	*					*										Political
46	Change in industrial code of practice			*						*	*						*	*					*										Political and construction
47	Insolvency of Subcontractors			*			*			*	*						*	*	*				*								*		Construction
48	Labor availability			*						*	*						*	*	*				*	*		*		*			*		Construction
49	Construction/design changes			*			*	*		*	*	*			*		*	*		*			*		*			*			*		Construction/Design
50	Labor disputes/strikes			*						*	*						*	*					*										Construction
51	Land use			*						*	*						*	*					*										Construction
52	Waste of materials			*						*	*						*	*					*										Construction
53	Construction completion			*			*	*		*	*				*		*	*	*	*			*					*			*		Construction
54	Supporting utilities risk			*						*	*				*		*	*					*										Construction
55	Protection of geological and historical objects			*						*	*						*	*					*										Construction
56	Operator default			*						*	*						*	*					*	*			*						Operation
57	Quality of operation			*						*	*						*	*					*				*						Operation
58	Condition of facility			*						*	*						*	*					*				*						Operation
59	Contractual risk			*						*	*						*	*					*				*						Legal
60	Third party tort liability			*						*	*						*	*					*				*					*	Stakeholders' issue
61	Ownership assets			*						*	*						*	*					*	*			*						Legal
62	Insolvency of Concession company			*						*	*	*					*	*					*				*						Legal
63	Insufficient income			*						*	*						*	*					*	*									Market
64	Fluctuation of material cost (by government)			*						*	*						*	*					*										Market
65	Fluctuation of material cost (by private sector)			*						*	*						*	*					*										Market
66	Tariff change			*						*	*				*		*	*					*										Market
67	Market demand change/Demand below anticipation			*			*	*		*	*	*			*		*	*	*	*			*	*				*			*		Market/Operation
68	Exclusivity			*			*			*	*						*	*		*			*					*			*		Market
69	Foreign currency exchange			*						*	*				*		*	*					*	*			*						Economic
70	Residual risk			*			*			*	*	*					*	*					*					*			*		Operation
71	Changes in value of granted land due to development																							*			*						Economic
72	Changes in value of granted land due to inflation																							*			*						Economic
73	Financial problems due to environmental protection																							*			*						Economic
74	Need for land appraisal																							*			*						Economic
75	Limited capital																							*			*						Economic
76	Delay in resolving contractual dispute											*												*									Stakeholders' issue
77	Inadequate study and unsufficient data																							*			*						Legal
78	Lack of standard model for PPP agreements																							*			*						Legal
79	Need for land acquisition						*					*			*				*	*				*				*			*		Stakeholders' issue
80	Delay in resolving litigation or arbitration dispute											*												*			*						Legal
81	Influencial economic events																							*									Political
82	Poor public decision making process							*							*									*							*		Political/Feasibility study
83	Sanction																							*									Political
84	Arbitrary definition of tariff of services by government																							*									Market
85	Competition											*			*									*									Market
86	Operating revenues below expectation						*	*				*							*	*				*				*			*		Market/Operation
87	Lack of coordination and commitment																							*								*	Stakeholders' issue
88	Need for environmental approval																							*			*						Legal
89	Third party delays																							*									Stakeholders' issue
90	Government intervention														*																		Political
91	Government reliability						*	*							*				*	*											*		Construction
92	Third-party reliability						*	*							*				*	*											*		Construction
93	Immature juristic system														*																		Legal
94	Improper contract														*																		Legal

Risks mapped to their corresponding countries

	Risk factors	Hong Kong	Hong Kong	Hong Kong	Hong Kong	Scotland	UK	UK	UK	Australia	Australia	Australia	Australia	China & Australia	China	China	China	China	China	India	India	Singapore	South Africa	Iran	Indonesia	Malysia	Thailand	Portugal	Worldwide	Worldwide	Worldwide	Worldwide	Risk Group
95	Delay in supply														*																		Construction
96	Technological risk						*	*							*				*	*											*		Operation
97	Payment risk														*																		Economic and financing
98	Uncompetetive tender														*																		Political
99	Consortium inability						*								*				*	*											*		Operation
100	Private investor change											*			*																		Stakeholders' issue
101	Subjective evaluation														*																		Stakeholders' issue
102	Insufficient financial audit														*																		Economic and financing
103	Change in output specification											*																					Design
104	Innovative design											*																					Design
105	Design complexity											*																					Design
106	Constructability											*																					Construction
107	Defects in construction											*																					Construction
108	Delay in operation											*															*						Operation
109	Excessive maintenance and refurbishment											*															*						Operation
110	Filre/delay in commissioning test											*																					Commissioning risks
111	Technical obsolescence											*																					Market
112	Misunderstanding the role of stakeholders											*																					Stakeholders' issue
113	Misinterpretation of contract											*																					Stakeholders' issue
114	Stakeholder management																									*							Stakeholders' issue
115	Low financial attraction of project to investors						*	*												*								*			*		Economic and Financing
116	Inadequate negotiation period prior to initiation																													*		*	Stakeholders' issue
117	Staff crisis																													*		*	Stakeholders' issue
118	Cultural differences between main stakeholders																													*		*	Stakeholders' issue

APPENDIX F: DATA CLEANING AND TRANSFORMATION FOR PROJECTS GENERAL DATA

Data Cleaning and transformation for projects' general data

Statistical Analysis and Normalization

Dataset 1: Traditional Projects	Project #	Primary purpose	Project scope	Cost	Original duration (months)	Final duration	Delay (months)	% Delay
	1	infrastructure	Upgrade	25,657,895.00	16	22	6	37.5
	2	infrastructure	Refurbishment	13,589,460.00	13	18	5	38.5
	3	infrastructure	Replace	347,751,310.00	45	54	9	20
	4	Electricity	New-build	776,500,000.00	9	10	1	11.1
	5	Electricity	New-build	343,500,000.00	8	10	2	25
	6	Electricity	Upgrade	233,433,089.00	29	32	3	10.3
	7	Electricity	Upgrade	527,687,890.00	30	32	2	6.7
	8	wastewater	New-build	130,000,000.00	26	32	6	23.1
	9	wastewater	New-build	118,000,000.00	24	26	2	8.3
	10	other	Upgrade	15,435,000.00	20	30	10	50

	Original duration (months)	Final duration	Delay (months)	% Delay
Mean	22	26.6	4.6	23.05
Standard Deviation	11.3	12.9	3.1	14.8
Median	22	28	4	21.5
Minimum set value	-0.59	0.81	-1.67	-6.58
Maximum Set value	44.6	52.4	10.9	52.7

	Original duration (months)	Final duration	Delay (months)	% Delay
Actual Minimum value	8	10	1	6.7
Actual Maximum value	45	54	10	50

Normalization for Dataset 1

Dataset 1: Traditional Projects	Project #	Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
	1	16	0.216	22	0.273	6	0.556	37.5	0.712
	2	13	0.135	18	0.182	5	0.444	38.5	0.734
	3	45	1.000	54	1.000	9	0.889	20	0.308
	4	9	0.027	10	0.000	1	0.000	11.1	0.103
	5	8	0.000	10	0.000	2	0.111	25	0.423
	6	29	0.568	32	0.500	3	0.222	10.3	0.085
	7	30	0.595	32	0.500	2	0.111	6.7	0.000
	8	26	0.486	32	0.500	6	0.556	23.1	0.379
	9	24	0.432	26	0.364	2	0.111	8.3	0.038
	10	20	0.324	30	0.455	10	1.000	50	1.000

Dataset 2: PPP projects	Project #	Primary purpose	Project scope	Cost	Original duration (months)	Final duration	Delay (months)	% Delay
	1	Wastewater	New-build	140,000,000.00	21	23	2	9.5
	2	Electricity	New-build	380,000,000.00	44	50	6	13.6

	Original duration (months)	Final duration	Delay (months)	% Delay
Mean	32.5	36.5	4	11.58
Standard Deviation	16.26	19.09	2.83	2.91
Median	32.5	36.5	4	11.58
Minimum set value	-0.03	-1.68	-1.66	5.76
Maximum Set value	65.03	74.68	9.66	17.40

	Original duration (months)	Final duration	Delay (months)	% Delay
Actual Minimum value	21	23	2	9.5
Actual Maximum value	44	50	6	13.6

Normalization for Dataset 2

Dataset 2: PPP Projects	Project #	Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
	1	21	0.000	23	0.000	2	0.000	9.5	0.000
	2	44	1.000	50	1.000	6	1.000	13.6	1.000

APPENDIX G-A: OVERALL RISK MATRIX – TRADITIONAL PROJECTS

Dataset # 1 (Traditional projects)

	#	Risk factors	1		2		3		4		5		6		7		8		9		10	
			Occurrence	Magnitude	Occurrence	Magnitude	Occurrence	Magnitude	Occurrence	Magnitude	Occurrence	Magnitude	Occurrence	Magnitude	Occurrence	Magnitude	Occurrence	Magnitude	Occurrence	Magnitude	Occurrence	Magnitude
Stakeholder Risks	1	Public opposition																				
	2	Lack of communication between stakeholders	√	15	√	12																
	3	Third party tort liability			√	10	√	12.96	√	13.33	√	8.33	√	8.89	√	8.33					√	8.33
	4	Need for land acquisition					√	11.11			√	8.33	√	7.78	√	11.67	√	50			√	20
	5	Lack of support from government			√	13.33	√	18.52	√	20	√	8.33	√	7.78	√	11.67	√	50			√	20
	6	Inadequate distribution of responsibilities									√	5	√	8.89	√	13.33					√	5
	7	Inadequate PPP experience																				
	8	Lack of commitment between parties																				
	9	Inadequate distribution of authorities									√	5	√	8.89	√	13.33					√	5
	10	Differences in working methods/Knowhow between parties							√	10												
	11	Delay in resolving contractual dispute	√	14.44	√	12.67	√	6.67	√	10	√	10	√	8.89	√	8.33	√	6.67	√	50	√	20.67
	12	Lack of coordination	√	19.45	√	6.67	√	16.67	√	10	√	8.33	√	4.44	√	5	√	6.11	√	16.67	√	17.33
	13	Private investor change																				
	14	Third party delays			√	8	√	12.96	√	13.33		8.33	√	8.89	√	8.33					√	8.33
	15	Subjective evaluation																				
	16	Misunderstanding the role of stakeholders																				
	17	Misinterpretation of contract			√	11.33																
	18	Stakeholder management									√	5	√	8.89	√	13.33					√	5
	19	Inadequate negotiation period prior to initiation																				
	20	Staff crisis					√	6.3					√	6.67								
	21	Cultural differences between main stakeholders																				
	#	Risk factors																				
Construction Risks	22	Material availability			√	8																
	23	Construction cost overrun	√		√		√		√		√		√		√		√		√		√	
	24	Geological conditions					√	7.04	√	10	√	6.67	√	4.44	√	11.67						
	25	High finance cost					√	18.52	√	6.67	√	10	√	6.67	√	10	√	17.78	√	13.33	√	4
	26	Availability of finance					√	18.52	√	6.67	√	10	√	6.67	√	10	√	17.78	√	13.33	√	4
	27	Construction completion	√	100	√	100	√	100	√	100	√	100	√	100	√	100	√	100	√	100	√	100
	28	Site availability			√	10		11.11			√	8.33	√	7.78	√	11.67	√	50			√	20
	29	Poor quality workmanship			√	12	√	5.56	√	16.67		10	√	11.11	√	13.33					√	4.33
	30	Labor availability	√	3.33																		
	31	Site safety and security											√	6.67								
	32	Insolvency of Subcontractors									√	8.33	√	13.33							√	8.33
	33	Construction delays			√	12	√	5.56	√	16.67	√	10	√	11.11	√	13.33					√	4.33
	34	Supporting utilities risk	√	3.89																		
	35	Labor disputes/strikes											√	6.67								
	36	Land use															√	50				
	37	Waste of materials									√	8.33	√	10	√	11.67	√	5				
	38	Protection of geological and historical objects																				
	39	Government reliability					√	18.52	√	6.67	√	10	√	6.67	√	10	√	17.78	√	13.33	√	4
	40	Third-party reliability			√	10	√	12.96			√	16.66	√	22.22	√	8.33						
	41	Excessive contract variation	√	15.56	√	6.67	√	16.67	√	10	√	8.33	√	17.78	√	5	√	6.11	√	16.67	√	17.33
	42	Delay in supply	√	15																		
	43	Constructability																				
	44	Defects in construction			√	12	√	5.56	√	16.67	√	10	√	11.11	√	13.33					√	4.33

Mean	23.334	Mean	16.311	Mean	16.956	Mean	17.779	Mean	12.877	Mean	12.890	Mean	14.840	Mean	31.436	Mean	31.904	Mean	14.753
Standard Deviation	31.5	Standard Deviation	23.3	Standard Deviation	21.3	Standard Deviation	23.1	Standard Deviation	19.6	Standard Deviation	18.6	Standard Deviation	19.7	Standard Deviation	29.0	Standard Deviation	32.8	Standard Deviation	21.7
Median	15	Median	11.33	Median	12.96	Median	10	Median	8.33	Median	8.89	Median	11.67	Median	17.78	Median	16.67	Median	8.33
Minimum set value	-39.68	Minimum set value	-30.19	Minimum set value	-25.69	Minimum set value	-28.45	Minimum set value	-26.34	Minimum set value	-24.23	Minimum set value	-24.53	Minimum set value	-26.51	Minimum set value	-33.74	Minimum set value	-28.66
Maximum Set value	86.4	Maximum Set value	62.8	Maximum Set value	59.6	Maximum Set value	64.0	Maximum Set value	52.1	Maximum Set value	50.0	Maximum Set value	54.2	Maximum Set value	89.4	Maximum Set value	97.5	Maximum Set value	58.2

Actual Minimum value	3.33	Actual Minimum value	6.67	Actual Minimum value	5.56	Actual Minimum value	6.67	Actual Minimum value	5	Actual Minimum value	4.44	Actual Minimum value	5	Actual Minimum value	5	Actual Minimum value	13.33	Actual Minimum value	4
Actual Maximum value	100	Actual Maximum value	100	Actual Maximum value	100	Actual Maximum value	100	Actual Maximum value	100	Actual Maximum value	100	Actual Maximum value	100	Actual Maximum value	100	Actual Maximum value	100	Actual Maximum value	100

After Outlier removal		After Outlier removal		After Outlier removal		After Outlier removal		After Outlier removal		After Outlier removal		After Outlier removal		After Outlier removal				After Outlier removal	
Mean	12.381	Mean	10.334	Mean	12.071	Mean	11.906	Mean	8.729	Mean	9.26	Mean	10.5825	Mean	25.20			Mean	10.02
Standard deviation	6.219	Standard deviation	2.229	Standard deviation	5.171	Standard deviation	4.279	Standard deviation	2.466	Standard deviation	3.967465514	Standard deviation	2.6640627	Standard deviation	20.26			Standard deviation	6.90
Median	15	Median	10.665	Median	12.96	Median	10.000	Median	8.33	Median	8.89	Median	11.67	Median	17.78			Median	6.665

Actual Minimum value	3.33	Actual Minimum value	6.67	Actual Minimum value	5.56	Actual Minimum value	6.67	Actual Minimum value	5	Actual Minimum value	4.44	Actual Minimum value	5	Actual Minimum value	5			Actual Minimum value	4
Actual Maximum value	19.45	Actual Maximum value	13.33	Actual Maximum value	18.52	Actual Maximum value	20	Actual Maximum value	16.66	Actual Maximum value	22.22	Actual Maximum value	13.33	Actual Maximum value	50			Actual Maximum value	20.67

APPENDIX G-B: OVERALL RISK MATRIX – PPP PROJECTS

Dataset # 2 (PPP projects)

#	Risk factors	1 Magnitude	2 Magnitude	Mean	Standard deviation	Actual minimum value	Actual Maximum value
1	Public opposition						
2	Lack of communication between stakeholders						
3	Third party tort liability	20		20			
4	Need for land acquisition		5.56	5.56			
5	Lack of support from government	28.33	5.56	16.945	16.1008214	5.56	28.33
6	Inadequate distribution of responsibilities		8.33	8.33			
7	Inadequate PPP experience	33.33	28.33	30.83	3.53553391	28.33	33.33
8	Lack of commitment between parties		16.67	16.67			
9	Inadequate distribution of authorities		8.33	8.33			
10	Differences in working methods/Knowhow between parties						
11	Delay in resolving contractual dispute						
12	Lack of coordination		20.56	20.56			
13	Private investor change						
14	Third party delays	20		20			
15	Subjective evaluation		10	10			
16	Misunderstanding the role of stakeholders	33.33	10	21.665	16.4968012	10	33.33
17	Misinterpretation of contract						
18	Stakeholder management		8.33	8.33			
19	Inadequate negotiation period prior to initiation	33.33	10	21.665	16.4968012	10	33.33
20	Staff crisis						
21	Cultural differences between main stakeholders	28.33		28.33			
#	Risk factors						
22	Material availability						
23	Construction cost overrun						
24	Geological conditions						
25	High finance cost		6.11	6.11			
26	Availability of finance		6.11	6.11			
27	Construction completion	100		100			
28	Site availability		5.56	5.56			
29	Poor quality workmanship						
30	Labor availability						
31	Site safety and security						
32	Insolvency of Subcontractors						
33	Construction delays		7.22	7.22			
34	Supporting utilities risk						
35	Labor disputes/strikes						
36	Land use						
37	Waste of materials	13.33		13.33			
38	Protection of geological and historical objects						
39	Government reliability		6.11	6.11			
40	Third-party reliability	20		20			
41	Excessive contract variation		20.56	20.56			
42	Delay in supply						
43	Constructability						
44	Defects in construction						

APPENDIX H-A: DELAY EVENT DETAILS- TRADITIONAL PROJECTS

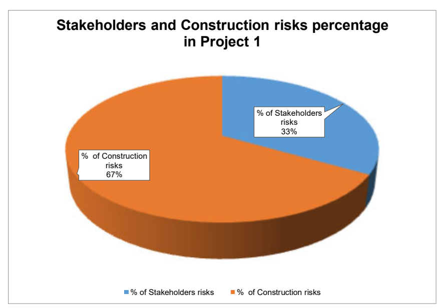
Dataset # 1 (Traditional projects)

Project 1							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
16	0.216	22	0.273	6	0.556	37.5	0.712

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						% Contribution to total delay of the project (180 days)
	Direct effect (days)	Delay analysis method used	Combined Effect on final duration (days)	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	
Delay events															
Late purchase of IT racks by Contractor	35	TIA	20	The Engineer specified its intention to change the type of IT racks. The Contractor inquired about the type of the racks several times but the Engineer did not reply on time which delayed the Contractor.	Stakeholders Construction	Lack of communication between stakeholders Delay in Supply	Owner /Engineer	Contractor	√	√	√	-	-	√ (Schedule update)	11.11
Delay in installation of glass partitions	18	TIA	6	The glass partitions were not installed by the Contractor on time due to a lack of specialized personnel	Construction	Labor availability	Contractor	-	√	√	-	-	-	√ (Schedule update)	3.33
Recent modifications raised by Owner	54	TIA	28	There were several modifications raised by the Owner in the design which affected many subsequent activities such as construction, purchase of materials, etc. Such modifications were introduced late in the project which caused also rework activities.	Stakeholders Construction	Lack of coordination Excessive contract variation	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	15.56
Late application for permanent power by Contractor	15	TIA	7	The Contractor did not apply for permanent power on time which delayed the delivery of permanent power to the Site.	Stakeholders Construction	Lack of communication between Stakeholders Lack of coordination Supporting utilities risk Delay in supply	Contractor	-	√	√	-	-	√	√ (Schedule update)	3.89
Unresolved claims	40	TIA	26	There have been several unresolved claims which were pending for a long time. The Owner took longer than expected to respond and there have been several negotiation meetings without reaching a concrete resolution.	Stakeholders	Delay in resolving contractual dispute	Owner	-	√	√	√	√	√	√ (Schedule update)	14.44
Construction completion	-	-	87	As the project suffered from delays, it is evident that the construction period exceeded the planned period.	Construction	Construction completion	Owner /Contractor	-	√	√	√	√	√	√ (Schedule update)	100.00
Additional incurred costs	-	-	-	This risk is associated with the additional costs incurred during construction. Cost overruns occur when the costs being incurred are in excess of the amounts that have been budgeted for.	Construction	Construction Cost overruns	Owner /Contractor	Owner /Contractor	√	√	√	√	√	-	-
Total (Construction + Stakeholders)			87												48.33

Number of Stakeholders risks	Number of Construction risks	Total
3	6	9

% of Stakeholders risks	% of Construction risks
33.33	66.67



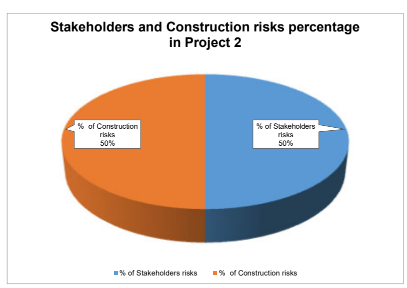
Dataset # 1 (Traditional projects)

Project 2							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
13	0.135	18	0.182	5	0.444	38.462	0.734

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						% Contribution to total delay of the project (150 days)
	Direct effect (days)	Delay analysis method used	Combined Effect on final duration (days)	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	
Delay events															
Subcontractor´s delays	30	Impacted As-planned	15	There has been several delays caused by the Subcontractor responsible for pipe installation	Stakeholders Construction	Third party tort liability Third party delays Third party reliability	Subcontractor (Third Party) Subcontractor (Third Party)	Contractor Contractor	√ √	√ √	√ √	√ √	√ √	√ (Schedule update) √ (Schedule update)	10.00
Delays in access to site	15	Impacted As-planned	15	The date on which the Contractor should have given access to the Site was delayed.	Construction	Site availability	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	10.00
Unresolved claims	40	Impacted As-planned	19	There have been several unresolved claims which were pending for a long time. The Owner took longer than expected to respond and there have been several negotiation meetings without reaching a concrete resolution.	Stakeholders	Delay in resolving contractual dispute	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	12.67
Instructions that were communicated from the Owner to the Engineer and were not communicated on time to the Contractor	31	Impacted As-planned	18	There was a problem in the transfer of information from the Owner to the Contractor through the Engineer which delayed the project.	Stakeholders	Lack of communication between stakeholders	Engineer	Owner	√	-	√	-	√	√ (Schedule update)	12.00
Modifications raised by Owner	27	Impacted As-planned	10	There were several modifications raised by the Owner in the design which affected many subsequent activities such as construction, purchase of materials, etc. Such modifications were introduced late in the project which caused also rework activities.	Stakeholders Construction	Lack of coordination Excessive contract variation	Owner /Engineer	Contractor	√	√	√	√	√	√ (Schedule update)	6.67
Shortage in the type pf manhole covers required by the Employer	30	Impacted As-planned	12	The manhole covers required by the Owner were not readily available and there has been a problem in their production overseas which delayed their delivery and several subsequent activities. Meanwhile, the Owner did not accept alternatives.	Construction Stakeholders	Material availability Third party delays	Supplier	-	√	√	-	√	√	√ (Schedule update)	8.00
Discrepancy between contract documents	21	Impacted As-planned	17	There has been some conflicting information between the drawings and the specifications and the Contractor, erroneously, did the pricing based on the wrong priority of documents in the tender stage which caused subsequent delays in the execution stage.	Stakeholders	Misinterpretation of contract	Contractor	-						√ (Schedule update)	11.33
Permits issue	20	Impacted As-planned	20	The Contractor faced delays in obtaining the relevant permits for the project. When the Contractor contacted the Owner, the latter specified that it is the role of the Contractor to obtain such permit and that the Owner shall only provide "reasonable assistance". The lack of support from the Owner delayed the project.	Stakeholders	Lack of support from government	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	13.33
Problems in construction	18	Impacted As-planned	18	There were problems in some of the items constructed by the Contractor as they did not pass the necessary tests. Such defective works needed rework by the Contractor which caused subsequent delays.	Construction	Poor quality workmanship Defects in Construction Construction delays	Contractor	-	√	√	√	√	√	√ (Schedule update	12.00
Construction completion	-	Impacted As-planned	144	As the project suffered from delays, it is evident that the construction period exceeded the planned period.	Construction	Construction completion	Owner /Contractor	-	√	√	√	√	√	√ (Schedule update)	100.00
Additional incurred costs	-	-	-	This risk is associated with the additional costs incurred during construction. Cost overruns occur when the costs being incurred are in excess of the amounts that have been budgeted for.	Construction	Construction Cost overruns	Owner /Contractor	Owner /Contractor	√	√	√	√	√	-	-
Total (Construction + Stakeholders)			**144**												**96.00**

Number of Stakeholders risks	Number of Construction risks	Total
7	7	**14**

% of Stakeholders risks	% of Construction risks
50.00	50.00



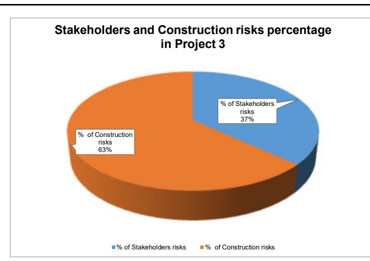
Dataset # 1 (Traditional projects)

Project 3							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	%Delay	Normalized delay %
45	1.000	54	1.000	9	0.889	20.000	0.308

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						% Contribution to total delay of the project (270 days)
Delay events	Direct effect (days)	Delay analysis method used	Combined Effect on final duration (days)	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	
Subcontractor´s delays	50	Impacted As-planned	35	There has been several delays caused by the Subcontractor responsible for cables installation	Stakeholders Construction	Third party tort liability Third party delays Third party reliability	Subcontractor (Third Party)	Contractor	√	√	√	√	√	√ (Schedule update)-	12.96
Permits issue	20	Impacted As-planned	20	The Contractor faced delays in obtaining the relevant permits for the project. When the Contractor contacted the Owner, the latter specified that it is the role of the Contractor to obtain such permit and that the Owner shall only provide "reasonable assistance". The lack of support from the Owner delayed the project.	Stakeholders	Lack of support from government	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	7.41
Unresolved claims	30	Impacted As-planned	18	There have been several unresolved claims which were pending for a long time. The Employer took longer than expected to respond and there have been several negotiation meetings without reaching a concrete resolution.	Stakeholders	Delay in resolving contractual dispute	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	6.67
Modifications raised by Client	60	Impacted As-planned	45	There were several modifications raised by the Owner in the design which affected many subsequent activities such as construction, purchase of materials, etc. Such modifications were introduced late in the project which caused also rework activities.	Stakeholders Construction	Lack of coordination Excessive contract variation	Owner /Engineer	Contractor	√	√	√	√	√	√ (Schedule update)	16.67
Departure of the project manager	25	Impacted As-planned	17	There has been an unplanned and unforeseen departure of the project manager which caused delays on site	Stakeholders	Staff crisis	Contractor	-	√	√	√	√	√	√ (Schedule update)	6.30
Delayed payments by the Owner	70	Impacted As-planned	50	The project owner faced severe financing problems due to the floating problem that occurred in Egypt in 2016. This problem affected the Contractor along with Subcontractors.	Construction	High Finance cost Availability of finance Government reliability	Supplier	-	√	√	√	√	√	√ (Schedule update)	18.52
Soil issues	25	Impacted As-planned	19	There were subsurface soil conditions which were not discovered during the due diligence and which needed further studies from the Contractor´s side	Construction	Geological Conditions	-	-	√	√	-	√	√	√ (Schedule update)	7.04
There were delays in site handing over to the Contractor	45	Impacted As-planned	30	The Owner delayed the site handing over to the Contractor and delayed giving the latter access to the Site	Stakeholders Construction	Lack of support from government Need for land acquisition Site availability	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	11.11
Defected items in construction and rework to remedy such defects	20	Impacted As-planned	15	There were several defects that were discovered by the Engineer in the construction procedures which needed rework from the Contractor´s side. Tests needed to be repeated for defected items.	Construction	Poor quality workmanship Defects in Construction Construction delays	Contractor	-	√	√	-	-	√	√ (Schedule update)	5.56
Construction completion	-	Impacted As-planned	249	As the project suffered from delays, it is evident that the construction period exceeded the planned period.	Construction	Construction completion	Owner /Contractor	-	√	√	√	√	√	√ (Schedule update)	100.00
Additional incurred costs	-	-	-	This risk is associated with the additional costs incurred during construction. Cost overruns occur when the costs being incurred are in excess of the amounts that have been budgeted for.	Construction	Construction Cost overruns	Owner /Contractor	Owner /Contractor	√	√	√	√	√	-	-
Total (Construction + Stakeholders)			249												92.22

Number of Stakeholders risks	Number of Construction risks	Total
7	12	19

% of Stakeholders risks	% of Construction risks
36.84	63.16



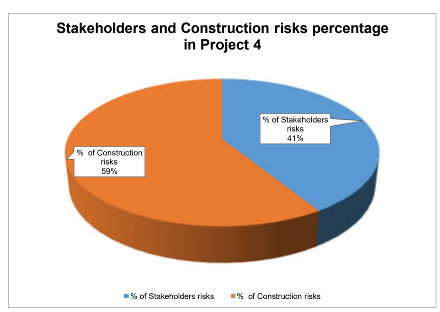
Dataset # 1 (Traditional projects)

Project 4							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
9	0.027	10	0.000	1	0.000	11.100	0.103

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						
	Direct effect (days)	Delay analysis method used	Combined Effect on final duration (days)	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	% Contribution to total delay of the project (30 days)
Delay events															
Negotiations regarding the mounting of one of the generators.	10	Impacted As-planned	3	The Owner/Engineer instructed the Contractor to perform the mounting of one of the generators. However, the Contractor proposed an alternative method. Negotiations were held between both parties until reaching a resolution.	Stakeholders	Differences in working methods/ knowhow between the parties	Owner /Engineer and Contractor	-	√	√	√	√	√	√ (Schedule update)	10.00
Accident turbine	20	Impacted As-planned	4	During transportation, an accident occurred to the steam turbine. It was the supplier´s fault. The damages were not severe but the turbine needed few repairs.	Stakeholders	Third party tort liability Third party delays	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	13.33
Permits issue	5	Impacted As-planned	3	The Contractor faced delays in obtaining the relevant permits for the project. When the Contractor contacted the Owner, the latter specified that it is the role of the Contractor to obtain such permit and that the Owner shall only provide "reasonable assistance". The lack of support from the Owner delayed the project.	Stakeholders	Lack of support from government	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	10.00
Unresolved claims	10	Impacted As-planned	3	There have been several unresolved claims which were pending for a long time. The Employer took longer than expected to respond and there have been several negotiation meetings without reaching a concrete resolution.	Stakeholders	Delay in resolving contractual dispute	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	10.00
Modifications raised by Client	12	Impacted As-planned	3	There were several modifications raised by the Owner in the design which affected many subsequent activities such as construction, purchase of materials, etc. Such modifications were introduced late in the project which caused also rework activities.	Stakeholders Construction	Lack of coordination Excessive contract variation	Owner /Engineer	Contractor	√	√	√	√	√	√ (Schedule update)	10.00
Delayed reply by the Owner	10	Impacted As-planned	3	The Owner delayed the Contractor in sending its reply.	Stakeholders	Lack of support from government	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	10.00
Delayed payments by the Owner	9	Impacted As-planned	2	The project owner faced severe financing problems due to the floating problem that occurred in Egypt in 2016. This problem affected the Contractor along with Subcontractors.	Construction	High Finance cost Availability of finance Government reliability	Supplier	-	√	√	√	√	√	√ (Schedule update)	6.67
Soil issues	7	Impacted As-planned	3	There were subsurface soil conditions which were not discovered during the due diligence and which needed further studies from the Contractor´s side	Construction	Geological Conditions	-	-	√	√	-	√	√	√ (Schedule update)	10.00
Defected items in construction and rework to remedy such defects	5	Impacted As-planned	5	There were several defects that were discovered by the Engineer in the construction procedures which needed rework from the Contractor´s side. Tests needed to be repeated for defected items.	Construction	Poor quality workmanship Defects in Construction Construction delays	Contractor	-	√	√	-	-	√	√ (Schedule update)	16.67
Construction completion	-	Impacted As-planned	29	As the project suffered from delays, it is evident that the construction period exceeded the planned period.	Construction	Construction completion	Owner /Contractor	-	√	√	√	√	√	√ (Schedule update)	100.00
Additional incurred costs	-	-	-	This risk is associated with the additional costs incurred during construction. Cost overruns occur when the costs being incurred are in excess of the amounts that have been budgeted for.	Construction	Construction Cost overruns	Owner /Contractor	Owner /Contractor	√	√	√	√	√	-	-
Total (Construction + Stakeholders)			29												96.67

Number of Stakeholders risks	Number of Construction risks	Total
7	10	17

% of Stakeholders risks	% of Construction risks
41.18	58.82



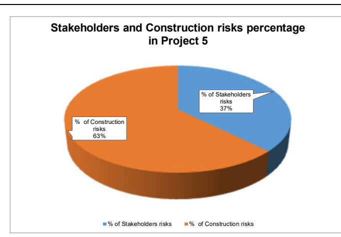
Dataset # 1 (Traditional projects)

Project 5							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
8	0.000	10	0.000	2	0.111	25.000	0.423

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						
	Direct effect (days)	Delay analysis method used	Combined Effect on final duration	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	% Contribution to total delay of the project (60 days)
Delay events															
There were delays in site handing over to the Contractor	45	Impacted As-planned	5	The Owner delayed the site handing over to the Contractor and delayed giving the latter access to the Site	Stakeholders	Lack of support from government Need for land acquisition	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	8.33
					Construction	Site availability									
Subcontractor´s delays	30	Impacted As-planned	5	There has been several delays caused by the Subcontractor responsible for pipe installation	Stakeholders	Third party tort liability Third party delays	Subcontractor (Third Party)	Contractor	√	√	√	√	√	√ (Schedule update)	8.33
					Construction	Third party reliability	Subcontractor (Third Party)	Contractor	√	√	√	√	√	√ (Schedule update)	
Unresolved claims	30	Impacted As-planned	6	There have been several unresolved claims which were pending for a long time. The Employer took longer than expected to respond and there have been several negotiation meetings without reaching a concrete resolution.	Stakeholders	Delay in resolving contractual dispute	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	10.00
Delayed Advance payment by the Owner	15	Impacted As-planned	6	The Owner	Construction	High Finance cost Availability of finance Government reliability	Supplier	-	√	√	√	√	√	√ (Schedule update)	10.00
Delays in access to site	15	Impacted As-planned	5	The date on which the Contractor should have given access to the Site was delayed.	Construction	Site availability	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	8.33
Modifications raised by Client	60	Impacted As-planned	5	There were several modifications raised by the Owner in the design which affected many subsequent activities such as construction, purchase of materials, etc. Such modifications were introduced late in the project which caused also rework activities.	Stakeholders	Lack of coordination	Owner /Engineer	Contractor	√	√	√	√	√	√ (Schedule update)	8.33
					Construction	Excessive contract variation									
Problems in construction	18	Impacted As-planned	6	There were problems in some of the items constructed by the Contractor as they did not pass the necessary tests. Such defective works needed rework by the Contractor which caused subsequent delays.	Construction	Poor quality workmanship Defects in Construction Construction delays	Contractor	-	√	√	√	√	√	√ (Schedule update	10.00
Bankruptcy of one of the Subcontractors	70	Impacted As-planned	5	One of the Subcontractors faced a problem of bankruptcy due to major losses in one of the other projects it was involved in. This matter delayed the works on site as there was a need to restart the subcontracting procedures during the course o the project.	Construction	Insolvency of Subcontractors Third party reliability	Third party (Subcontractor)	-	√	√	√	√	√	√ (Schedule update)	8.33
Waste disposal	30	Impacted As-planned	5	There was a problem with waste disposal on site. The Owner asked the Contractor to dispose waste at an area that is far away from the Site and with the political instabilities, the disposal process was interrupted several times also because this area suffered curfew issues until the issue was resolved.	Construction	Waste of materials	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	8.33
Soil issues	25	Impacted As-planned	4	There were subsurface soil conditions which were not discovered during the due diligence and which needed further studies from the Contractor´s side	Construction	Geological Conditions	-	-	√	√	-	√	√	√ (Schedule update)	6.67
Permits issue	32	Impacted As-planned	3	The Owner requested the Contractor to obtain certain permits which were hard for the Contractor to obtain and which subsequently delayed the Contractor. Getting such permits was a huge responsibility on the Contractor which would be easier if it was obtained by the Owner; especially that the Owner is public so it will be easier for the public sector to obtain specific permits or at least provide reasonable assistance to the Contractor.	Stakeholders	Inadequate distribution of responsibilities Inadequate distribution of authorities Stakeholder management	Owner /Engineer	Contractor	√	√	√	√	√	√ (Schedule update)	5.00
Construction completion	-	Impacted As-planned	55	As the project suffered from delays, it is evident that the construction period exceeded the planned period.	Construction	Construction completion	Owner /Contractor	-	√	√	√	√	√	√ (Schedule update)	100.00
Additional incurred costs	-	-	-	This risk is associated with the additional costs incurred during construction. Cost overruns occur when the costs being incurred are in excess of the amounts that have been budgeted for.	Construction	Construction Cost overruns	Owner /Contractor	Owner /Contractor	√	√	√	√	√	-	-
Total (Construction + Stakeholders)			**55**												**91.67**

Number of Stakeholders risks	Number of Construction risks	Total
9	15	**24**

% of Stakeholders risks	% of Construction risks
37.50	62.50



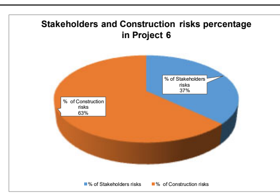
Dataset # 1 (Traditional projects)

Project 6							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
29	0.568	32	0.500	3	0.222	10.300	0.085

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						
Delay events	Direct effect (days)	Delay analysis method used	Combined Effect on final duration	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	% Contribution to total delay of the project (90 days)
Unresolved claims	10	Impacted As-planned	8	There have been several unresolved claims which were pending for a long time. The Owner took longer than expected to respond and there have been several negotiation meetings without reaching a concrete resolution.	Stakeholders	Delay in resolving contractual dispute	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	8.89
There were delays in site handing over to the Contractor	7	Impacted As-planned	7	The Owner delayed the site handing over to the Contractor and delayed giving the latter access to the Site	Stakeholders	Lack of support from government Need for land acquisition	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	7.78
					Construction	Site availability									
Subcontractor´s delays	19	Impacted As-planned	8	There has been several delays caused by the Subcontractor responsible for pipe installation	Stakeholders	Third party tort liability Third party delays	Subcontractor (Third Party)	Contractor	√	√	√	√	√	√ (Schedule update)	8.89
					Construction	Third party reliability	Subcontractor (Third Party)	Contractor	√	√	√	√	√	√ (Schedule update)	
Delayed Advance payment by the Owner	15	Impacted As-planned	6	The Owner delayed the Advance Payment to the Contractor which severely affected the latter´s vash flow.	Construction	High Finance cost Availability of finance Government reliability	Supplier	-	√	√	√	√	√	√ (Schedule update)	6.67
Problems in construction	19	Impacted As-planned	10	There were problems in some of the items constructed by the Contractor as they did not pass the necessary tests. Such defective works needed rework by the Contractor which caused subsequent delays.	Construction	Poor quality workmanship Defects in Construction Construction delays	Contractor	-	√	√	√	√	√	√ (Schedule update	11.11
Bankruptcy of one of the Subcontractors	30	Impacted As-planned	12	One of the Subcontractors faced a problem of bankruptcy due to major losses in one of the other projects it was involved in. This matter delayed the works on site as there was a need to restart the subcontracting procedures during the course o the project.	Construction	Insolvency of Subcontractors Third party reliability	Third party (Subcontractor)	-	√	√	√	√	√	√ (Schedule update)	13.33
Waste disposal	18	Impacted As-planned	9	There was a problem with waste disposal on site. The Owner asked the Contractor to dispose waste at an area that is far away from the Site and with the political instabilities, the disposal process was interrupted several times also because this area suffered curfew issues until the issue was resolved.	Construction	Waste of materials	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	10.00
Soil issues	25	Impacted As-planned	4	There were subsurface soil conditions which were not discovered during the due diligence and which needed further studies from the Contractor´s side	Construction	Geological Conditions	-	-	√	√	-	√	√	√ (Schedule update)	4.44
Permits issue	10	Impacted As-planned	8	The Owner requested the Contractor to obtain certain permits which were hard for the Contractor to obtain and which subsequently delayed the Contractor. Getting such permits was a huge responsibility on the Contractor which would be easier if it was obtained by the Owner; especially that the Owner is public so it will be easier for the public sector to obtain specific permits or at least provide reasonable assistance to the Contractor.	Stakeholders	Inadequate distribution of responsibilities Inadequate distribution of authorities Stakeholder management	Owner /Engineer	Contractor	√	√	√	√	√	√ (Schedule update)	8.89
Recent modifications raised by Owner	15	Impacted As-planned	4	There were several modifications raised by the Owner in the design which affected many subsequent activities such as construction, purchase of materials, etc. Such modifications were introduced late in the project which caused also rework activities.	Stakeholders	Lack of coordination	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	4.44
					Construction	Excessive contract variation									
Riots and instabilities on site	12	Impacted As-planned	6	There were instabilities on site as labor strikes occurred in order to ask for higher salaries. Work was seriously affected on site and several delays occurred.	Stakeholders	Staff crisis	-	-	√	√	√	√	√	√ (Schedule update)	6.67
					Construction	Labor disputes/ strikes Site Safety and security									
Construction completion	-	Impacted As-planned	82	As the project suffered from delays, it is evident that the construction period exceeded the planned period.	Construction	Construction completion	Owner /Contractor	-	√	√	√	√	√	√ (Schedule update)	100.00
Additional incurred costs	-	-	-	This risk is associated with the additional costs incurred during construction. Cost overruns occur when the costs being incurred are in excess of the amounts that have been budgeted for.	Construction	Construction Cost overruns	Owner /Contractor	Owner /Contractor	√	√	√	√	√	-	-
Total (Construction + Stakeholders)			**82**												**91.11**

Number of Stakeholders risks	Number of Construction risks	Total
10	17	**27**

% of Stakeholders risks	% of Construction risks
37.04	62.96



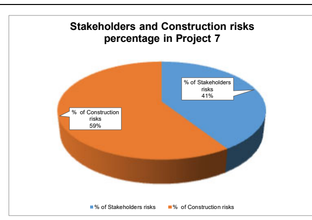
Dataset # 1 (Traditional projects)

Project 7							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
30	0.595	32	0.500	2	0.111	6.700	0.000

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						% Contribution to total delay of the project (60 days)
Delay events	Direct effect (days)	Delay analysis method used	Combined Effect on final duration	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	
Unresolved claims	15	Impacted As-planned	5	There have been several unresolved claims which were pending for a long time. The Owner took longer than expected to respond and there have been several negotiation meetings without reaching a concrete resolution.	Stakeholders	Delay in resolving contractual dispute	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	8.33
There were delays in site handing over to the Contractor	7	Impacted As-planned	7	The Owner delayed the site handing over to the Contractor and delayed giving the latter access to the Site	Stakeholders	Lack of support from government Need for land acquisition	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	11.67
					Construction	Site availability									
Subcontractor´s delays	15	Impacted As-planned	5	There has been several delays caused by the Subcontractor responsible for pipe installation	Stakeholders	Third party tort liability Third party delays	Subcontractor (Third Party)	Contractor	√	√	√	√	√	√ (Schedule update)	8.33
					Construction	Third party reliability	Subcontractor (Third Party)	Contractor	√	√	√	√	√	√ (Schedule update)	
Delayed Advance payment by the Owner	15	Impacted As-planned	6	The Owner delayed the Advance Payment to the Contractor which severely affected the latter´s cash flow.	Construction	High Finance cost Availability of finance Government reliability	Supplier	-	√	√	√	√	√	√ (Schedule update)	10.00
Problems in construction	15	Impacted As-planned	8	There were problems in some of the items constructed by the Contractor as they did not pass the necessary tests. Such defective works needed rework by the Contractor which caused subsequent delays.	Construction	Poor quality workmanship Defects in Construction Construction delays	Contractor	-	√	√	√	√	√	√ (Schedule update	13.33
Waste disposal	17	Impacted As-planned	7	There was a problem with waste disposal on site. The Owner asked the Contractor to dispose waste at an area that is far away from the Site.	Construction	Waste of materials	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	11.67
Soil issues	10	Impacted As-planned	7	There were subsurface soil conditions which were not discovered during the due diligence and which needed further studies from the Contractor´s side	Construction	Geological Conditions	-	-	√	√	-	√	√	√ (Schedule update)	11.67
Permits issue	15	Impacted As-planned	8	The Owner requested the Contractor to obtain certain permits which were hard for the Contractor to obtain and which subsequently delayed the Contractor. Getting such permits was a huge responsibility on the Contractor which would be easier if it was obtained by the Owner; especially that the Owner is public so it will be easier for the public sector to obtain specific permits or at least provide reasonable assistance to the Contractor.	Stakeholders	Inadequate distribution of responsibilities Inadequate distribution of authorities Stakeholder management	Owner /Engineer	Contractor	√	√	√	√	√	√ (Schedule update)	13.33
Recent modifications raised by Owner	15	Impacted As-planned	3	There were several modifications raised by the Owner in the design which affected many subsequent activities such as construction, purchase of materials, etc. Such modifications were introduced late in the project which caused also rework activities.	Stakeholders	Lack of coordination	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	5.00
					Construction	Excessive contract variation									
Construction completion	-	Impacted As-planned	56	As the project suffered from delays, it is evident that the construction period exceeded the planned period.	Construction	Construction completion	Owner /Contractor	-	√	√	√	√	√	√ (Schedule update)	-
Additional incurred costs	-	-	-	This risk is associated with the additional costs incurred during construction. Cost overruns occur when the costs being incurred are in excess of the amounts that have been budgeted for.	Construction	Construction Cost overruns	Owner /Contractor	Owner /Contractor	√	√	√	√	√	-	-
Total (Construction + Stakeholders)			**56**												**93.33**

Number of Stakeholders risks	Number of Construction risks	Total
9	13	22

% of Stakeholders risks	% of Construction risks
40.91	59.09



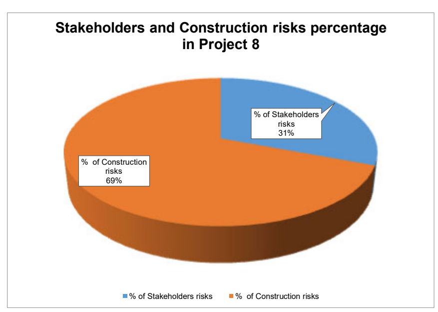
Dataset # 1 (Traditional projects)

Project 8							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
26	0.486	32	0.500	6	0.556	23.100	0.379

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						% Contribution to total delay of the project (180 days)
	Direct effect (days)	Delay analysis method used	Combined Effect on final duration	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	
Delay events															
There were delays in site handing over to the Contractor	90	Impacted As-planned	90	Despite several and continuous demands from the Contractor´s side, the Owner delayed the site handing over to the Contractor and delayed giving the latter access to the Site. This was due to the fact that the site was located in an area with some political instabilities. Finally, after the site was handed over to the Contractor, there were some areas with restricted access.	Stakeholders Construction	Lack of support from government Need for land acquisition Site availability Land use	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	50.00
Unresolved claims	15	Impacted As-planned	12	There have been several unresolved claims which were pending for a long time. The Owner took longer than expected to respond and there have been several negotiation meetings without reaching a concrete resolution.	Stakeholders	Delay in resolving contractual dispute	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	6.67
Delayed Advance payment by the Owner	60	Impacted As-planned	32	The Owner delayed the Advance Payment to the Contractor which severely affected the latter´s cash flow.	Construction	High Finance cost Availability of finance Government reliability	Supplier	-	√	√	√	√	√	√ (Schedule update)	17.78
Recent modifications raised by Owner	17	Impacted As-planned	11	There were several modifications raised by the Owner in the design which affected many subsequent activities such as construction, purchase of materials, etc. Such modifications were introduced late in the project which caused also rework activities.	Stakeholders Construction	Lack of coordination Excessive contract variation	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	6.11
Waste disposal	30	Impacted As-planned	9	There was a problem with waste disposal on site. The Owner asked the Contractor to dispose waste at an area that is far away from the Site and with the political instabilities, the disposal process was interrupted several times also because this area suffered curfew issues until the issue was resolved.	Construction	Waste of materials	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	5.00
Construction completion	-	Impacted As-planned	64	As the project suffered from delays, it is evident that the construction period exceeded the planned period.	Construction	Construction completion	Owner /Contractor	-	√	√	√	√	√	√ (Schedule update)	100.00
Additional incurred costs	-	-	-	This risk is associated with the additional costs incurred during construction. Cost overruns occur when the costs being incurred are in excess of the amounts that have been budgeted for.	Construction	Construction Cost overruns	Owner /Contractor	Owner /Contractor	√	√	√	√	√	-	-
Total (Construction + Stakeholders)			**64**												**85.56**

Number of Stakeholders risks	Number of Construction risks	Total
4	9	13

% of Stakeholders risks	% of Construction risks
30.77	69.23



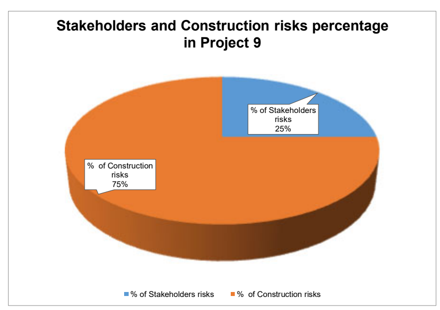
Dataset # 1 (Traditional projects)

Project 9							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
24	0.432	26	0.364	2	0.111	8.300	0.038

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						
	Direct effect (days)	Delay analysis method used	Combined Effect on final duration	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	% Contribution to total delay of the project (60 days)
Delay events															
Unresolved claims	30	Impacted As-planned	30	There have been several unresolved claims which were pending for a long time. The Owner took longer than expected to respond and there have been several negotiation meetings without reaching a concrete resolution.	Stakeholders	Delay in resolving contractual dispute	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	50.00
Delayed Advance payment by the Owner	15	Impacted As-planned	8	The Owner delayed the Advance Payment to the Contractor which severely affected the latter´s cash flow.	Construction	High Finance cost Availability of finance Government reliability	Supplier	-	√	√	√	√	√	√ (Schedule update)	13.33
Recent modifications raised by Owner	16	Impacted As-planned	10	There were several modifications raised by the Owner in the design which affected many subsequent activities such as construction, purchase of materials, etc. Such modifications were introduced late in the project which caused also rework activities.	Stakeholders Construction	Lack of coordination Excessive contract variation	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	16.67
Construction completion	-	Impacted As-planned	48	As the project suffered from delays, it is evident that the construction period exceeded the planned period.	Construction	Construction completion	Owner /Contractor	-	√	√	√	√	√	√ (Schedule update)	100.00
Additional incurred costs	-	-	-	This risk is associated with the additional costs incurred during construction. Cost overruns occur when the costs being incurred are in excess of the amounts that have been budgeted for.	Construction	Construction Cost overruns	Owner /Contractor	Owner /Contractor	√	√	√	√	√	-	-
Total (Construction + Stakeholders)			48												80.00

Number of Stakeholders risks	Number of Construction risks	Total
2	6	8

% of Stakeholders risks	% of Construction risks
25.00	75.00



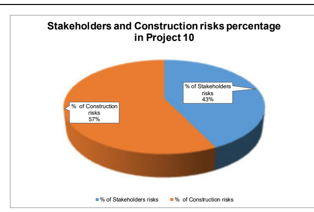
Dataset # 1 (Traditional projects)

Project 9							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
20	0.324	30	0.455	10	1.000	50.000	1.000

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						% Contribution to total delay of the project (300 days)
Delay events	Direct effect (days)	Delay analysis method used	Combined Effect on final duration	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	
Unresolved claims	100	Impacted As-planned	62	There have been several unresolved claims which were pending for a long time. The Owner took longer than expected to respond and there have been several negotiation meetings without reaching a concrete resolution. Then, a Dispute Adjudication Board was formed in order to solve the pending claims and disputed matters.	Stakeholders	Delay in resolving contractual dispute	Owner /Engineer and Contractor	-	√	√	√	√	√	√ (Schedule update)	20.67
There were delays in site handing over to the Contractor	60	Impacted As-planned	60	The Owner delayed the site handing over to the Contractor and delayed giving the latter access to the Site	Stakeholders	Lack of support from government Need for land acquisition	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	20.00
					Construction	Site availability									
Subcontractor´s delays	62	Impacted As-planned	25	There has been several delays caused by the Subcontractor responsible for pipe installation	Stakeholders	Third party tort liability Third party delays	Subcontractor (Third Party)	Contractor	√	√	√	√	√	√ (Schedule update)	8.33
					Construction	Third party reliability	Subcontractor (Third Party)	Contractor	√	√	√	√	√	√ (Schedule update)	
Delayed Advance payment by the Owner	15	Impacted As-planned	12	The Owner delayed the Advance Payment to the Contractor which severely affected the latter´s cash flow.	Construction	High Finance cost Availability of finance Government reliability	Supplier	-	√	√	√	√	√	√ (Schedule update)	4.00
Problems in construction	28	Impacted As-planned	13	There were problems in some of the items constructed by the Contractor as they did not pass the necessary tests. Such defective works needed rework by the Contractor which caused subsequent delays.	Construction	Poor quality workmanship Defects in Construction Construction delays	Contractor	-	√	√	√	√	√	√ (Schedule update	4.33
Permits issue	15	Impacted As-planned	15	The Owner requested the Contractor to obtain certain permits which were hard for the Contractor to obtain and which subsequently delayed the Contractor. Getting such permits was a huge responsibility on the Contractor which would be easier if it was obtained by the Owner; especially that the Owner is public so it will be easier for the public sector to obtain specific permits or at least provide reasonable assistance to the Contractor.	Stakeholders	Inadequate distribution of responsibilities Inadequate distribution of authorities Stakeholder management	Owner /Engineer	Contractor	√	√	√	√	√	√ (Schedule update)	5.00
Recent modifications raised by Owner	60	Impacted As-planned	52	There were several modifications raised by the Owner in the design which affected many subsequent activities such as construction, purchase of materials, etc. Such modifications were introduced late in the project which caused also rework activities.	Stakeholders	Lack of coordination	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	17.33
					Construction	Excessive contract variation									
Bankruptcy of one of the Subcontractors	70	Impacted As-planned	25	One of the Subcontractors faced a problem of bankruptcy due to major losses in one of the other projects it was involved in. This matter delayed the works on site as there was a need to restart the subcontracting procedures during the course o the project.	Construction	Insolvency of Subcontractors Third party reliability	Third party (Subcontractor)	-	√	√	√	√	√	√ (Schedule update)	8.33
Construction completion	-	Impacted As-planned	264	As the project suffered from delays, it is evident that the construction period exceeded the planned period.	Construction	Construction completion	Owner /Contractor	-	√	√	√	√	√	√ (Schedule update)	100.00
Additional incurred costs	-	-	-	This risk is associated with the additional costs incurred during construction. Cost overruns occur when the costs being incurred are in excess of the amounts that have been budgeted for.	Construction	Construction Cost overruns	Owner /Contractor	Owner /Contractor	√	√	√	√	√	-	-
Total (Construction + Stakeholders)			264												88.00

Number of Stakeholders risks	Number of Construction risks	Total
9	12	21

% of Stakeholders risks	% of Construction risks
42.86	57.14



APPENDIX H-B: DELAY EVENT DETAILS- PPP PROJETCS

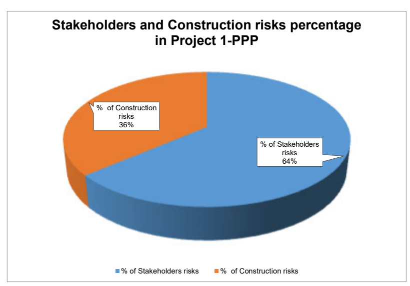
Dataset # 2 (PPP projects)

Project 1							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
21	0.000	23	0.000	2	0.000	9.500	0.000

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						% Contribution to total delay of the project (60 days)
	Direct effect (days)	Delay analysis method used	Combined Effect on final duration	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	
Delay events															
Water availability for hydraulic tests	50	Impacted As-planned	17	The Contractor faced problems of the discontinuous and insufficient water supply needed for the hydro tests. Several letters have been sent to the governmental entities highlighting this problem and its effects on the project. The Contractor proposed several solutions and prepared scenarios with different amount of daily water supply to study its effects on the scheduled operation date and how to mitigate delays as much as possible.	Stakeholders	Lack of support from government Cultural differences between main stakeholders	Owner	-	√	√	√	√	√	√ (Schedule update)	28.33
Subcontractor's delays	44	Impacted As-planned	12	There has been several delays caused by the Subcontractor responsible for pipe installation	Stakeholders	Third party tort liability Third party delays	Subcontractor (Third Party)	Contractor	√	√	√	√	√	√ (Schedule update)	20.00
					Construction	Third party reliability	Subcontractor (Third Party)	Contractor	√	√	√	√	√	√ (Schedule update)	
Final disposal of effluent	12	Impacted As-planned	8	The Contractor received a variation order concerning the final disposal of effluent material.	Construction	waste of materials	Owner	Contractor	√	√	√	√	√	√	13.33
Lack of experience in PPP projects	60	Impacted As-planned	20	There have been several delays due to negotiations which took longer than expected which delayed the project.	Stakeholders	Inadequate PPP experience Misunderstanding of the role of stakeholders Inadequate negotiation period prior to initiation	Contractor and Owner	-	√	√	√	√	√	-	33.33
Construction completion	-	Impacted As-planned	57	As the project suffered from delays, it is evident that the construction period exceeded the planned period.	Construction	Construction completion	Owner /Contractor	-	√	√	√	√	√	√ (Schedule update)	100.00
Additional incurred costs	-	-	-	This risk is associated with the additional costs incurred during construction. Cost overruns occur when the costs being incurred are in excess of the amounts that have been budgeted for.	Construction	Construction Cost overruns	Owner /Contractor	Owner /Contractor	√	√	√	√	√	-	-
Total (Construction + Stakeholders)			**57**												**95.00**

Number of Stakeholders risks	Number of Construction risks	Total
7	4	**11**

% of Stakeholders risks	% of Construction risks
63.64	36.36



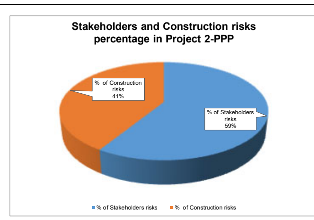
Dataset # 2 (PPP projects)

Project 2							
Original duration (months)	Normalized original duration	Final duration	Normalized final duration	Delay (months)	Normalized delays	% Delay	Normalized delay %
44	1.000	50	1.000	6	1.000	13.600	1.000

	Effect			Cause	Risk		Responsible partner		Corresponding document justifying the delay						% Contribution to total delay of the project (180 days)
	Direct effect (days)	Delay analysis method used	Combined Effect on final duration	Root cause	Risk Group	Risk name	Direct	Indirect	Letter	MOM	Claim	Variation Order	Reports	Other (Specify)	
Delay events															
Delay in selection of substation contractor	30	Impacted As-planned	30	The Contractor was delayed in selecting the substation contractor. This delay caused a subsequent delay to the procurement schedule as well as the primary design of substation electrical equipment.	Stakeholders	Lack of commitment between parties	Contractor	-	√	√	√	√	√	√ (Schedule update)	16.67
Delay in structural design by the Contractor	20	Impacted As-planned	15	The Contractor was delayed in the structural design which I the basis for building permit application.	Stakeholders	Inadequate PPP experience	Contractor	-	√	√	√	√	√	√ (Schedule update)	8.33
Lack of coordinated time schedule	30	Impacted As-planned	18	The coordinated project time schedule needs further coordination. There is a mismatch between delivery dates of some equipment and finishing dates for other components. This is due to the new technology used in the porject and the leck of time to do a thorough study for the project and make appripriate planning accordingly.	Stakeholders	Subjective evaluation Inadequate PPP experience	Contractor	-	√	√	√	√	√	√ (Schedule update)	10.00
There were delays in site handing over to the Contractor	15	Impacted As-planned	10	The Owner delayed the site handing over to the Contractor and delayed giving the latter access to the Site	Stakeholders Construction	Lack of support from government Need for land acquisition Site availability	Owner /Engineer	-	√	√	√	√	√	√ (Schedule update)	5.56
Delayed Advance payment by the Owner	15	Impacted As-planned	11	The Owner delayed the Advance Payment to the Contractor which severely affected the latter´s cash flow.	Construction	High Finance cost Availability of finance Government reliability	Supplier	-	√	√	√	√	√	√ (Schedule update)	6.11
Delay of assembly of some items	28	Impacted As-planned	13	Due to the new nature of the porject and the new technologies used, there has been a delay in the assembly proecedure. The current mitigation plan was not sufficent.	Construction	Construction delays	Contractor	-	√	√	√	√	√	√ (Schedule update	7.22
Permits issue	15	Impacted As-planned	15	The Owner requested the Contractor to obtain certain permits which were hard for the Contractor to obtain and which subsequently delayed the Contractor. Getting such permits was a huge responsibility on the Contractor which would be easier if it was obtained by the Owner; especially that the Owner is public so it will be easier for the public sector to obtain specific permits or at least	Stakeholders	Inadequate distribution of responsibilities Inadequate distribution of authorities Stakeholder management	Owner /Engineer	Contractor	√	√	√	√	√	√ (Schedule update)	8.33
Recent modifications raised by Owner	60	Impacted As-planned	37	There were several modifications raised by the Owner in the design which affected many subsequent activities such as construction, purchase of materials, etc. Such modifications were introduced late in the project which caused also rework activities.	Stakeholders Construction	Lack of coordination Excessive contract variation	Owner	Contractor	√	√	√	√	√	√ (Schedule update)	20.56
Lack of experience in PPP projects	30	Impacted As-planned	18	There have been several delays due to negotiations which took longer than expected which delayed the project.	Stakeholders	Inadequate PPP experience Misunderstanding of the role of stakeholders Inadequate negotiation period prior to initiation	Contractor and Owner	-	√	√	√	√	√	-	10.00
Construction completion	-	Impacted As-planned	191	As the project suffered from delays, it is evident that the construction period exceeded the planned period.	Construction	Construction completion	Owner /Contractor	-	√	√	√	√	√	√ (Schedule update)	100.00
Additional incurred costs	-	-	-	This risk is associated with the additional costs incurred during construction. Cost overruns occur when the costs being incurred are in excess of the amounts that have been budgeted for.	Construction	Construction Cost overruns	Owner /Contractor	Owner /Contractor	√	√	√	√	√	-	-
Total (Construction + Stakeholders)			167												92.78

Number of Stakeholders risks	Number of Construction risks	Total
10	7	17

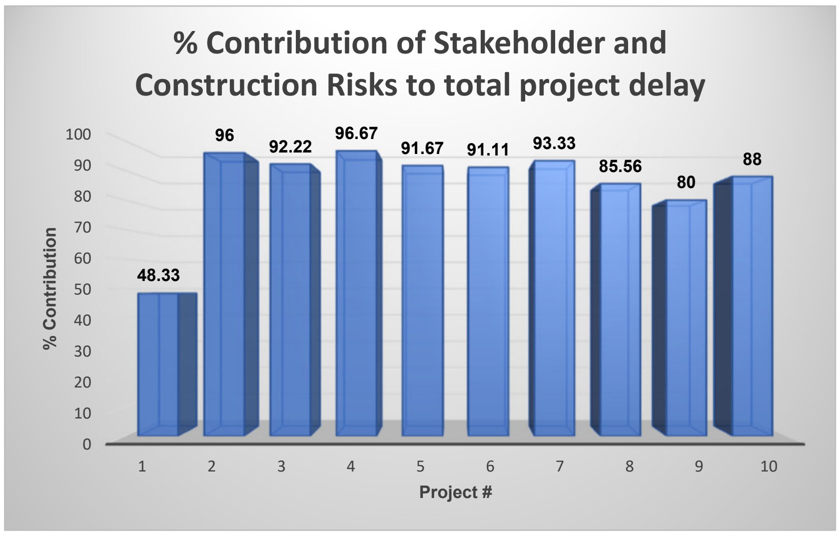
% of Stakeholders risks	% of Construction risks
58.82	41.18

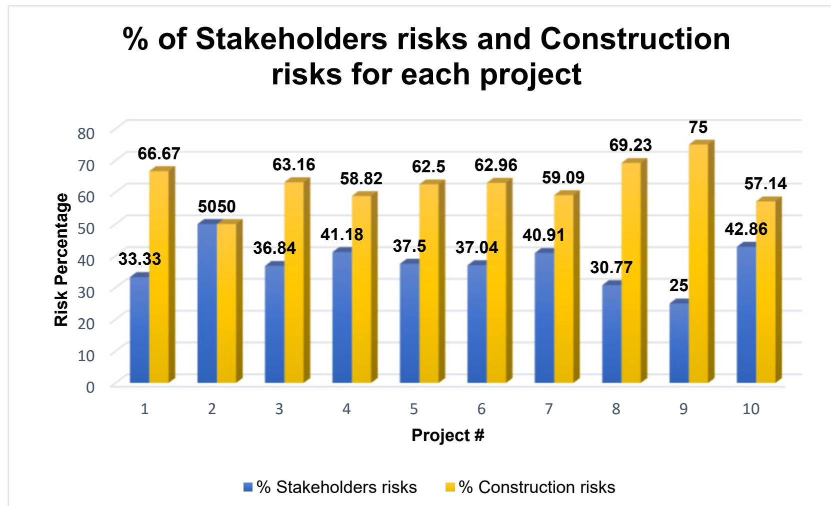


APPENDIX I-A: DATA INTEGRATION RESULTS-TRADITIONAL PROJECTS

Dataset # 1 (Traditional projects)

	Project #	Original duration (months)	Final duration	Delay (months)	% Delay	% Contribution of Stakeholder and Construction Risks to total project delay	% Stakeholders risks	% Construction risks
Dataset 1: Traditional Projects	1	16	22	6	37.5	48.33	33.33	66.67
	2	13	18	5	38.5	96	50	50
	3	45	54	9	20	92.22	36.84	63.16
	4	9	10	1	11.1	96.67	41.18	58.82
	5	8	10	2	25	91.67	37.5	62.5
	6	29	32	3	10.3	91.11	37.04	62.96
	7	30	32	2	6.7	93.33	40.91	59.09
	8	26	32	6	23.1	85.56	30.77	69.23
	9	24	26	2	8.3	80	25	75
	10	20	30	10	50	88	42.86	57.14

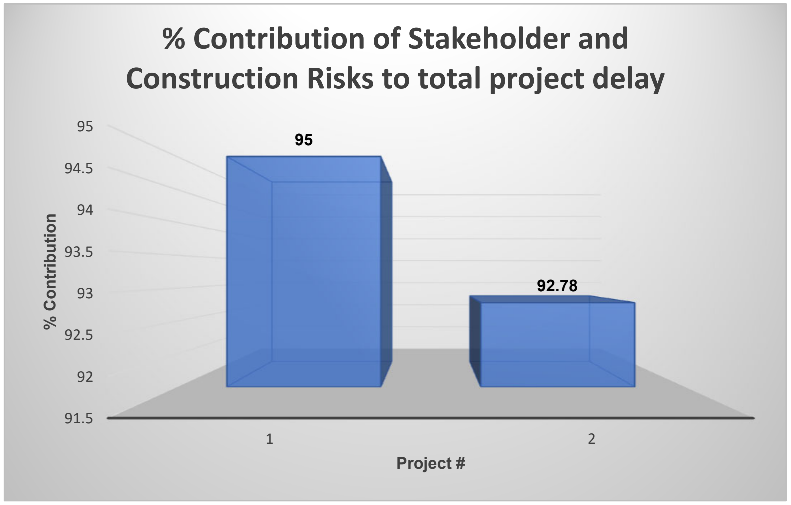


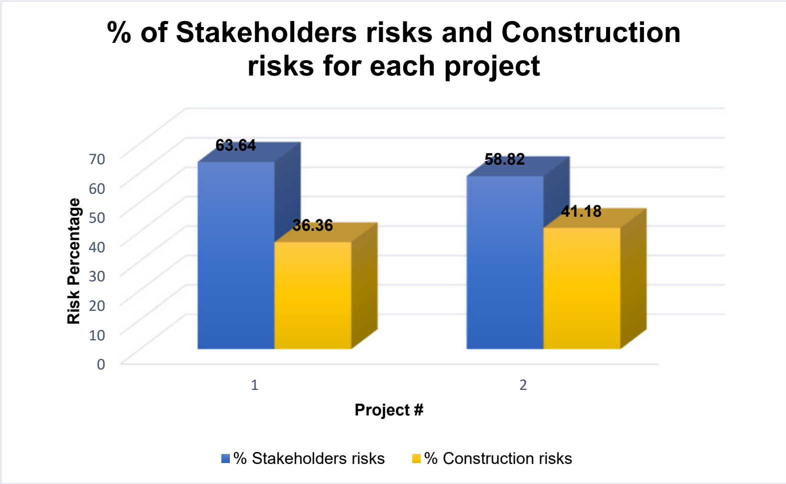


APPENDIX I-B: DATA INTEGRATION RESULTS- PPP PROJECTS

Dataset # 2 (PPP projects)

Dataset 2: PPP Projects	Project #	Original duration (months)	Final duration	Delay (months)	% Delay	% Contribution of Stakeholder and Construction Risks to total project delay	% Stakeholders risks	% Construction risks
	1	21	23	2	9.52381	95	63.64	36.36
	2	44	50	6	13.6	92.78	58.82	41.18





APPENDIX J-A: NORMALIZATION AND STANDARDIZATION- TRADITIONAL PROJECTS

Dataset # 1 (Traditional projects)

			1			2			3			4			5		
			Magnitude (contribution to project delay)	Z value	Normalized value	Magnitude (contribution to project delay)	Z value	Normalized value	Magnitude (contribution to project delay)	Z value	Normalized value	Magnitude (contribution to project delay)	Z value	Normalized value	Magnitude (contribution to project delay)	Z value	Normalized value
	#	Risk factors															
Stakeholder Risks	1	Public opposition															
	2	Lack of communication between stakeholders	15.000	0.707	1.000	12.000	-0.707	0.000									
	3	Third party tort liability				10.000	-0.011	0.334	12.960	1.325	0.926	13.330	1.492	1.000	8.330	-0.765	0.000
	4	Need for land acquisition							11.110	-0.434	0.079				8.330	-0.606	0.013
	5	Lack of support from government				13.330	0.011	0.454	18.520	1.029	0.879	20.000	1.320	1.000	8.330	-0.969	0.045
	6	Inadequate distribution of responsibilities													5.000	-0.770	0.000
	7	Inadequate PPP experience															
	8	Lack of commitment between parties															
	9	Inadequate distribution of authorities													5.000	-0.770	0.000
	10	Differences in working methods/Knowhow between parties										10.000	0.000	0.000			
	11	Delay in resolving contractual dispute	14.440	0.788	0.555	12.670	0.391	0.429	6.670	-0.954	0.000	10.000	-0.208	0.238	10.000	-0.208	0.238
	12	Lack of coordination	19.450	1.439	1.000	6.670	-0.755	0.149	16.670	0.962	0.815	10.000	-0.183	0.370	8.330	-0.470	0.259
	13	Private investor change															
	14	Third party delays				8.000	-0.742	0.000	12.960	1.374	0.931	13.330	1.532	1.000	8.330	-0.601	0.062
	15	Subjective evaluation															
	16	Misunderstanding the role of stakeholders															
	17	Misinterpretation of contract				11.330	0.000	0.000									
	18	Stakeholder management													5.000	-0.770	0.000
	19	Inadequate negotiation period prior to initiation															
	20	Staff crisis							6.300	-0.707	0.000						
	21	Cultural differences between main stakeholders															
	#	Risk factors															
Construction Risks	22	Material availability				8.000	0.000	0.000									
	23	Construction cost overrun															
	24	Geological conditions							7.040	-0.323	0.360	10.000	0.711	0.769	6.670	-0.452	0.308
	25	High finance cost							18.520	1.444	1.000	6.670	-0.793	0.184	10.000	-0.165	0.413
	26	Availability of finance							18.520	1.444	1.000	6.670	-0.793	0.184	10.000	-0.165	0.413
	27	Construction completion	100.000			100.000			100.000			100.000			100.000		
	28	Site availability				10.000	-0.462	0.182	11.110	-0.389	0.273				8.330	-0.573	0.045
	29	Poor quality workmanship				12.000	0.365	0.622	5.560	-1.130	0.100	16.670	1.449	1.000	10.000	-0.099	0.459
	30	Labor availability	3.330	0.000	0.000												
	31	Site safety and security															
	32	Insolvency of Subcontractors													8.330	-0.577	0.000
	33	Construction delays				12.000	0.365	0.622	5.560	-1.130	0.100	16.670	1.449	1.000	10.000	-0.099	0.459
	34	Supporting utilities risk	3.890	0.000	0.000												
	35	Labor disputes/strikes															
	36	Land use															
	37	Waste of materials													8.330	-0.147	0.499
	38	Protection of geological and historical objects															
	39	Government reliability							18.520	1.444	1.000	6.670	-0.793	0.184	10.000	-0.165	0.413
	40	Third-party reliability				10.000	-0.725	0.120	12.960	-0.193	0.333				16.660	0.472	0.600
	41	Excessive contract variation	15.560	0.676	0.826	6.670	-1.018	0.131	16.670	0.888	0.913	10.000	-0.384	0.391	8.330	-0.702	0.261
	42	Delay in supply	15.000	0.000	0.000												
	43	Constructability															
	44	Defects in construction				12.000	0.365	0.622	5.560	-1.130	0.100	16.670	1.449	1.000	10.000	-0.099	0.459

			6			7			8			9			10		
			Magnitude (contribution to project delay)	Z value	Normalized value	Magnitude (contribution to project delay)	Z value	Normalized value	Magnitude (contribution to project delay)	Z value	Normalized value	Magnitude (contribution to project delay)	Z value	Normalized value	Magnitude (contribution to project delay)	Z value	Normalized value
	#	Risk factors															
Stakeholder Risks	1	Public opposition															
	2	Lack of communication between stakeholders															
	3	Third party tort liability	8.890	-0.512	0.112	8.330	-0.765	0.000							8.330	-0.765	0.000
	4	Need for land acquisition	7.780	-0.640	0.000	11.670	-0.400	0.092	50.000	1.965	1.000				20.000	0.114	0.289
	5	Lack of support from government	7.780	-1.077	0.000	11.670	-0.314	0.318	50.000						20.000	1.320	1.000
	6	Inadequate distribution of responsibilities	8.890	0.211	0.467	13.330	1.330	1.000							5.000	-0.770	0.000
	7	Inadequate PPP experience															
	8	Lack of commitment between parties															
	9	Inadequate distribution of authorities	8.890	0.211	0.467	13.330	1.330	1.000							5.000	-0.770	0.000
	10	Differences in working methods/Knowhow between parties															
	11	Delay in resolving contractual dispute	8.890	-0.457	0.159	8.330	-0.582	0.119	6.670	-0.954	0.000	50.000			20.670	2.184	1.000
	12	Lack of coordination	4.440	-1.137	0.000	5.000	-1.041	0.037	6.110	-0.851	0.111	16.670	0.962	0.815	17.330	1.075	0.859
	13	Private investor change															
	14	Third party delays	8.890	-0.362	0.167	8.330	-0.601	0.062							8.330	-0.601	0.062
	15	Subjective evaluation															
	16	Misunderstanding the role of stakeholders															
	17	Misinterpretation of contract															
	18	Stakeholder management	8.890	0.211	0.467	13.330	1.330	1.000							5.000	-0.770	0.000
	19	Inadequate negotiation period prior to initiation															
	20	Staff crisis	6.670	0.707	1.000												
	21	Cultural differences between main stakeholders															
	#	Risk factors															
Construction Risks	22	Material availability															
	23	Construction cost overrun															
	24	Geological conditions	4.440	-1.230	0.000	11.670	1.294	1.000									
	25	High finance cost	6.670	-0.793	0.184	10.000	-0.165	0.413	17.780	1.305	0.949	13.330	0.464	0.643	4.000	-1.298	0.000
	26	Availability of finance	6.670	-0.793	0.184	10.000	-0.165	0.413	17.780	1.305	0.949	13.330	0.464	0.643	4.000	-1.298	0.000
	27	Construction completion	100.000			100.000			100.000			100.000	0.000	0.000	100.000		
	28	Site availability	7.780	-0.609	0.000	11.670	-0.352		50.000						20.000	0.200	1.000
	29	Poor quality workmanship	11.110	0.158	0.549	13.330	0.673	0.729							4.330	-1.415	0.000
	30	Labor availability															
	31	Site safety and security	6.670	0.000	0.000												
	32	Insolvency of Subcontractors	13.330	1.155	1.000										8.330	-0.577	0.000
	33	Construction delays	11.110	0.158	0.549	13.330	0.673	0.729							4.330	-1.415	0.000
	34	Supporting utilities risk															
	35	Labor disputes/strikes	6.670	0.000	0.000												
	36	Land use							50.000	0.000	0.000						
	37	Waste of materials	10.000	0.439	0.750	11.670	1.025	1.000	5.000	-1.317	0.000						
	38	Protection of geological and historical objects															
	39	Government reliability	6.670	-0.793	0.184	10.000	-0.165	0.413	17.780	1.305	0.949	13.330	0.464	0.643	4.000	-1.298	0.000
	40	Third-party reliability	22.220	1.471	1.000	8.330	-1.025	0.000									
	41	Excessive contract variation	17.780	1.100	1.000	5.000	-1.337	0.000	6.110	-1.125	0.087	16.670	0.888	0.913	17.330	1.014	0.965
	42	Delay in supply															
	43	Constructability															
	44	Defects in construction	11.110	0.158	0.549	13.330	0.673	0.729							4.330	-1.415	0.000

APPENDIX J-B: NORMALIZATION AND STANDARDIZATION- PPP PROJECTS

Dataset # 1 (Traditional projects)

Dataset # 2 (PPP projects)

	#	Risk factors	1			2		
			Magnitude	Z value	Normalized value	Magnitude	Z value	Normalized value
Stakeholder Risks	1	Public opposition						
	2	Lack of communication between stakeholders						
	3	Third party tort liability	20	0	0		0	0
	4	Need for land acquisition		0	0	5.56	0	0
	5	Lack of support from government	28.33	0.70710678	1	5.56	-0.707107	0.803742
	6	Inadequate distribution of responsibilities		0	0	8.33	0	0
	7	Inadequate PPP experience	33.33	0.70710678	1	28.33	-0.707107	
	8	Lack of commitment between parties		0	0	16.67	0	0
	9	Inadequate distribution of authorities		0	0	8.33	0	0
	10	Differences in working methods/Knowhow between parties						
	11	Delay in resolving contractual dispute						
	12	Lack of coordination		0	0	20.56	0	0
	13	Private investor change						
	14	Third party delays	20	0	0		0	0
	15	Subjective evaluation		0	0	10	0	0
	16	Misunderstanding the role of stakeholders	33.33	0.70710678	1	10	-0.707107	0
	17	Misinterpretation of contract						
	18	Stakeholder management		0	0	8.33	0	0
	19	Inadequate negotiation period prior to initiation	33.33	0.70710678	1	10	-0.707107	0
	20	Staff crisis						
	21	Cultural differences between main stakeholders	28.33	0	0		0	0

	#	Risk factors	Magnitude	Z value	Normalized value	Magnitude	Z value	Normalized value
Construction Risks	22	Material availability						
	23	Construction cost overrun						
	24	Geological conditions						
	25	High finance cost		0	0	6.11	0	0
	26	Availability of finance		0	0	6.11	0	0
	27	Construction completion	100	0	0		0	0
	28	Site availability		0	0	5.56	0	0
	29	Poor quality workmanship						
	30	Labor availability						
	31	Site safety and security						
	32	Insolvency of Subcontractors						
	33	Construction delays		0	0	7.22	0	0
	34	Supporting utilities risk						
	35	Labor disputes/strikes						
	36	Land use						
	37	Waste of materials	13.33	0	0		0	0
	38	Protection of geological and historical objects						
	39	Government reliability		0	0	6.11	0	0
	40	Third-party reliability	20	0	0		0	0
	41	Excessive contract variation		0	0	20.56	0	0
	42	Delay in supply						
	43	Constructability						
	44	Defects in construction						

APPENDIX K: PLOTTED HISTOGRAMS AND DATA DISTRIBUTION

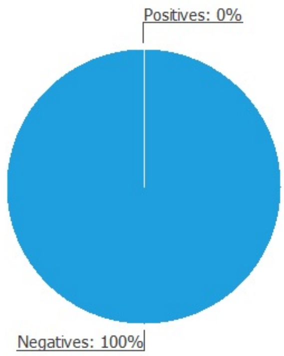
3 Data distribution

3.1 Task description

Histograms show how the data is distributed over its entire range. In approximation problems, a uniform distribution for all the variables is, in general, desirable. If the data is very irregularly distributed, then the model will probably be of bad quality.

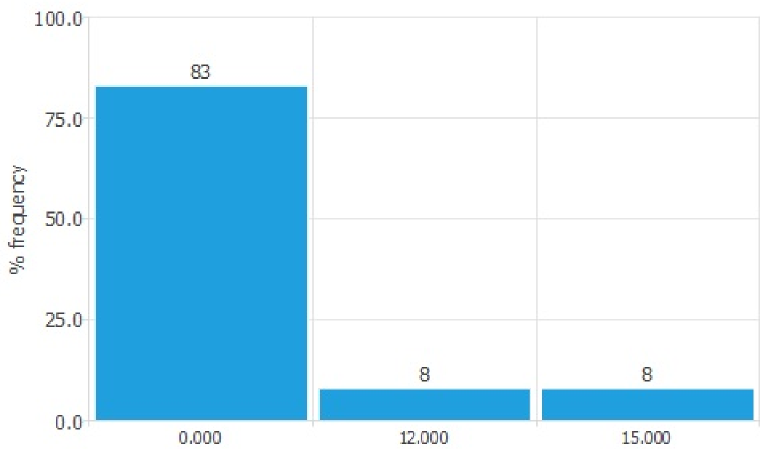
3.2 Public_opposition pie chart

The following pie chart shows the distribution for the binary variable Public_opposition. The percentage of negatives instances (100%) is greater than the percentage of positives instances (0%).



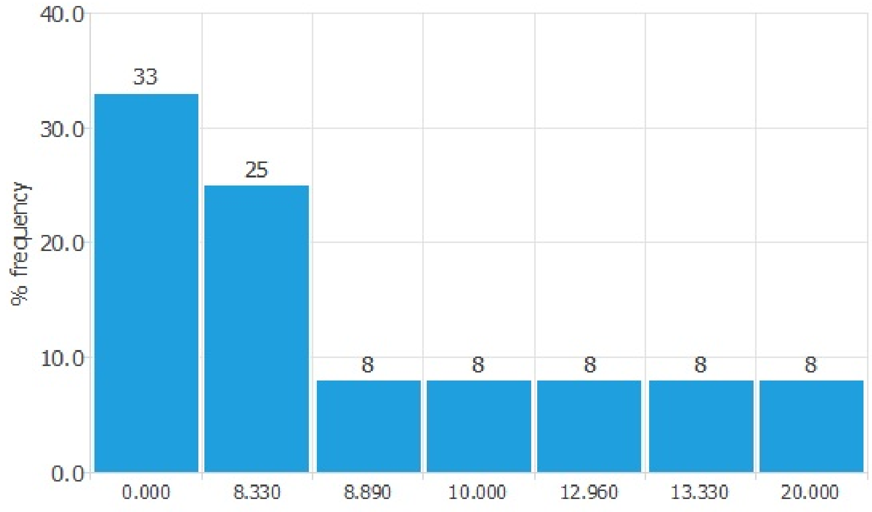
3.3 Lack_of_communication_between_stakeholders distribution

The following chart shows the histogram for the variable Lack_of_communication_between_stakeholders. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 12, 15. The maximum frequency is 83.3333%, which corresponds to the bin with center 0.



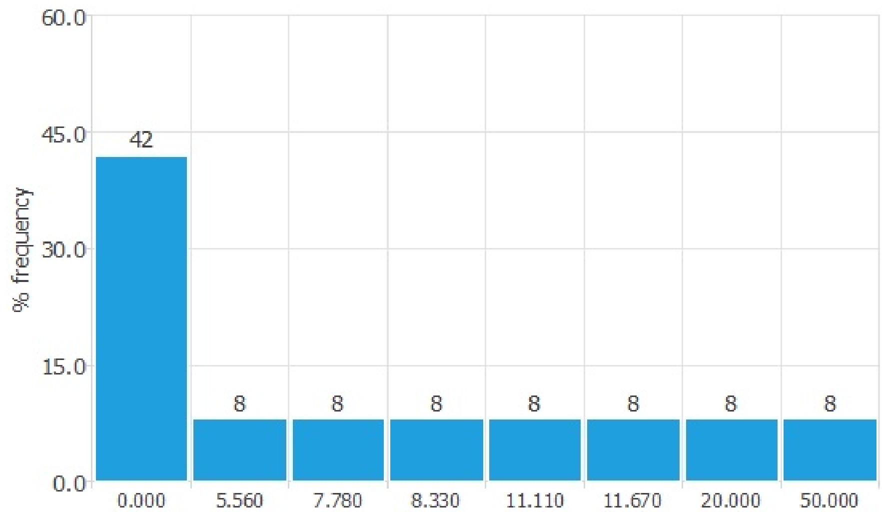
3.4 Third_party_tort_liability distribution

The following chart shows the histogram for the variable Third_party_tort_liability. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 8.89, 10, 12.96, 13.33, 20. The maximum frequency is 33.3333%, which corresponds to the bin with center 0.



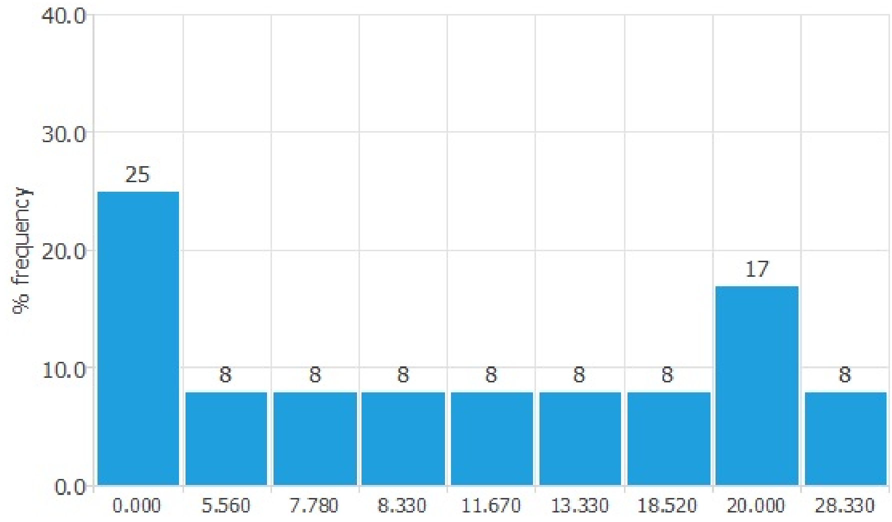
3.5 Need_for_land_acquisition distribution

The following chart shows the histogram for the variable Need_for_land_acquisition. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 5.56, 7.78, 8.33, 11.11, 11.67, 20, 50. The maximum frequency is 41.6667%, which corresponds to the bin with center 0.



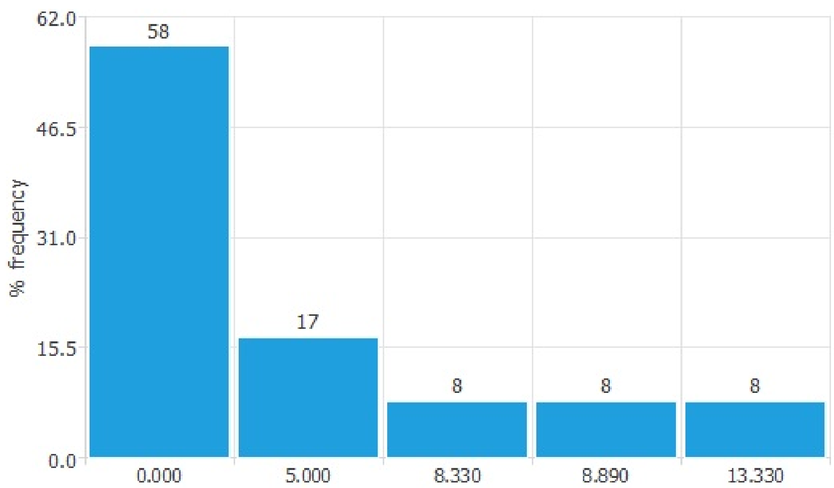
3.6 Lack_of_support_from_government distribution

The following chart shows the histogram for the variable Lack_of_support_from_government. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 5.56, 7.78, 8.33, 11.67, 13.33, 18.52, 28.33. The maximum frequency is 25%, which corresponds to the bin with center 0.



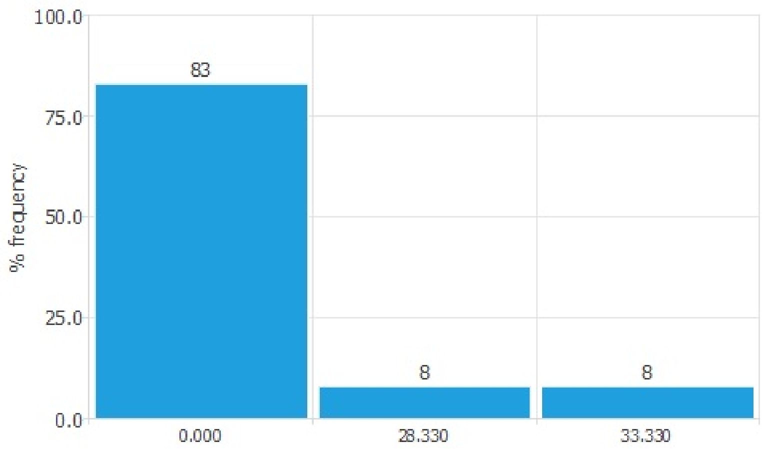
3.7 Inadequate_distribution_of_responsibilities distribution

The following chart shows the histogram for the variable Inadequate_distribution_of_responsibilities. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 8.33, 8.89, 13.33. The maximum frequency is 58.3333%, which corresponds to the bin with center 0.



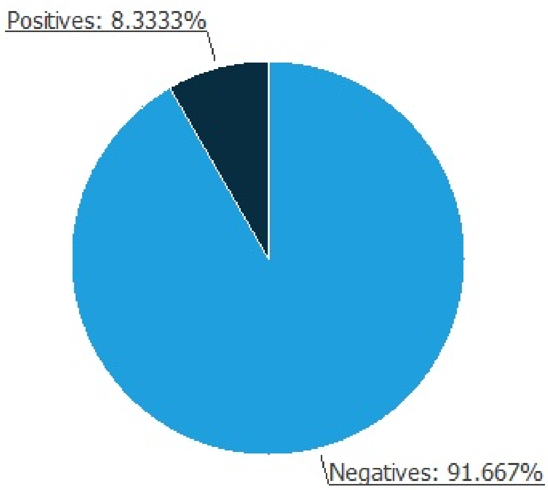
3.8 Inadequate_PPP_experience distribution

The following chart shows the histogram for the variable Inadequate_PPP_experience. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 28.33, 33.33. The maximum frequency is 83.3333%, which corresponds to the bin with center 0.



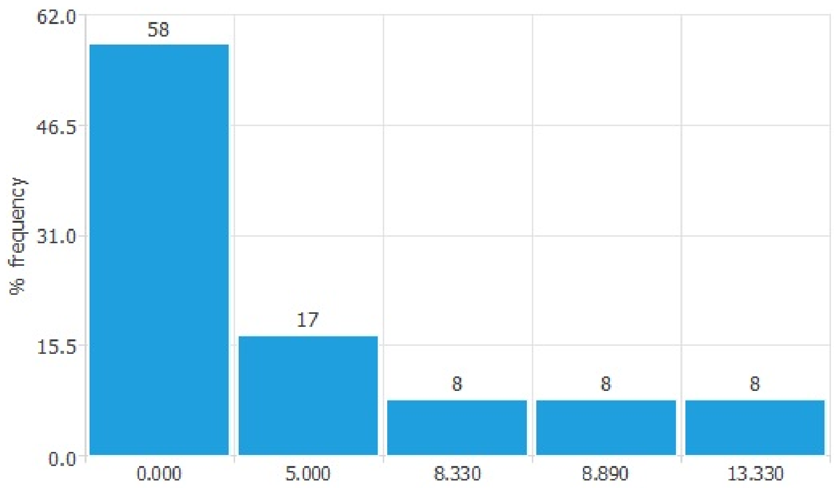
3.9 Lack_of_commitment_between_parties pie chart

The following pie chart shows the distribution for the binary variable Lack_of_commitment_between_parties. The percentage of negatives instances (91.6667%) is greater than the percentage of positives instances (8.33333%).



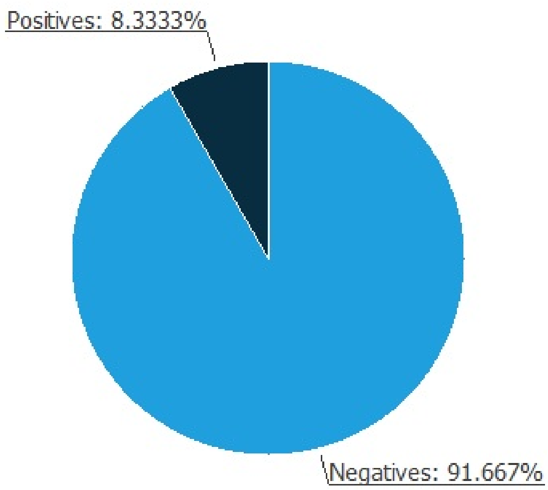
3.10 Inadequate_distribution_of_authorities distribution

The following chart shows the histogram for the variable Inadequate_distribution_of_authorities. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 8.33, 8.89, 13.33. The maximum frequency is 58.3333%, which corresponds to the bin with center 0.



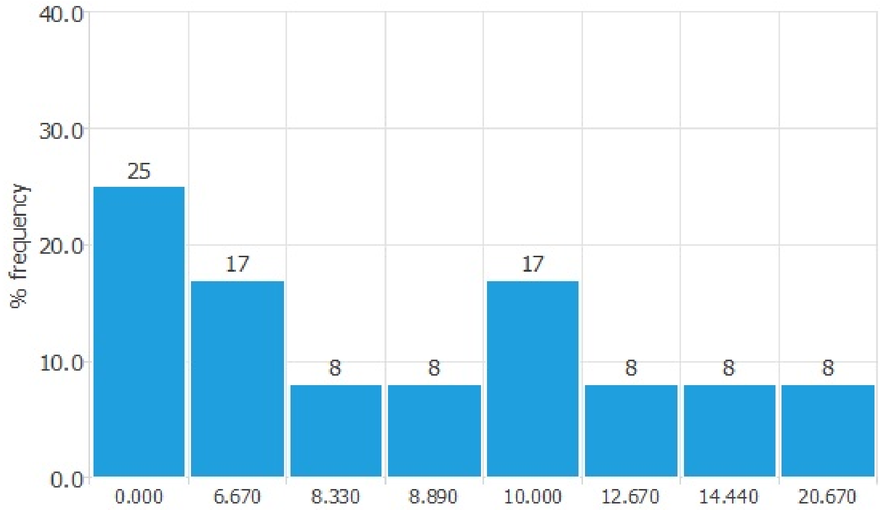
3.11 Differences_in_working_methods pie chart

The following pie chart shows the distribution for the binary variable Differences_in_working_methods. The percentage of negatives instances (91.6667%) is greater than the percentage of positives instances (8.33333%).



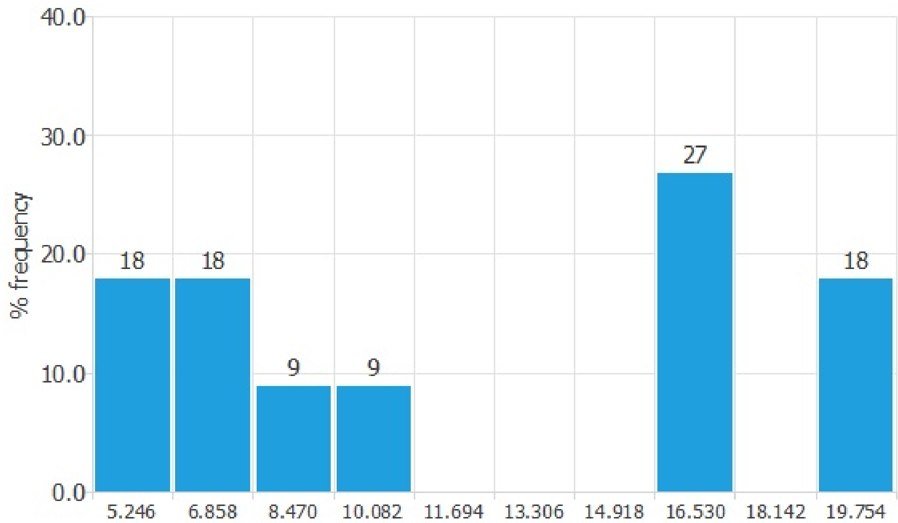
3.12 Delay_in_resolving_contractual_dispute distribution

The following chart shows the histogram for the variable Delay_in_resolving_contractual_dispute. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 8.33, 8.89, 12.67, 14.44, 20.67. The maximum frequency is 25%, which corresponds to the bin with center 0.



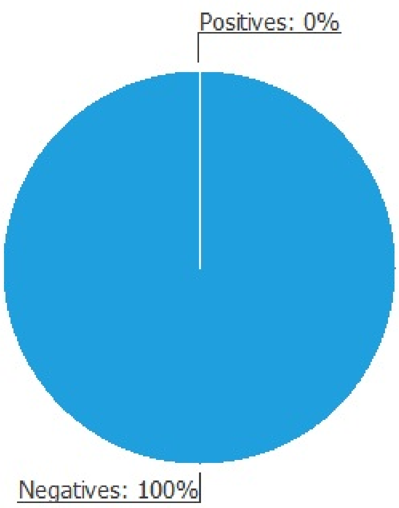
3.13 Lack_of_coordination distribution

The following chart shows the histogram for the variable Lack_of_coordination . The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 0%, which corresponds to the bins with centers 11.694, 13.306, 14.918, 18.142. The maximum frequency is 27.2727%, which corresponds to the bin with center 16.53.



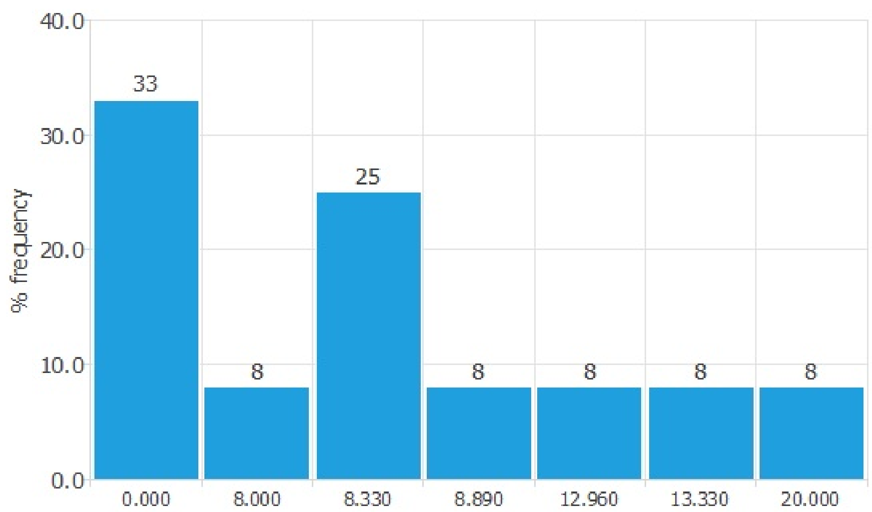
3.14 Private_investor_change pie chart

The following pie chart shows the distribution for the binary variable Private_investor_change. The percentage of negatives instances (100%) is greater than the percentage of positives instances (0%).



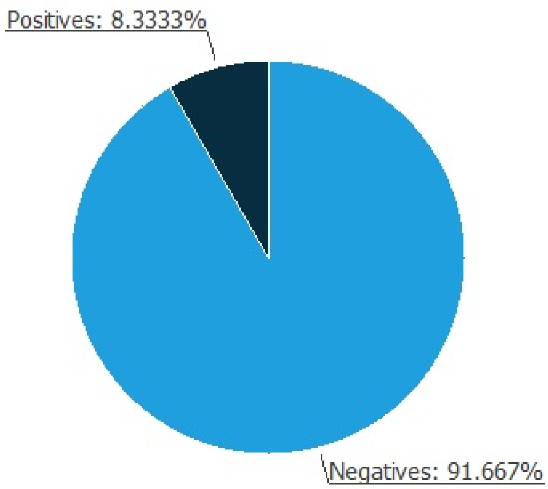
3.15 Third_party_delays distribution

The following chart shows the histogram for the variable Third_party_delays. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 8, 8.89, 12.96, 13.33, 20. The maximum frequency is 33.3333%, which corresponds to the bin with center 0.



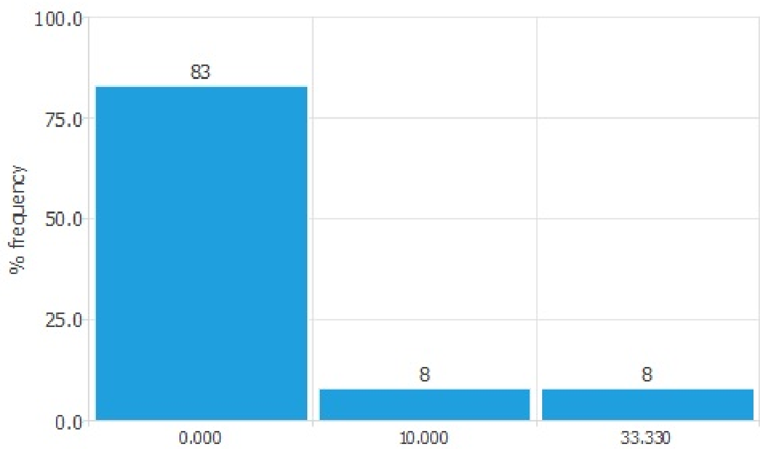
3.16 Subjective_evaluation pie chart

The following pie chart shows the distribution for the binary variable Subjective_evaluation. The percentage of negatives instances (91.6667%) is greater than the percentage of positives instances (8.33333%).



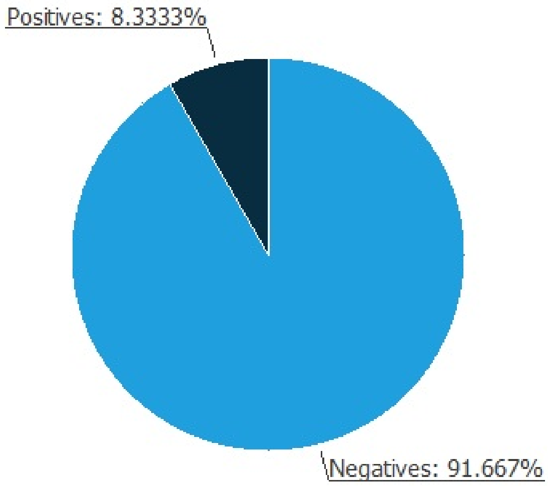
3.17 Misunderstanding_the_role_of_stakeholders distribution

The following chart shows the histogram for the variable Misunderstanding_the_role_of_stakeholders. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 10, 33.33. The maximum frequency is 83.3333%, which corresponds to the bin with center 0.



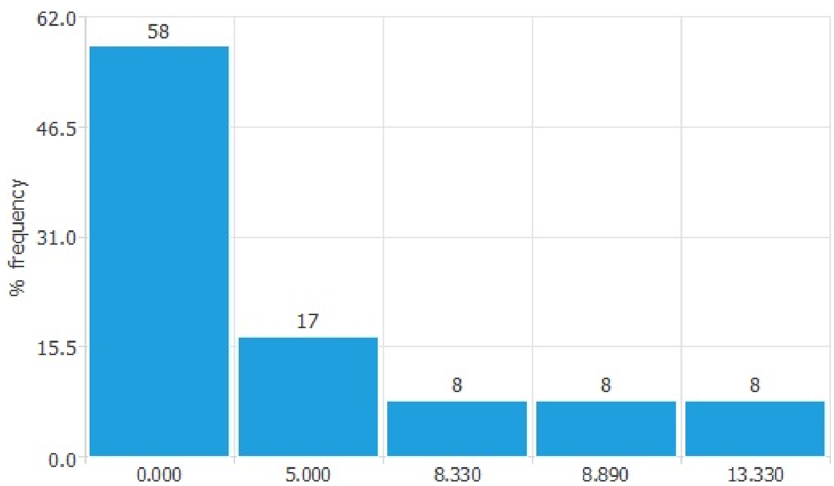
3.18 Misinterpretation_of_contract pie chart

The following pie chart shows the distribution for the binary variable Misinterpretation_of_contract. The percentage of negatives instances (91.6667%) is greater than the percentage of positives instances (8.33333%).



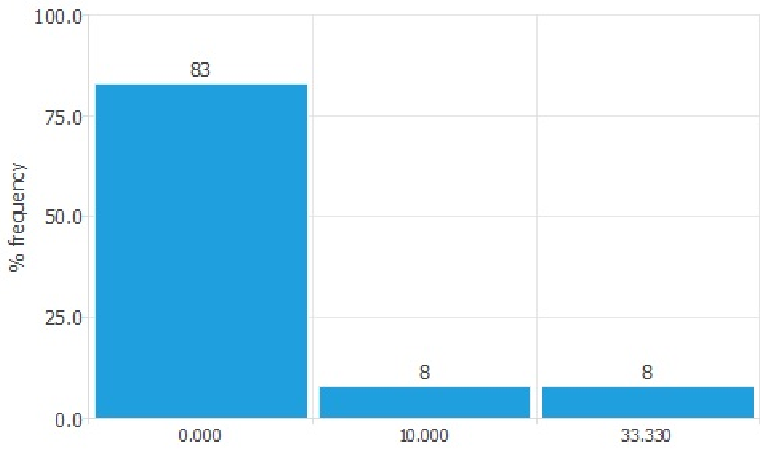
3.19 Stakeholder_management distribution

The following chart shows the histogram for the variable Stakeholder_management. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 8.33, 8.89, 13.33. The maximum frequency is 58.3333%, which corresponds to the bin with center 0.



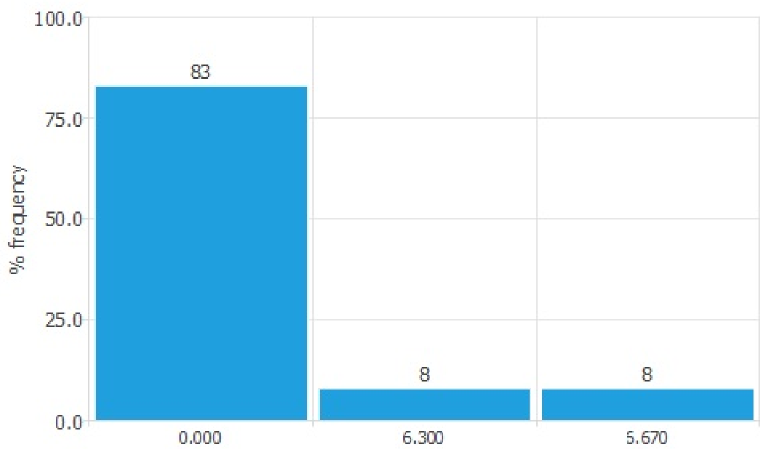
3.20 Inadequate_negotiation_period_prior_to_initiation distribution

The following chart shows the histogram for the variable Inadequate_negotiation_period_prior_to_initiation. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 10, 33.33. The maximum frequency is 83.3333%, which corresponds to the bin with center 0.



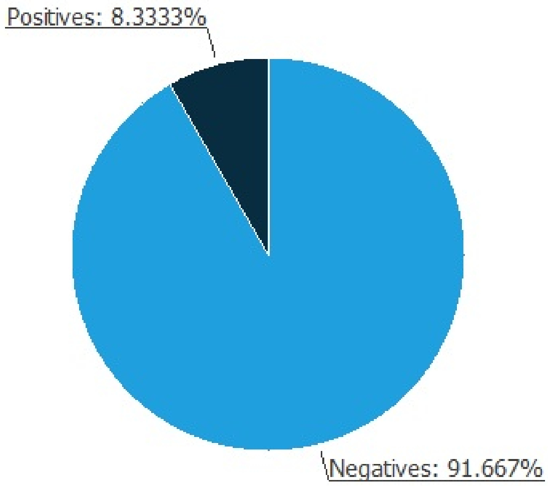
3.21 Staff_crisis distribution

The following chart shows the histogram for the variable Staff_crisis. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 6.3, 6.67. The maximum frequency is 83.3333%, which corresponds to the bin with center 0.



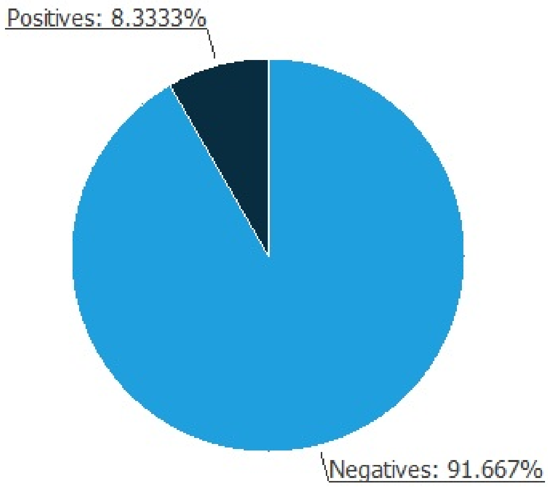
3.22 Cultural_differences pie chart

The following pie chart shows the distribution for the binary variable Cultural_differences. The percentage of negatives instances (91.6667%) is greater than the percentage of positives instances (8.33333%).



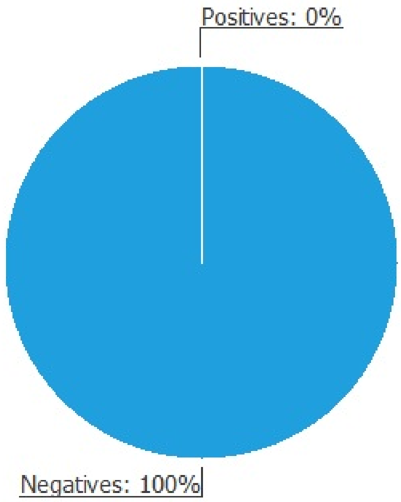
3.23 Material_availability pie chart

The following pie chart shows the distribution for the binary variable Material_availability. The percentage of negatives instances (91.6667%) is greater than the percentage of positives instances (8.33333%).



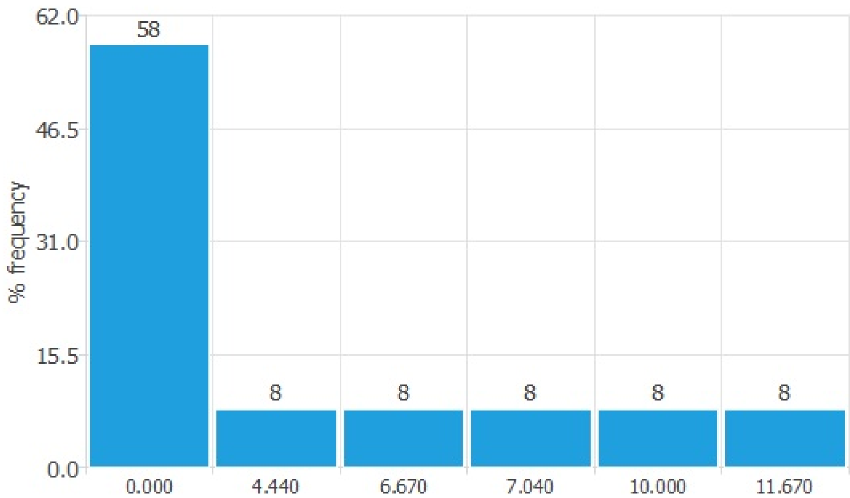
3.24 Construction_cost_overrun pie chart

The following pie chart shows the distribution for the binary variable Construction_cost_overrun. The percentage of negatives instances (100%) is greater than the percentage of positives instances (0%).



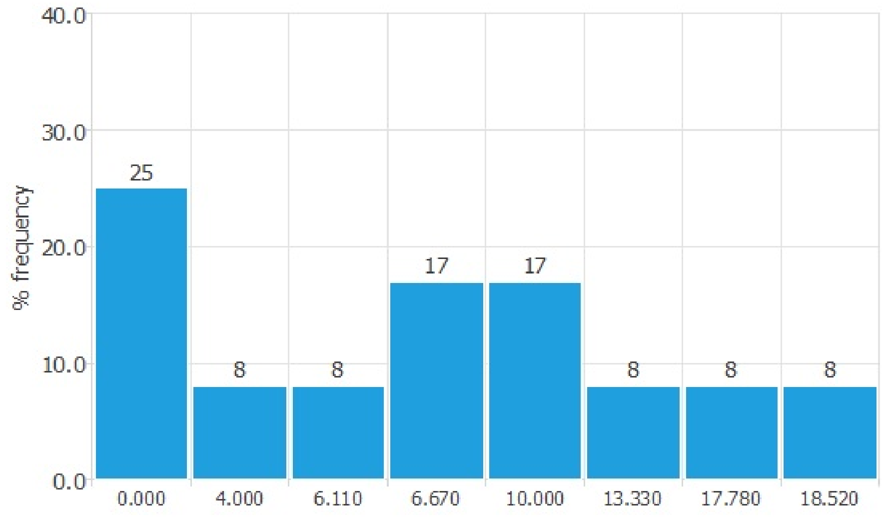
3.25 Geological_conditions distribution

The following chart shows the histogram for the variable Geological_conditions. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 4.44, 6.67, 7.04, 10, 11.67. The maximum frequency is 58.3333%, which corresponds to the bin with center 0.



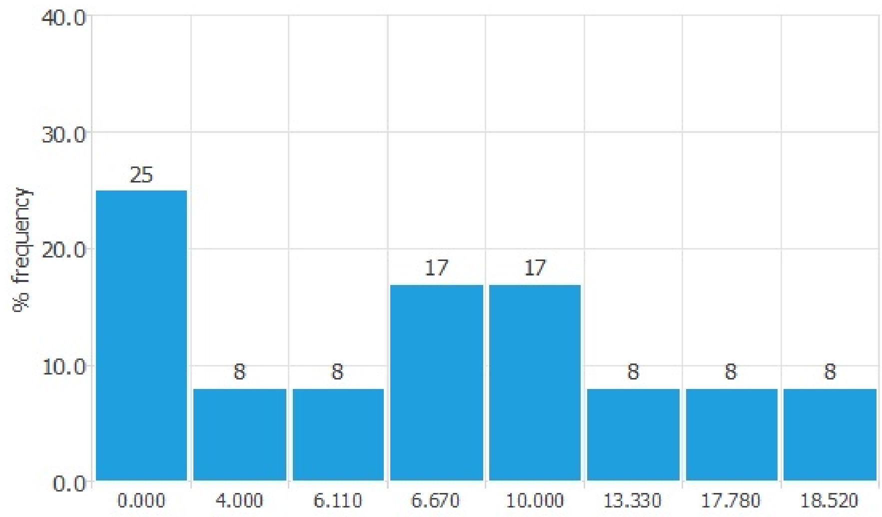
3.26 High_finance_cost distribution

The following chart shows the histogram for the variable High_finance_cost. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 4, 6.11, 13.33, 17.78, 18.52. The maximum frequency is 25%, which corresponds to the bin with center 0.



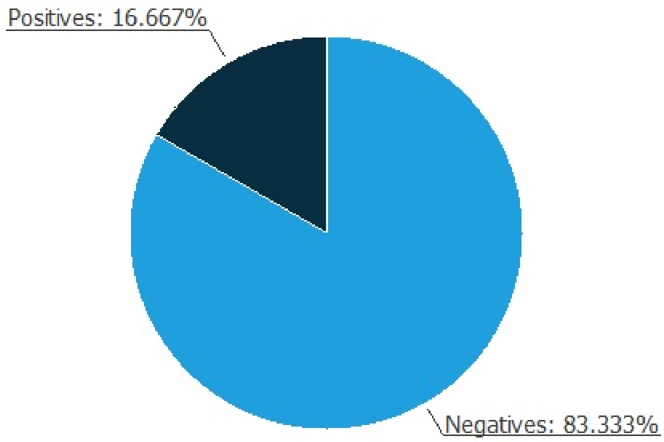
3.27 Availability_of_finance distribution

The following chart shows the histogram for the variable Availability_of_finance. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 4, 6.11, 13.33, 17.78, 18.52. The maximum frequency is 25%, which corresponds to the bin with center 0.



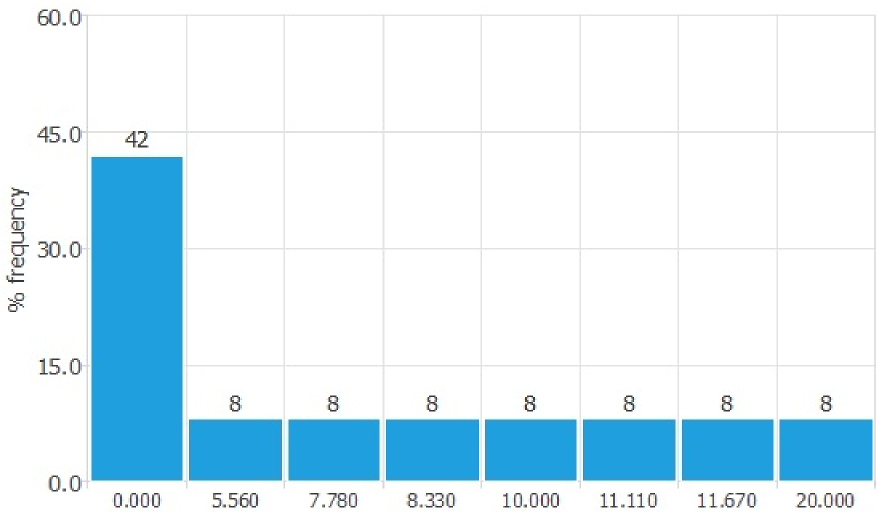
3.28 Construction_completion pie chart

The following pie chart shows the distribution for the binary variable Construction_completion. The percentage of negatives instances (83.3333%) is greater than the percentage of positives instances (16.6667%).



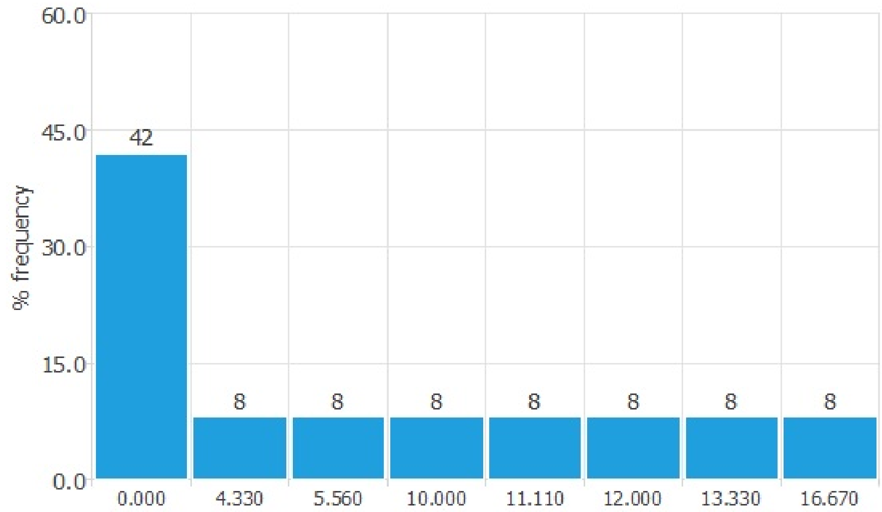
3.29 Site_availability distribution

The following chart shows the histogram for the variable Site_availability. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 5.56, 7.78, 8.33, 10, 11.11, 11.67, 20. The maximum frequency is 41.6667%, which corresponds to the bin with center 0.



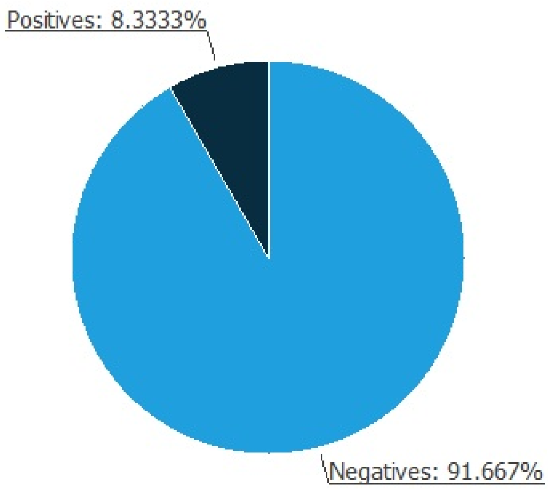
3.30 Poor_quality_workmanship distribution

The following chart shows the histogram for the variable Poor_quality_workmanship. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 4.33, 5.56, 10, 11.11, 12, 13.33, 16.67. The maximum frequency is 41.6667%, which corresponds to the bin with center 0.



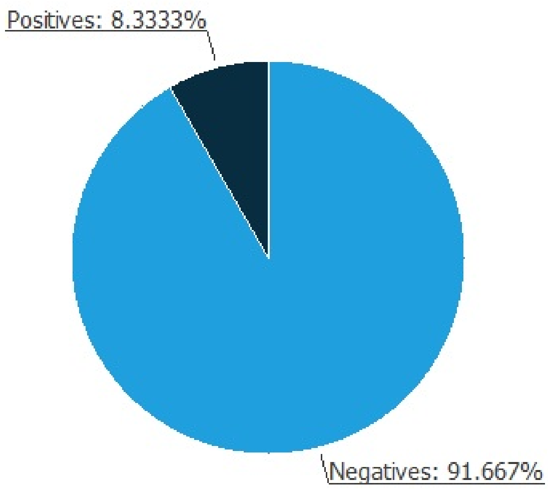
3.31 Labor_availability pie chart

The following pie chart shows the distribution for the binary variable Labor_availability. The percentage of negatives instances (91.6667%) is greater than the percentage of positives instances (8.33333%).



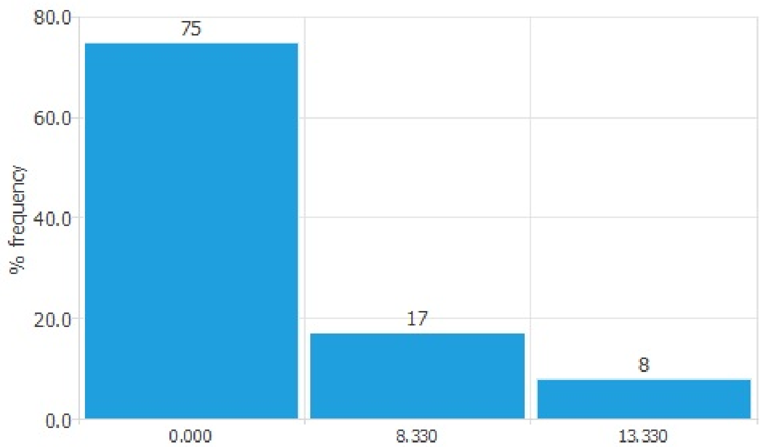
3.32 Site_safety pie chart

The following pie chart shows the distribution for the binary variable Site_safety. The percentage of negatives instances (91.6667%) is greater than the percentage of positives instances (8.33333%).



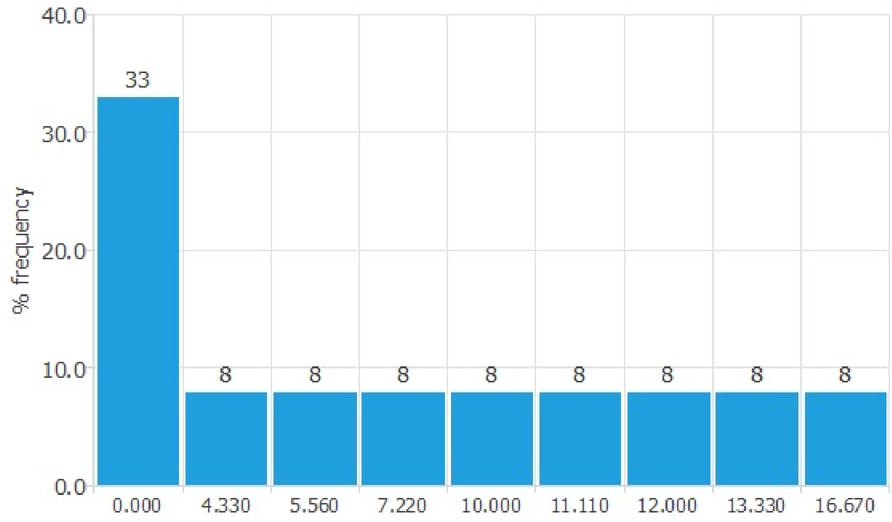
3.33 Insolvency_of_Subcontractors distribution

The following chart shows the histogram for the variable Insolvency_of_Subcontractors. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bin with center 13.33. The maximum frequency is 75%, which corresponds to the bin with center 0.



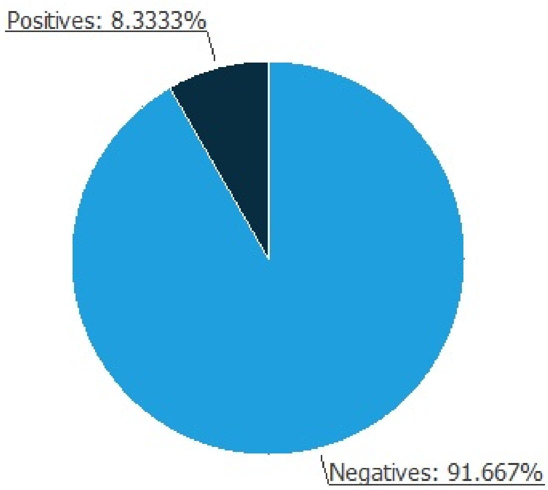
3.34 Construction_delays distribution

The following chart shows the histogram for the variable Construction_delays. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 4.33, 5.56, 7.22, 10, 11.11, 12, 13.33, 16.67. The maximum frequency is 33.3333%, which corresponds to the bin with center 0.



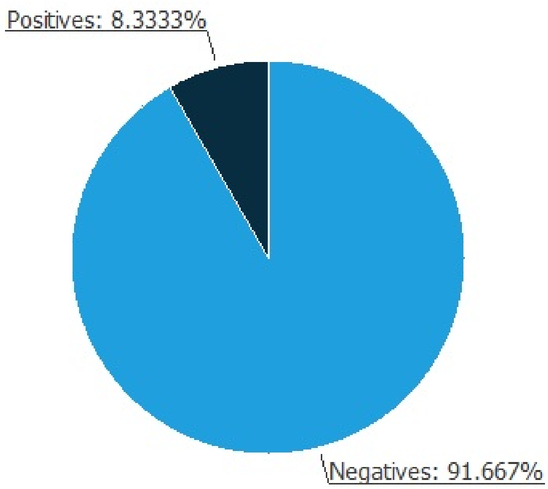
3.35 Supporting_utilities_risk pie chart

The following pie chart shows the distribution for the binary variable Supporting_utilities_risk. The percentage of negatives instances (91.6667%) is greater than the percentage of positives instances (8.33333%).



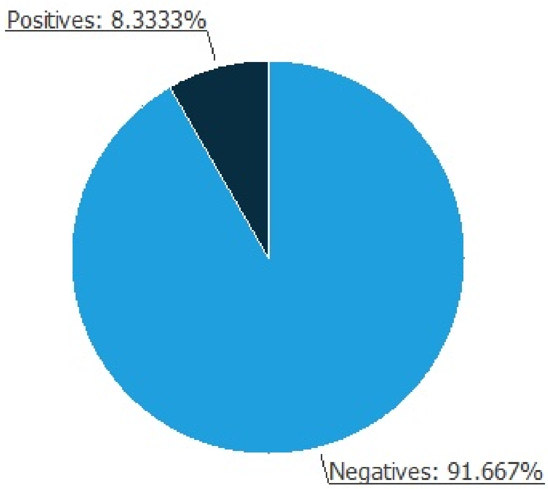
3.36 Labor_disputes pie chart

The following pie chart shows the distribution for the binary variable Labor_disputes. The percentage of negatives instances (91.6667%) is greater than the percentage of positives instances (8.33333%).



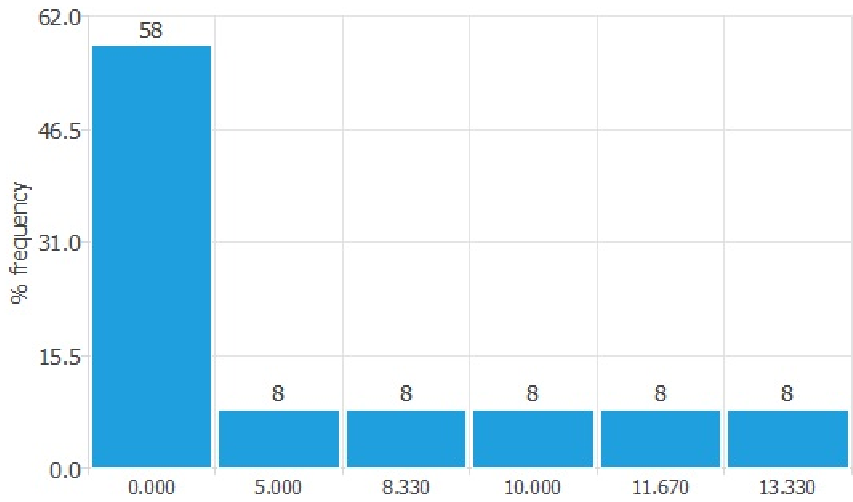
3.37 Land_use pie chart

The following pie chart shows the distribution for the binary variable Land_use. The percentage of negatives instances (91.6667%) is greater than the percentage of positives instances (8.33333%).



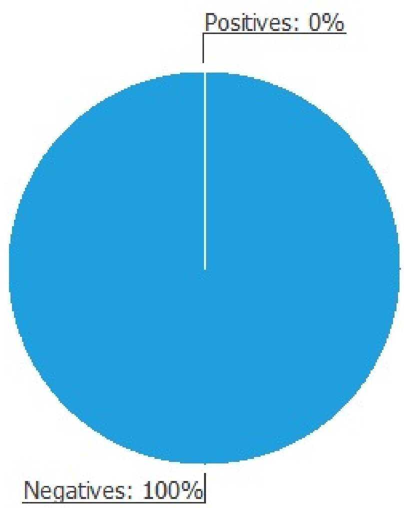
3.38 Waste_of_materials distribution

The following chart shows the histogram for the variable Waste_of_materials. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 5, 8.33, 10, 11.67, 13.33. The maximum frequency is 58.3333%, which corresponds to the bin with center 0.



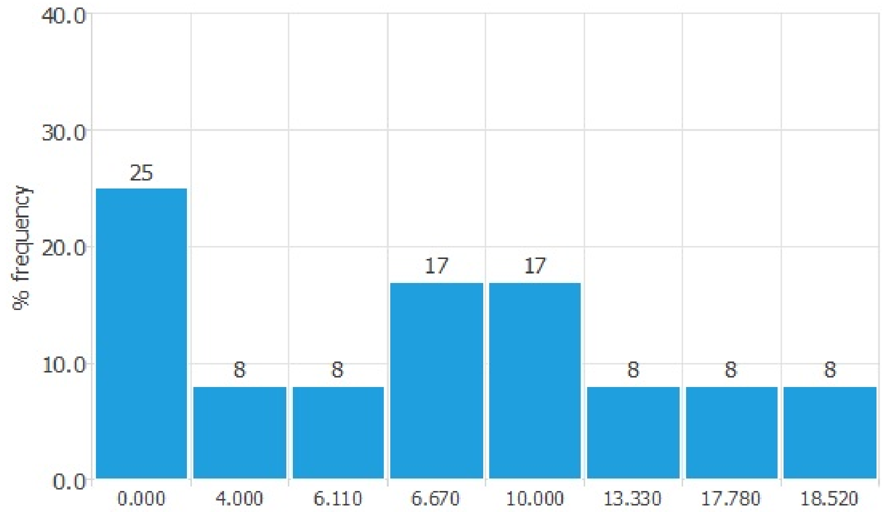
3.39 Protection_of_geological_and_historical_objects pie chart

The following pie chart shows the distribution for the binary variable Protection_of_geological_and_historical_objects. The percentage of negatives instances (100%) is greater than the percentage of positives instances (0%).



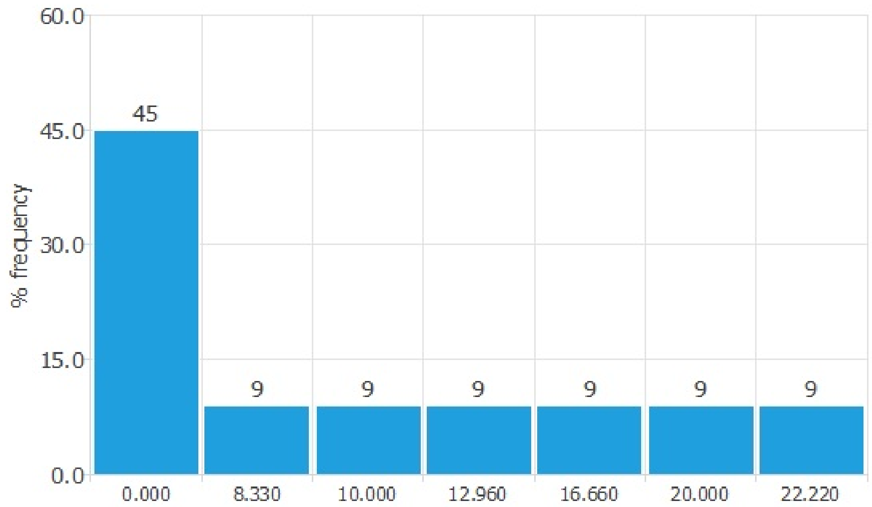
3.40 Government_reliability distribution

The following chart shows the histogram for the variable Government_reliability. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 4, 6.11, 13.33, 17.78, 18.52. The maximum frequency is 25%, which corresponds to the bin with center 0.



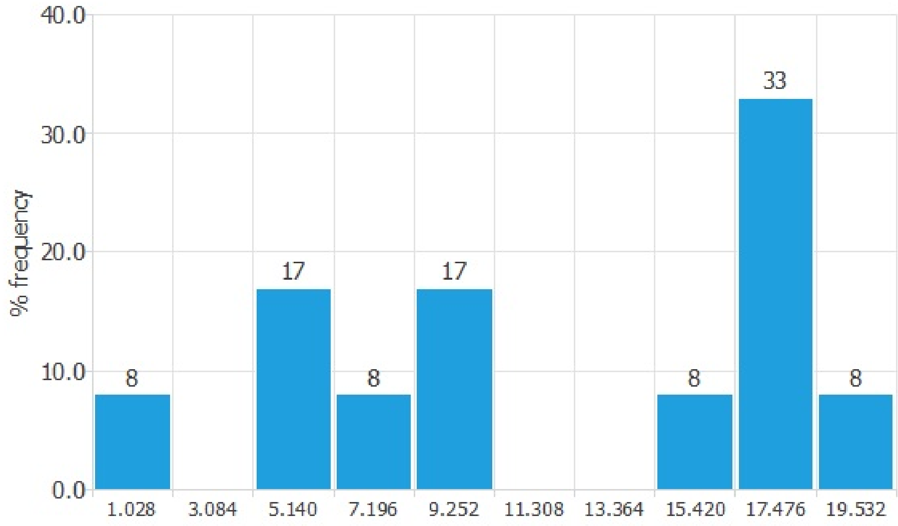
3.41 Third-party_reliability distribution

The following chart shows the histogram for the variable Third-party_reliability. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 9.09091%, which corresponds to the bins with centers 8.33, 10, 12.96, 16.66, 20, 22.22. The maximum frequency is 45.4545%, which corresponds to the bin with center 0.



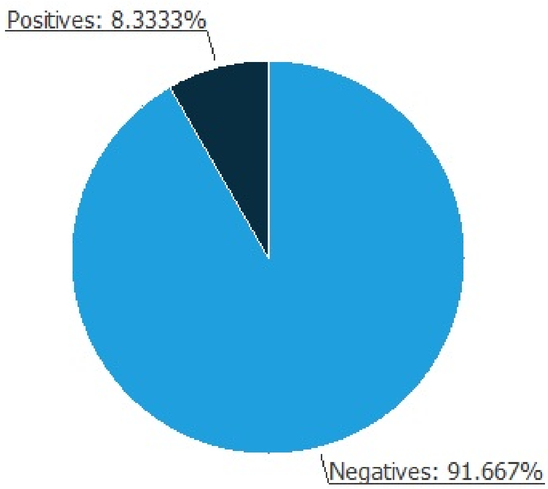
3.42 Excessive_contract_variation distribution

The following chart shows the histogram for the variable Excessive_contract_variation. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 0%, which corresponds to the bins with centers 3.084, 11.308, 13.364. The maximum frequency is 33.3333%, which corresponds to the bin with center 17.476.



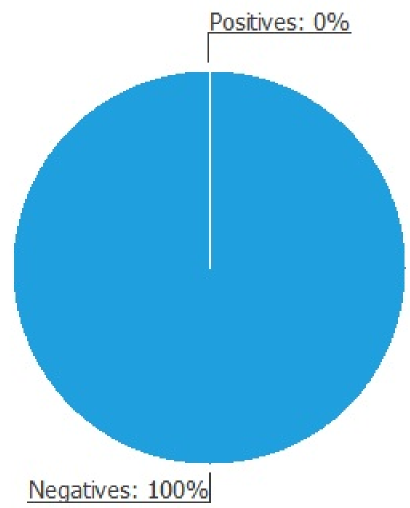
3.43 Delay_in_supply pie chart

The following pie chart shows the distribution for the binary variable Delay_in_supply. The percentage of negatives instances (91.6667%) is greater than the percentage of positives instances (8.33333%).



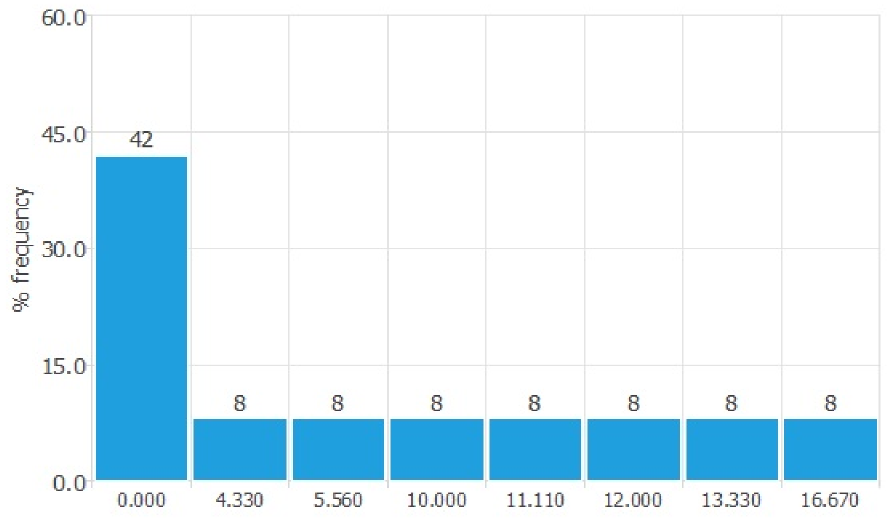
3.44 Constructability pie chart

The following pie chart shows the distribution for the binary variable Constructability. The percentage of negatives instances (100%) is greater than the percentage of positives instances (0%).



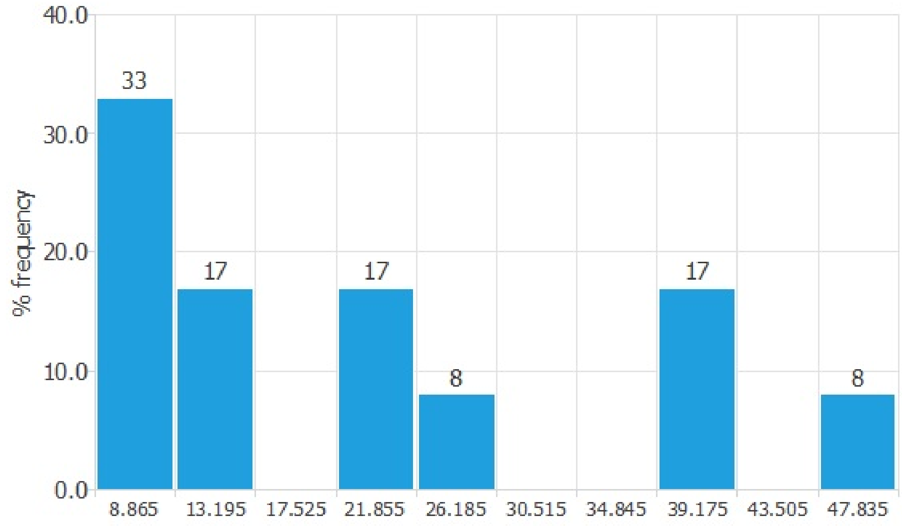
3.45 Defects_in_construction distribution

The following chart shows the histogram for the variable Defects_in_construction. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 8.33333%, which corresponds to the bins with centers 4.33, 5.56, 10, 11.11, 12, 13.33, 16.67. The maximum frequency is 41.6667%, which corresponds to the bin with center 0.



3.46 Schedule_Growth distribution

The following chart shows the histogram for the variable Schedule_Growth. The abscissa represents the centers of the containers, and the ordinate their corresponding frequencies. The minimum frequency is 0%, which corresponds to the bins with centers 17.525, 30.515, 34.845, 43.505. The maximum frequency is 33.3333%, which corresponds to the bin with center 8.865.



40.0
30.0
20.0
10.0
0.0
% frequency
33
17
17
8
17
8
8.865
13.195
17.525
21.855
26.185
30.515
34.845
39.175
43.505
47.835

APPENDIX L: BOX PLOTS FOR ALL RISK FACTORS

4 Box plot

4.1 Task description

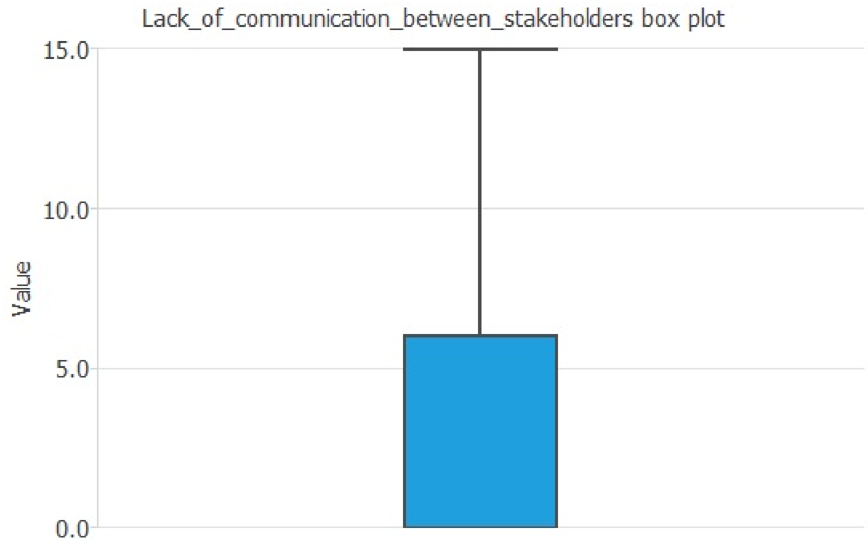
Box plots display information about the minimum, maximum, first quartile, second quartile or median and third quartile of every variable in the data set. They consist of two parts: a box and two whiskers. The length of the box represents the interquartile range(IQR), which is the distance between the third quartile and the first quartile. The middle half of the data falls inside the interquartile range. The whisker below the box shows the minimum of the variable while the whisker above the box shows the maximum of the variable. Within the box, it will also be drawn a line which represents the median of the variable. Box plots also provide information about the shape of the data. If most of the data are concentrated between the median and the maximum, the distribution is skewed right, if most of the data are concentrated between the median and the minimum, it is said that the distribution is skewed left and if there is the same number of values at the both sides of the median, the distribution is said to be symmetric.

4.2 Public_opposition box plot

The variable Public_opposition is constant and, therefore, no box plot is shown.

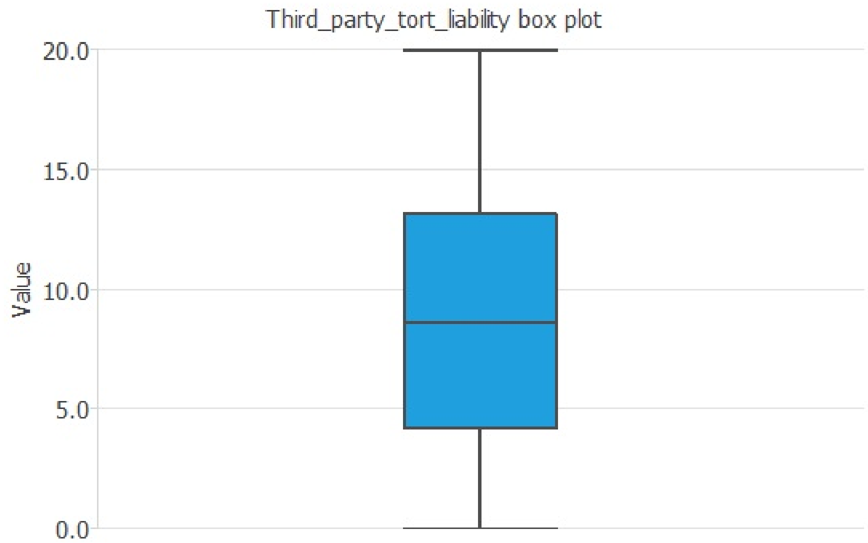
4.3 Lack_of_communication_between_stakeholders box plot

The following chart shows the box plot for the variable Lack_of_communication_between_stakeholders. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 6 and the maximum is 15.



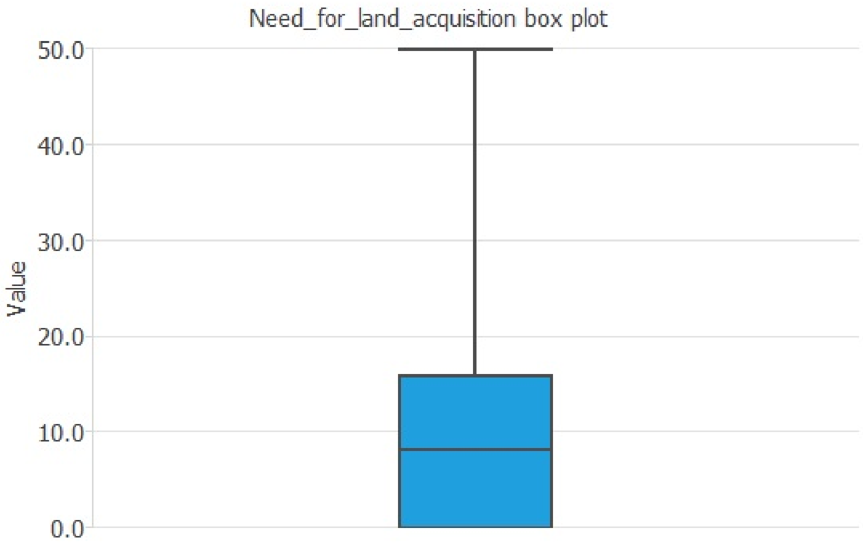
4.4 Third_party_tort_liability box plot

The following chart shows the box plot for the variable Third_party_tort_liability. The minimum of the variable is 0, the first quartile is 4.165, the second quartile or median is 8.61, the third quartile is 13.145 and the maximum is 20.



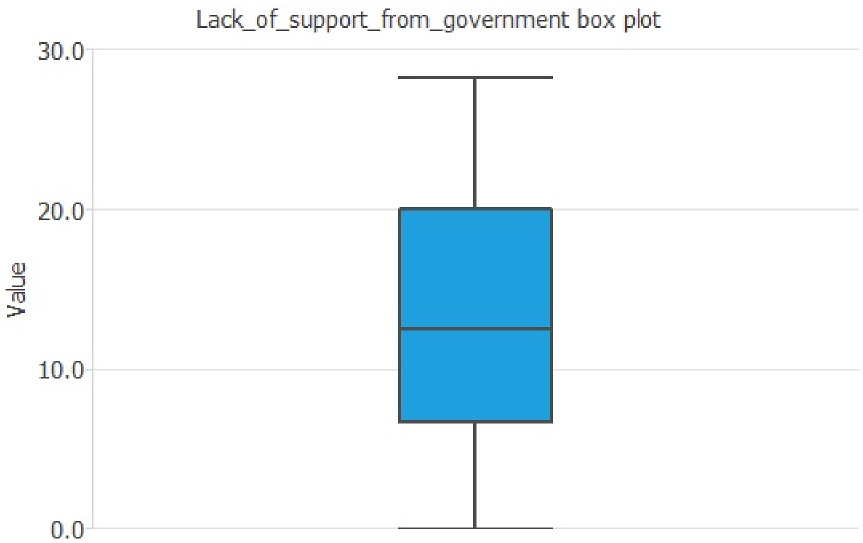
4.5 Need_for_land_acquisition box plot

The following chart shows the box plot for the variable Need_for_land_acquisition. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 8.055, the third quartile is 15.835 and the maximum is 50.



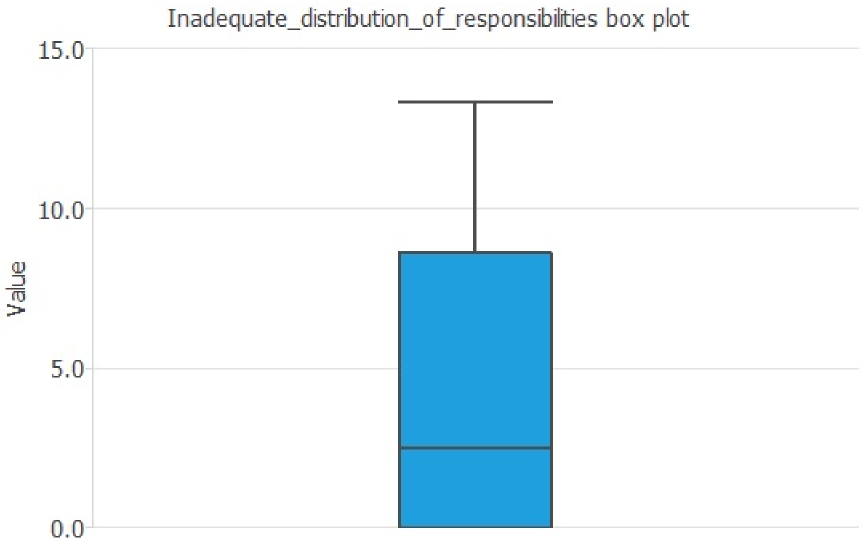
4.6 Lack_of_support_from_government box plot

The following chart shows the box plot for the variable Lack_of_support_from_government. The minimum of the variable is 0, the first quartile is 6.67, the second quartile or median is 12.5, the third quartile is 20 and the maximum is 28.33.



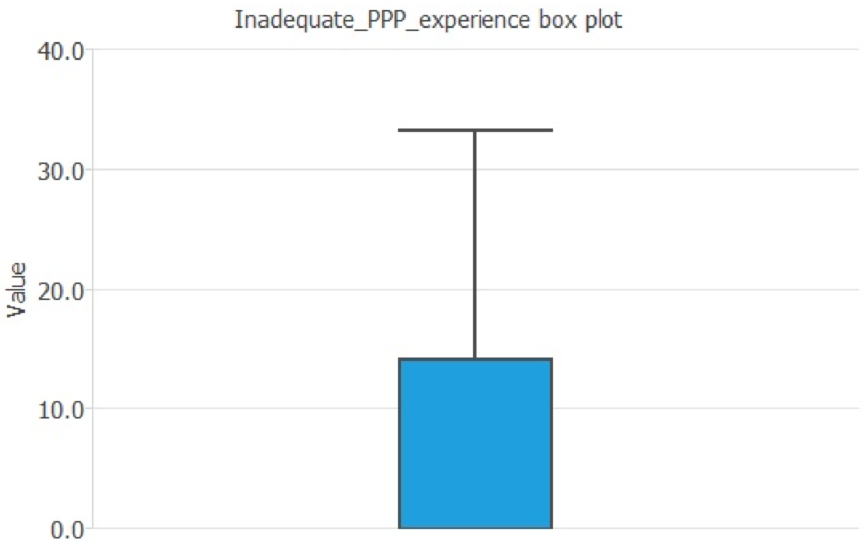
4.7 Inadequate_distribution_of_responsibilities box plot

The following chart shows the box plot for the variable Inadequate_distribution_of_responsibilities. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 2.5, the third quartile is 8.61 and the maximum is 13.33.



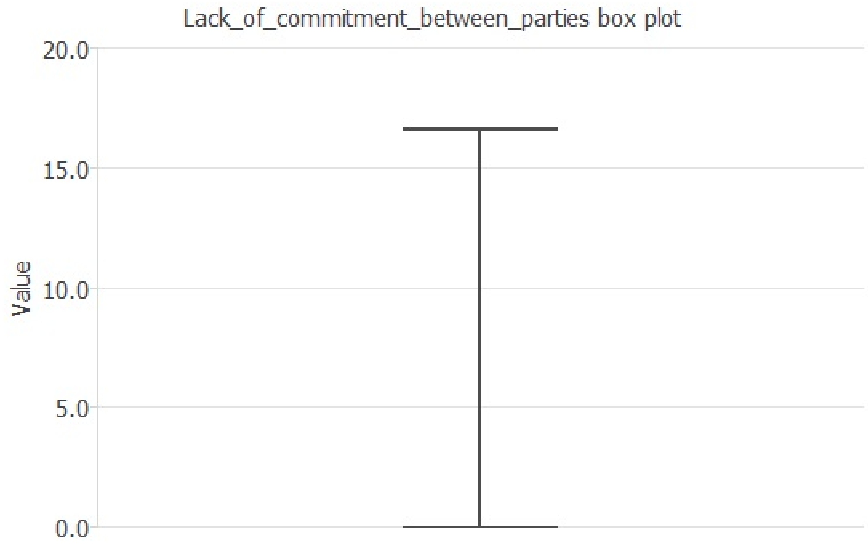
4.8 Inadequate_PPP_experience box plot

The following chart shows the box plot for the variable Inadequate_PPP_experience. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 14.165 and the maximum is 33.33.



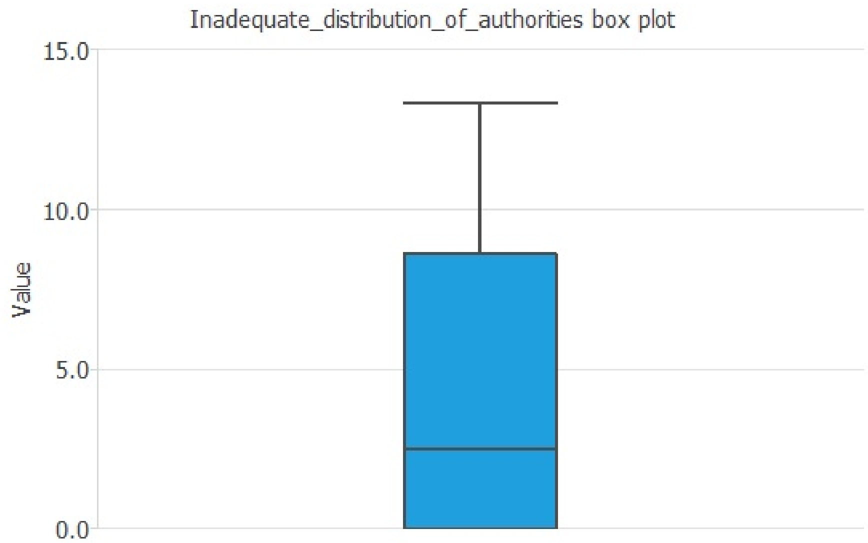
4.9 Lack_of_commitment_between_parties box plot

The following chart shows the box plot for the variable Lack_of_commitment_between_parties. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 0 and the maximum is 16.67.



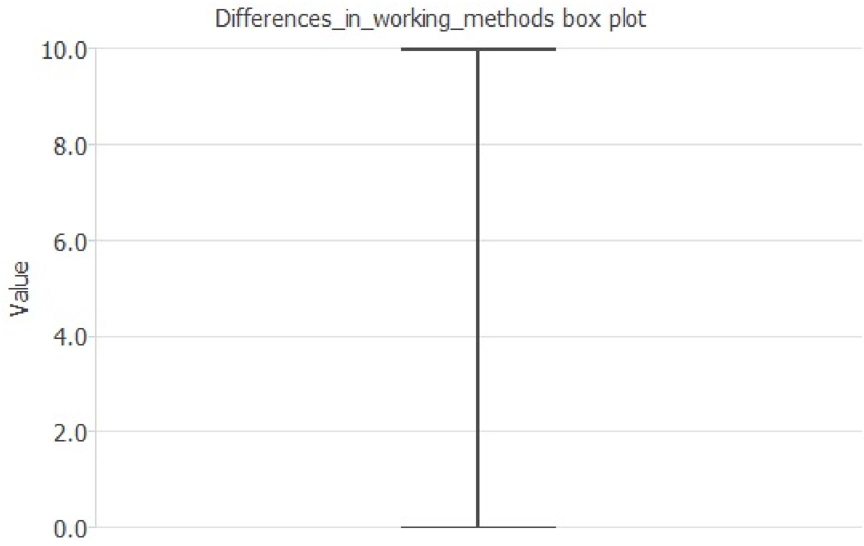
4.10 Inadequate_distribution_of_authorities box plot

The following chart shows the box plot for the variable Inadequate_distribution_of_authorities. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 2.5, the third quartile is 8.61 and the maximum is 13.33.



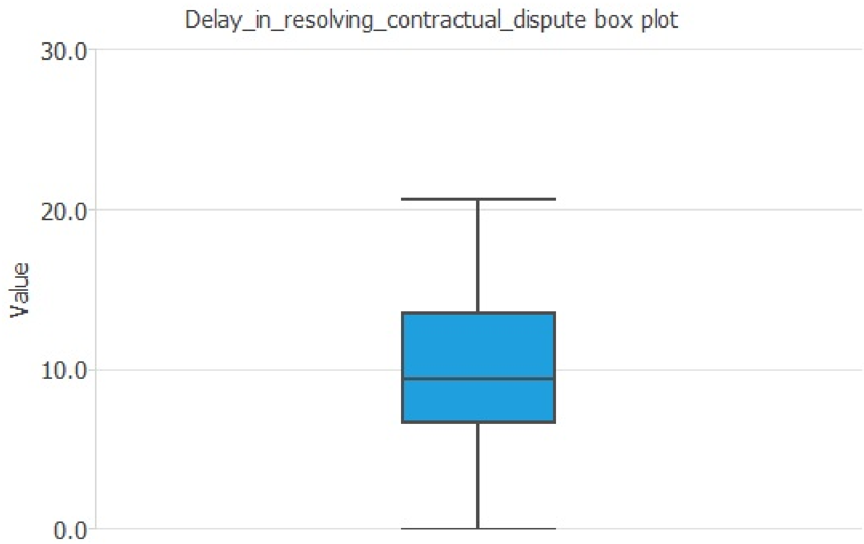
4.11 Differences_in_working_methods box plot

The following chart shows the box plot for the variable Differences_in_working_methods. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 0 and the maximum is 10.



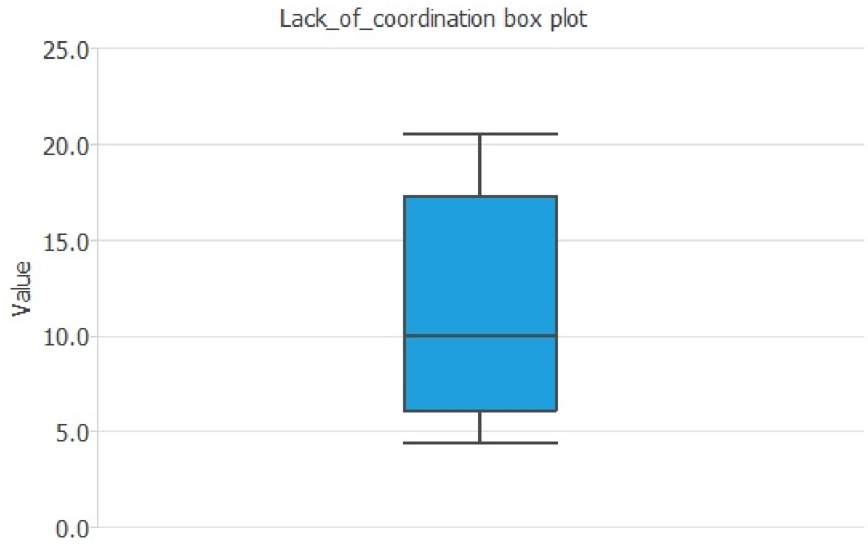
4.12 Delay_in_resolving_contractual_dispute box plot

The following chart shows the box plot for the variable Delay_in_resolving_contractual_dispute. The minimum of the variable is 0, the first quartile is 6.67, the second quartile or median is 9.445, the third quartile is 13.555 and the maximum is 20.67.



4.13 Lack_of_coordination box plot

The following chart shows the box plot for the variable Lack_of_coordination . The minimum of the variable is 4.44, the first quartile is 6.11, the second quartile or median is 10, the third quartile is 17.33 and the maximum is 20.56.

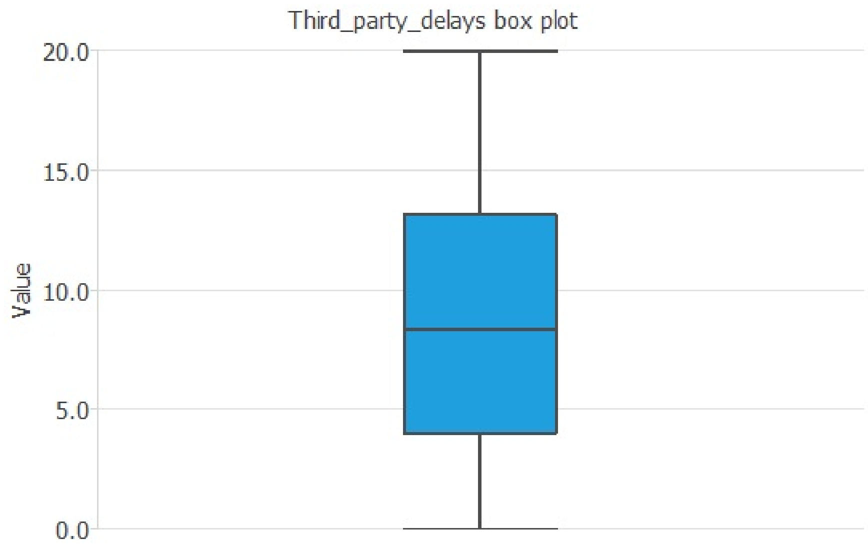


4.14 Private_investor_change box plot

The variable Private_investor_change is constant and, therefore, no box plot is shown.

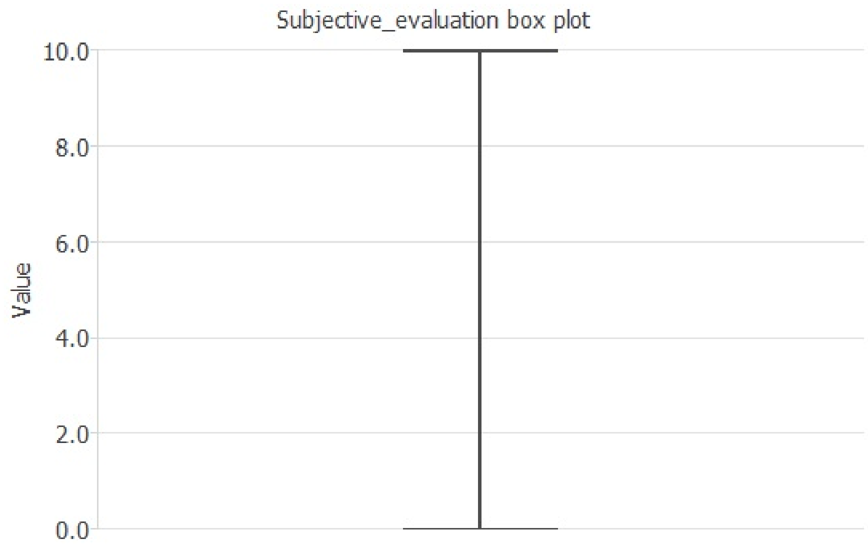
4.15 Third_party_delays box plot

The following chart shows the box plot for the variable Third_party_delays. The minimum of the variable is 0, the first quartile is 4, the second quartile or median is 8.33, the third quartile is 13.145 and the maximum is 20.



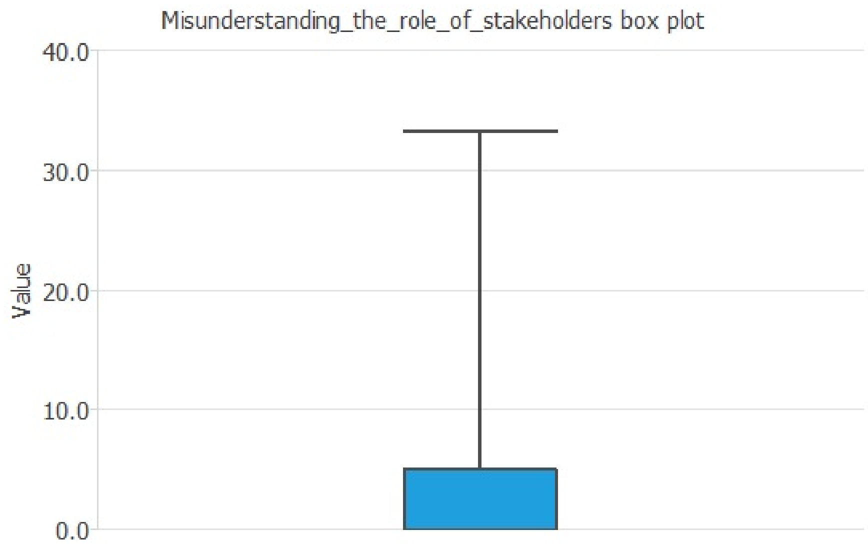
4.16 Subjective_evaluation box plot

The following chart shows the box plot for the variable Subjective_evaluation. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 0 and the maximum is 10.



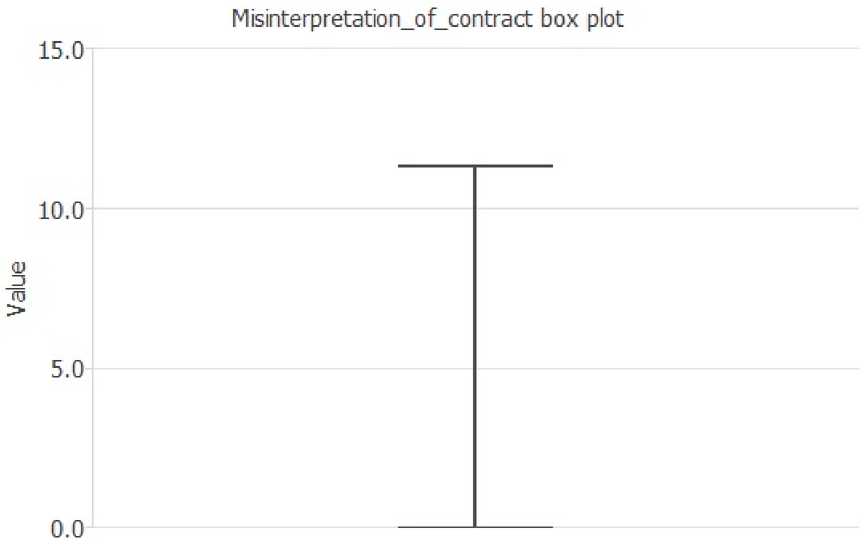
4.17 Misunderstanding_the_role_of_stakeholders box plot

The following chart shows the box plot for the variable Misunderstanding_the_role_of_stakeholders. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 5 and the maximum is 33.33.



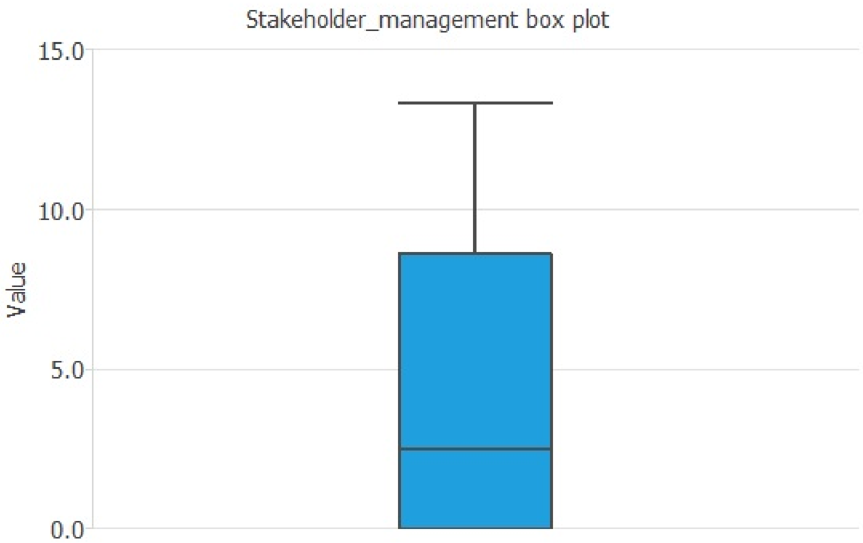
4.18 Misinterpretation_of_contract box plot

The following chart shows the box plot for the variable Misinterpretation_of_contract. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 0 and the maximum is 11.33.



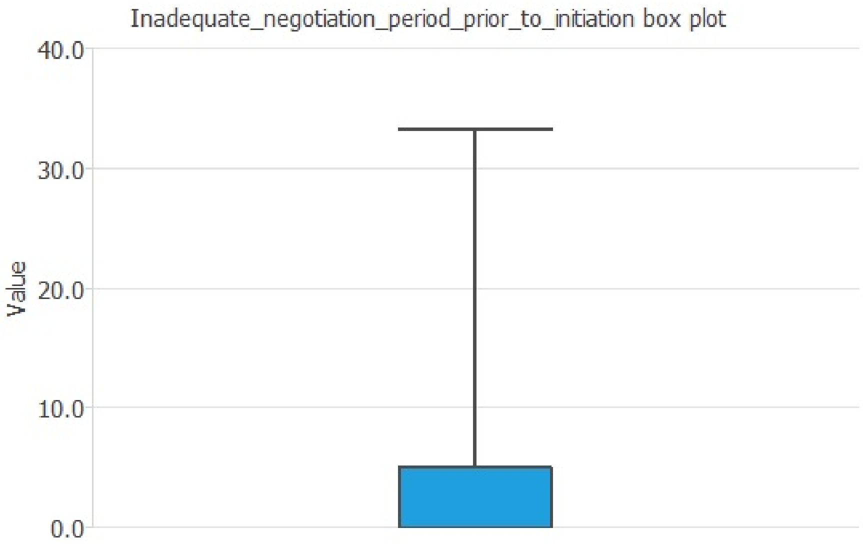
4.19 Stakeholder_management box plot

The following chart shows the box plot for the variable Stakeholder_management. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 2.5, the third quartile is 8.61 and the maximum is 13.33.



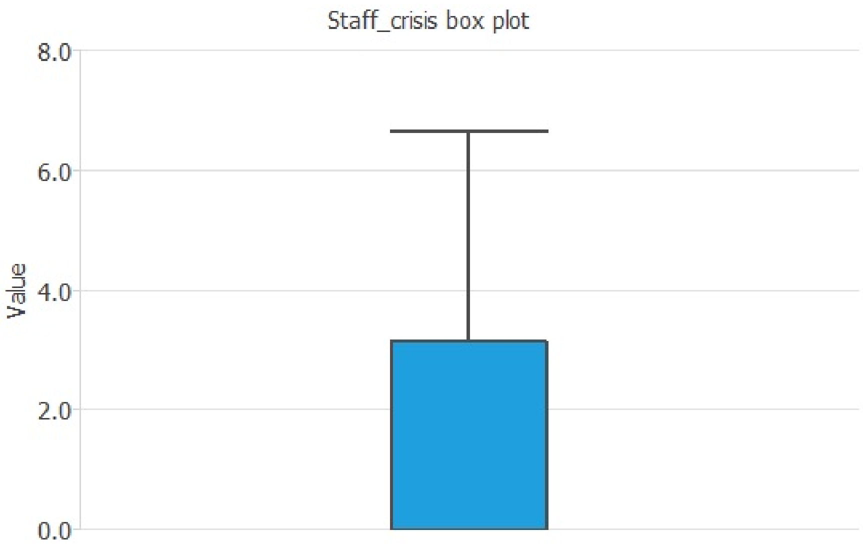
4.20 Inadequate_negotiation_period_prior_to_initiation box plot

The following chart shows the box plot for the variable Inadequate_negotiation_period_prior_to_initiation. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 5 and the maximum is 33.33.



4.21 Staff_crisis box plot

The following chart shows the box plot for the variable Staff_crisis. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 3.15 and the maximum is 6.67.

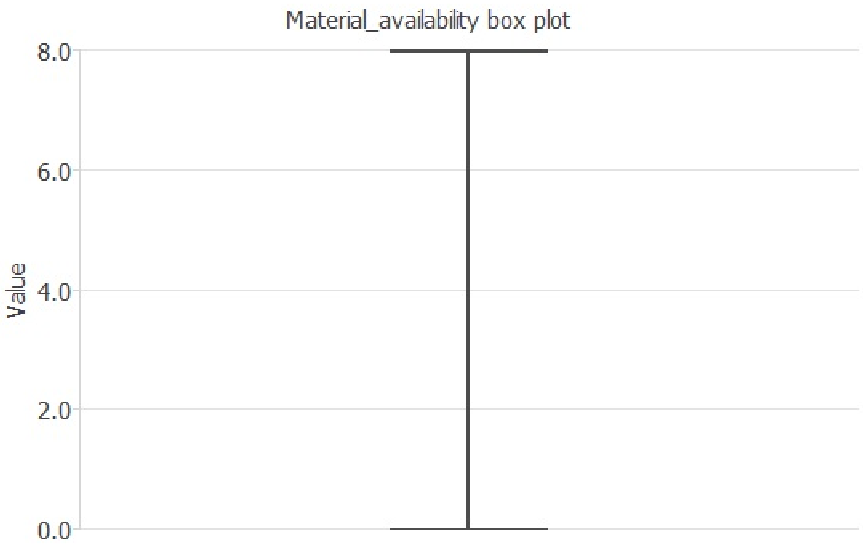


4.22 Cultural_differences box plot

The following chart shows the box plot for the variable Cultural_differences. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 0 and the maximum is 28.33.

4.23 Material_availability box plot

The following chart shows the box plot for the variable Material_availability. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 0 and the maximum is 8.

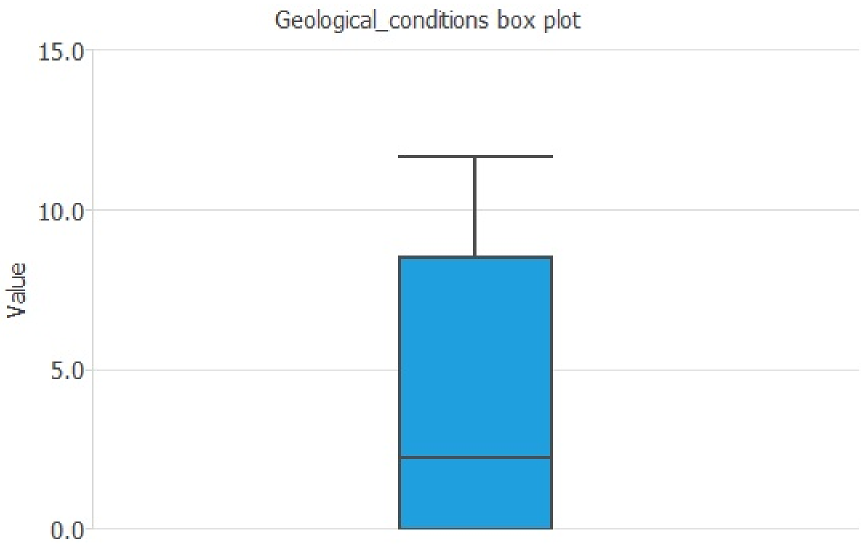


4.24 Construction_cost_overrun box plot

The variable Construction_cost_overrun is constant and, therefore, no box plot is shown.

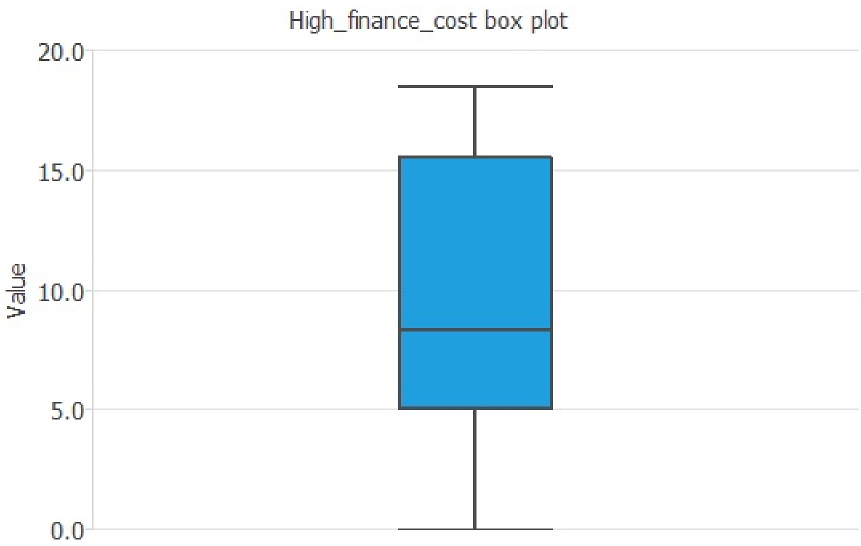
4.25 Geological_conditions box plot

The following chart shows the box plot for the variable Geological_conditions. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 2.22, the third quartile is 8.52 and the maximum is 11.67.



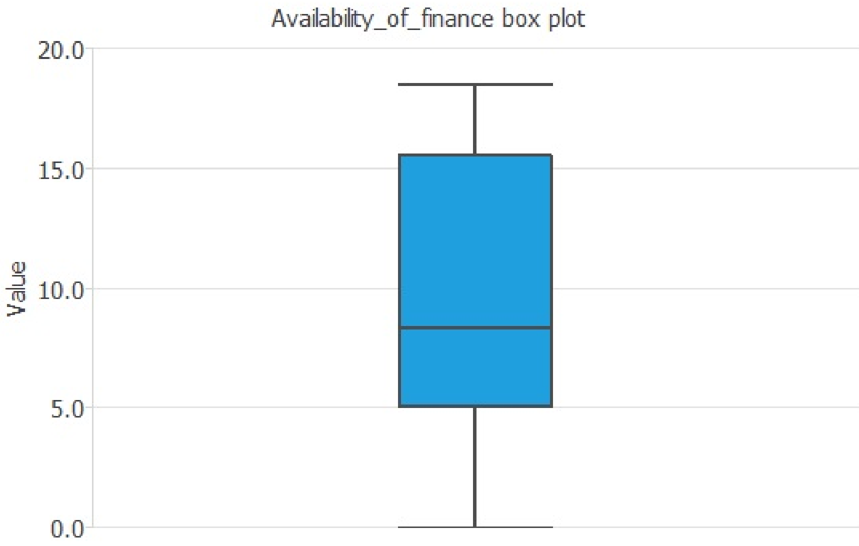
4.26 High_finance_cost box plot

The following chart shows the box plot for the variable High_finance_cost. The minimum of the variable is 0, the first quartile is 5.055, the second quartile or median is 8.335, the third quartile is 15.555 and the maximum is 18.52.



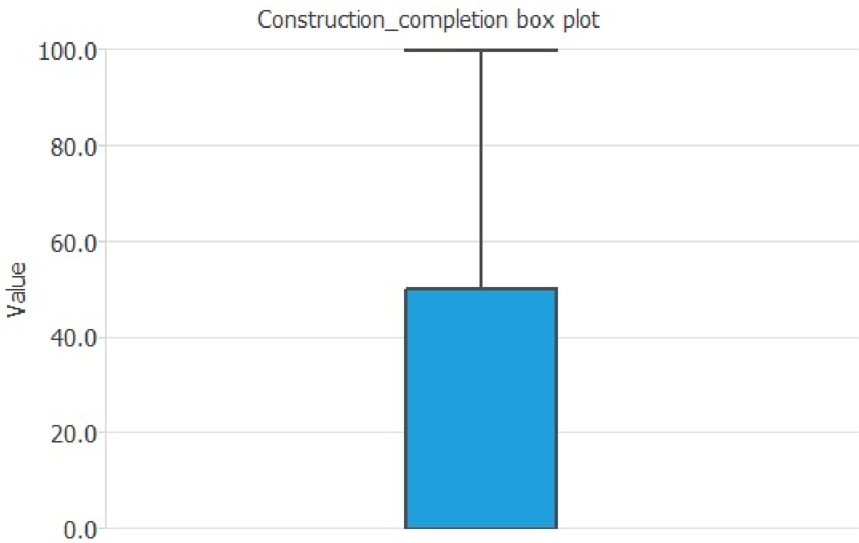
4.27 Availability_of_finance box plot

The following chart shows the box plot for the variable Availability_of_finance. The minimum of the variable is 0, the first quartile is 5.055, the second quartile or median is 8.335, the third quartile is 15.555 and the maximum is 18.52.



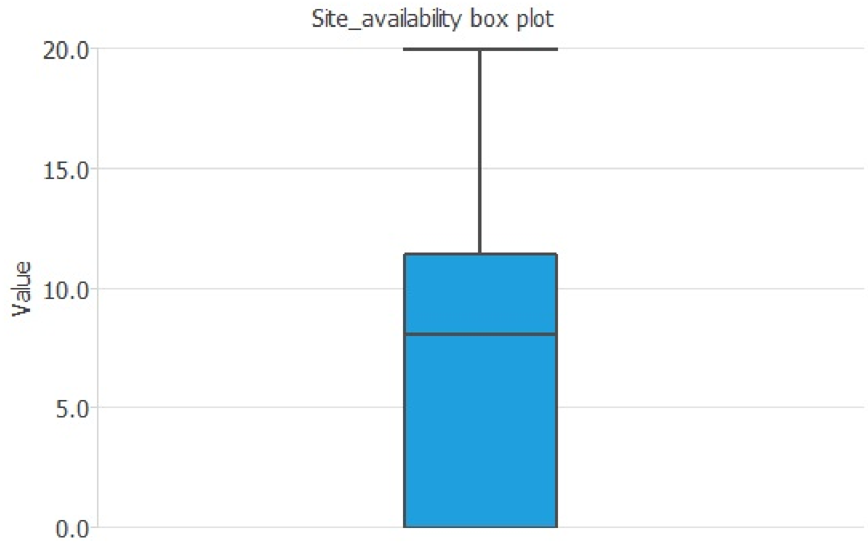
4.28 Construction_completion box plot

The following chart shows the box plot for the variable Construction_completion. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 50 and the maximum is 100.



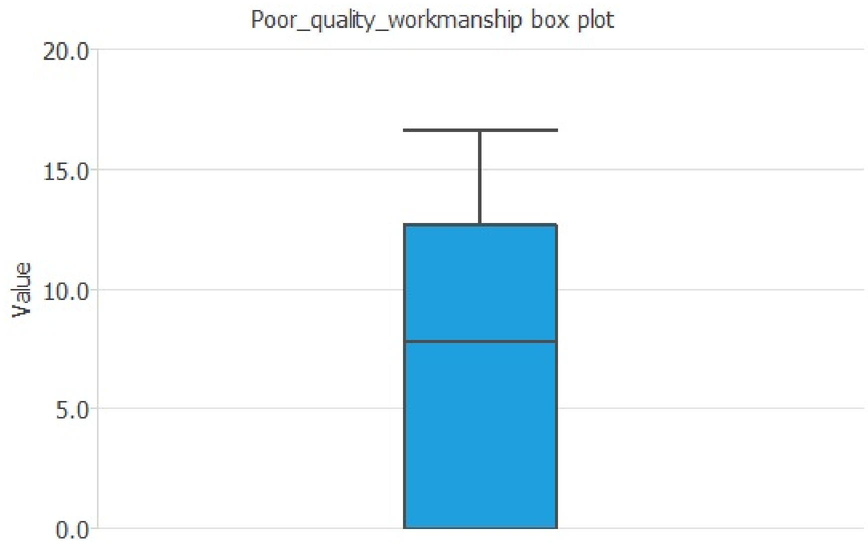
4.29 Site_availability box plot

The following chart shows the box plot for the variable Site_availability. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 8.055, the third quartile is 11.39 and the maximum is 20.



4.30 Poor_quality_workmanship box plot

The following chart shows the box plot for the variable Poor_quality_workmanship. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 7.78, the third quartile is 12.665 and the maximum is 16.67.



4.31 Labor_availability box plot

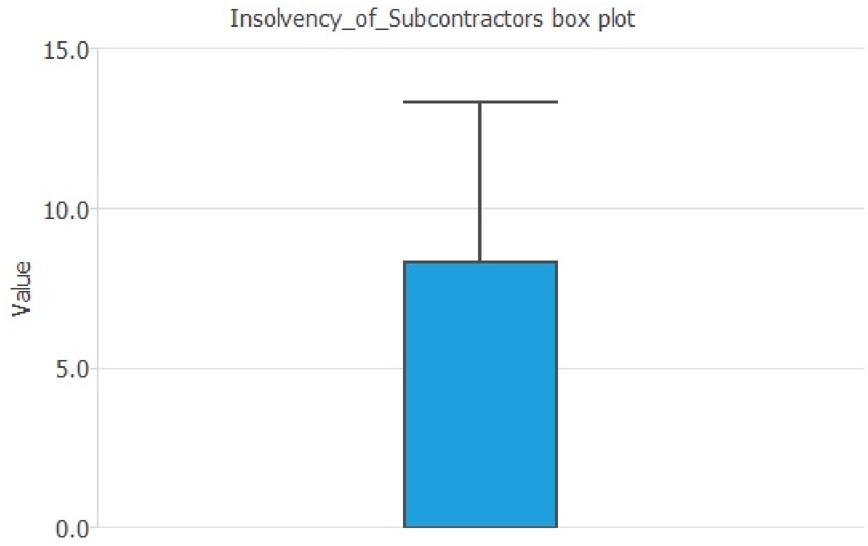
The following chart shows the box plot for the variable Labor_availability. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 0 and the maximum is 3.33.

4.32 Site_safety box plot

The following chart shows the box plot for the variable Site_safety. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 0 and the maximum is 6.67.

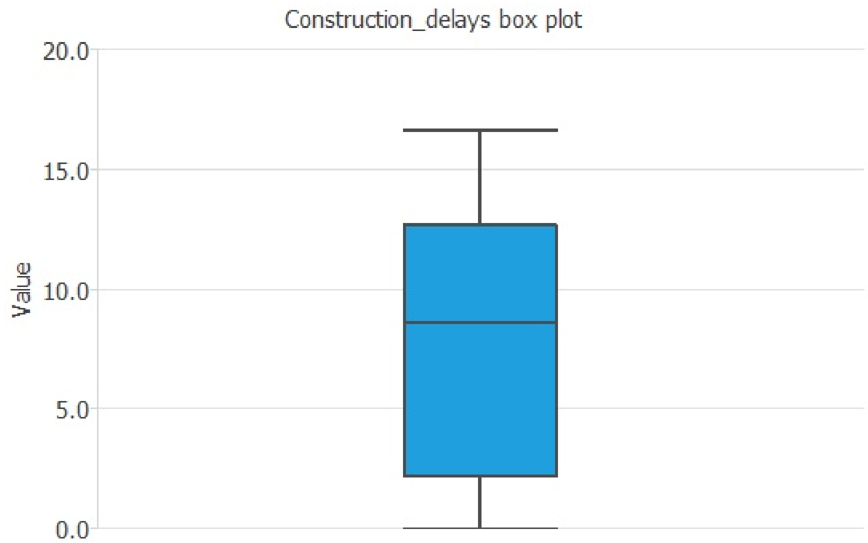
4.33 Insolvency_of_Subcontractors box plot

The following chart shows the box plot for the variable Insolvency_of_Subcontractors. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 8.33 and the maximum is 13.33.



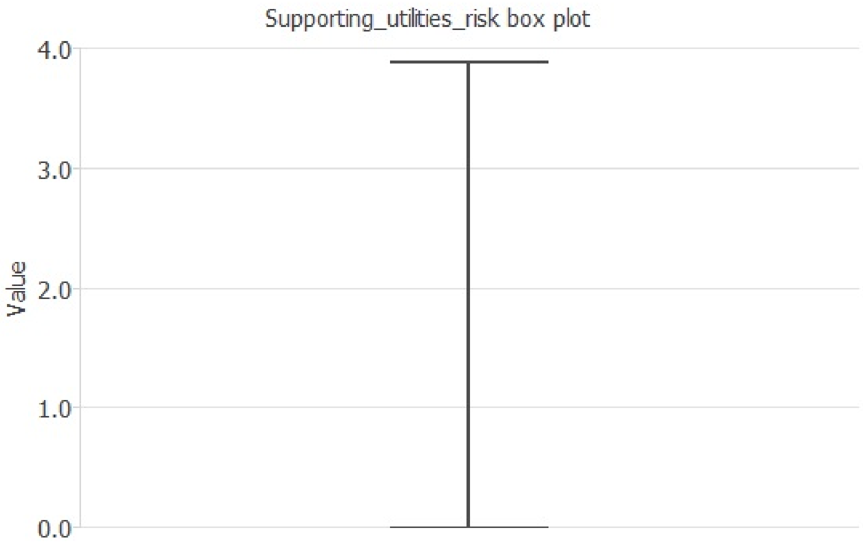
4.34 Construction_delays box plot

The following chart shows the box plot for the variable Construction_delays. The minimum of the variable is 0, the first quartile is 2.165, the second quartile or median is 8.61, the third quartile is 12.665 and the maximum is 16.67.



4.35 Supporting_utilities_risk box plot

The following chart shows the box plot for the variable Supporting_utilities_risk. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 0 and the maximum is 3.89.



4.36 Labor_disputes box plot

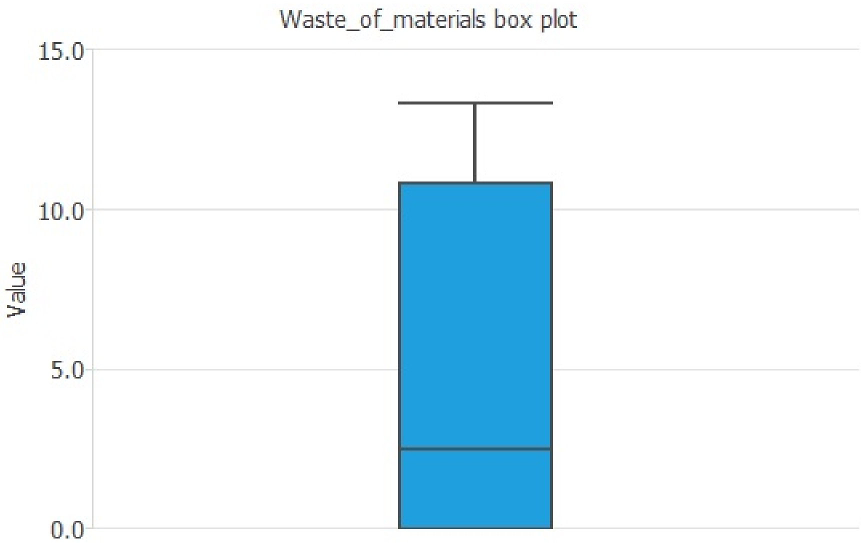
The following chart shows the box plot for the variable Labor_disputes. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 0 and the maximum is 6.67.

4.37 Land_use box plot

The following chart shows the box plot for the variable Land_use. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 0 and the maximum is 50.

4.38 Waste_of_materials box plot

The following chart shows the box plot for the variable Waste_of_materials. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 2.5, the third quartile is 10.835 and the maximum is 13.33.

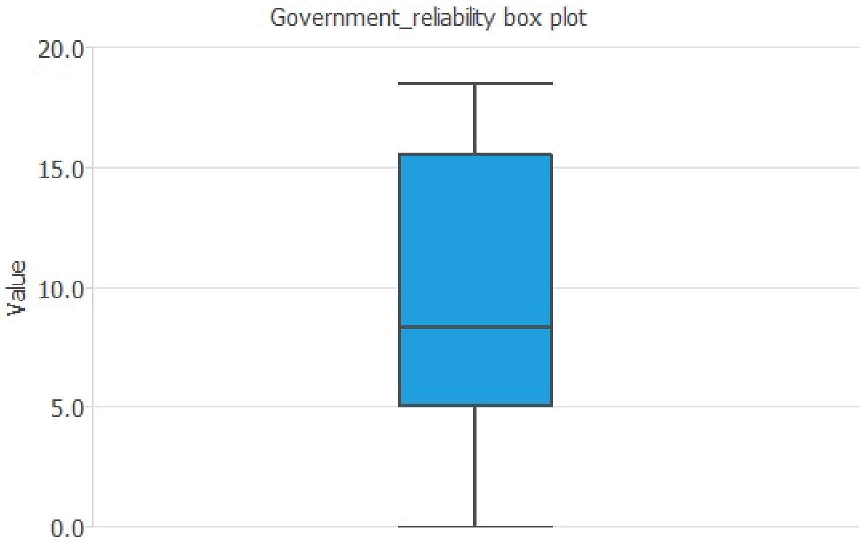


4.39 Protection_of_geological_and_historical_objects box plot

The variable Protection_of_geological_and_historical_objects is constant and, therefore, no box plot is shown.

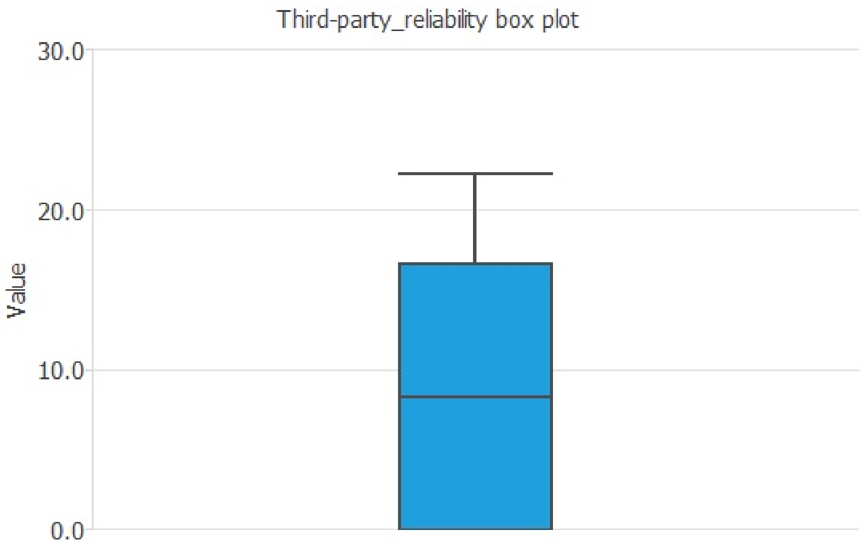
4.40 Government_reliability box plot

The following chart shows the box plot for the variable Government_reliability. The minimum of the variable is 0, the first quartile is 5.055, the second quartile or median is 8.335, the third quartile is 15.555 and the maximum is 18.52.



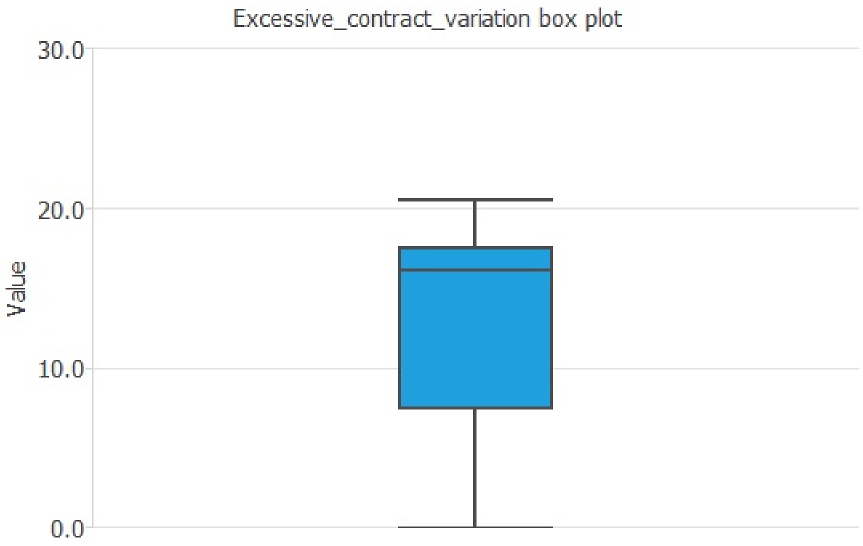
4.41 Third-party_reliability box plot

The following chart shows the box plot for the variable Third-party_reliability. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 8.33, the third quartile is 16.66 and the maximum is 22.22.



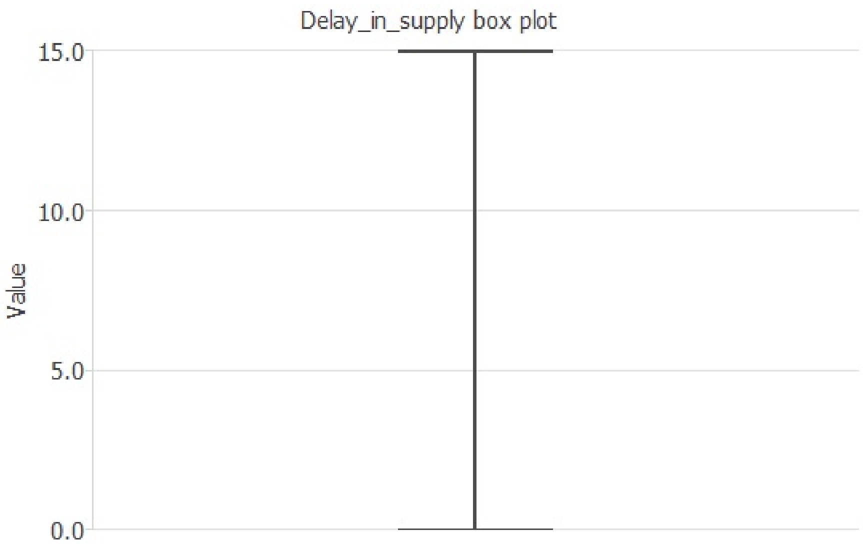
4.42 Excessive_contract_variation box plot

The following chart shows the box plot for the variable Excessive_contract_variation. The minimum of the variable is 0, the first quartile is 7.5, the second quartile or median is 16.115, the third quartile is 17.555 and the maximum is 20.56.



4.43 Delay_in_supply box plot

The following chart shows the box plot for the variable Delay_in_supply. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 0, the third quartile is 0 and the maximum is 15.

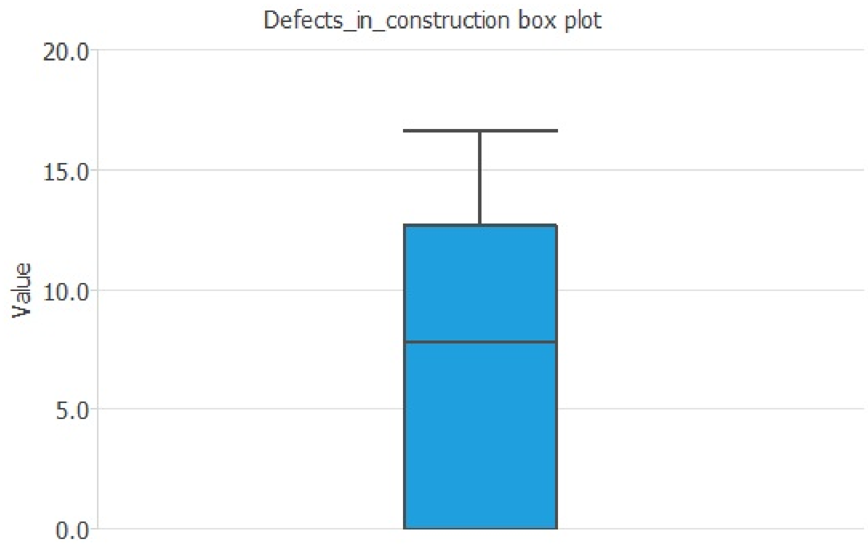


4.44 Constructability box plot

The variable Constructability is constant and, therefore, no box plot is shown.

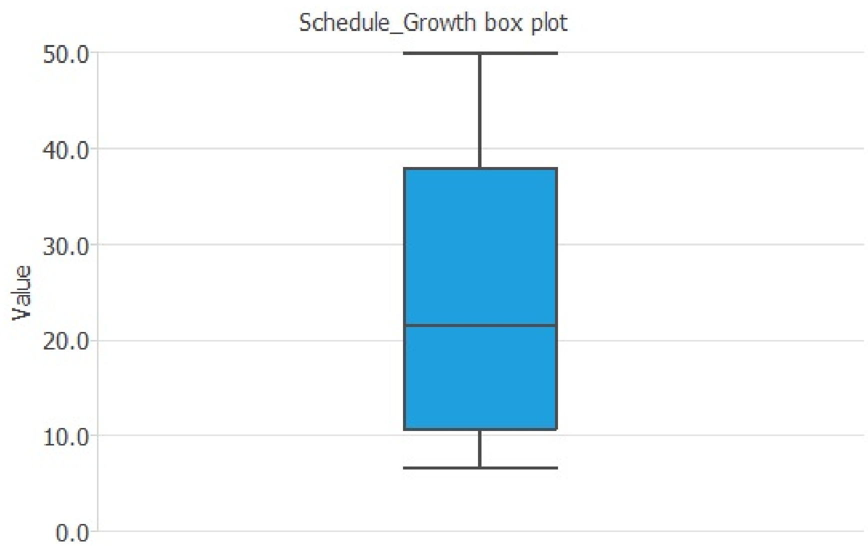
4.45 Defects_in_construction box plot

The following chart shows the box plot for the variable Defects_in_construction. The minimum of the variable is 0, the first quartile is 0, the second quartile or median is 7.78, the third quartile is 12.665 and the maximum is 16.67.



4.46 Schedule_Growth box plot

The following chart shows the box plot for the variable Schedule_Growth. The minimum of the variable is 6.7, the first quartile is 10.7, the second quartile or median is 21.55, the third quartile is 38 and the maximum is 50.



5 Inputs-targets correlations

5.1 Task description

It might be interesting to look for dependencies between single input and single target variables. This task calculates the values of the correlation coefficient between all inputs and all targets. Correlations close to 1 mean that a single target is correlated with a single input. Correlations close to 0 mean that there is not a