

T.C.
İSTANBUL KÜLTÜR UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

PROJECT RISK MANAGEMENT
USING BAYESIAN BELIEF NETWORK

Master of Science Thesis

Abdimalik Shueib Abdilatif

Department: Industrial Engineering

Program: Engineering Management

Supervisor: Prof. Dr. Murat Ermiş

FEBRUARY 2023

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Civil Engineer

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ABBREVIATIONS

PRM	: Project Risk Management
PMI	: Project Management Institute
BBN	: Bayesian Belief Network
SEM	: Structural Equation Modeling
BIC	: Bayesian Information Criterion
AIC	: Akaike's Information Criterion
DAG	: Direct Acyclic Graph

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ÖZET

BAYESGİL İNANÇ AĞLARI İLE PROJELERDE RİSK YÖNETİMİ

Abdimalik Shueib Abdilatif

Proje yönetimindeki temel motivasyonlardan biri projelerin başarı olasılığını artırmaktır. Başarısızlık olasılığını en aza indirmek için yatırımları ve riskleri optimize etmeye yönelik kurumsal politikalara risk yönetimi denir. Uzmanlar, proje yönetimi uygulamalarını değerlendirmek ve proje sonucunu iyileştirmek için bir takım Proje Risk Yönetimi (PRM) modeli geliştirmiştir. Bu çalışmada, risklerin proje performansı üzerindeki etkisini tahmin etmek için genel bir çerçeve ve bir yöntem geliştirilmek hedeflenmiştir. Proje yönetimi uzmanlarının bilgilerini resmileştirmek ve bir veri tabanından bilgi çıkarmak için Bayes ağları kullanıldı. İnşaat sektöründeki bir projede proje bütçesi/tamamlama süresi aşımı riskini azaltmada yöntemin nasıl uygulanabileceğini göstermek amacıyla gerçek hayattan bir vaka kullanılmıştır.

Anahtar Kelimeler: Bayes İnanç Ağları, Proje Yönetimi, Bilgi Modelleme

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ABSTRACT

PROJECT RISK MANAGEMENT USING BAYESIAN BELIEF NETWORK

Abdimalik Shueib Abdilatif

One of the main motivations in project management is to increase the probability of success of projects. Organizational policies to optimize investments and risks to minimize the possibility of failure are called risk management. Experts have developed several Project Risk Management (PRM) models to assess project management practices and improve the project outcome. The present study develops a general framework and a method to estimate the impact of risks on project performance. It uses Bayesian networks to formalize project management experts' knowledge and to extract knowledge from a database. A real-life case is used to demonstrate how the method can be applied to reduce the risk of project budget/completion time overrun on a project in the construction industry.

Keywords: Bayesian Belief Network, Project Management, Knowledge Modeling

1. INTRODUCTION

In recent years, with the rapidly developing technology and digitalization, there has been a drastic change and transformation in the good and service sectors. While the use of advanced technology in value creation processes offers opportunities such as speed, efficiency and cost advantage, it has also led to the emergence of new risks. It has become important in today's competitive environment to develop the ability to effectively manage uncertainty in engineering projects and to evaluate the risks encountered while creating value in a dynamic and agile manner. In order to manage risks, it is important to transform this process into a strategic decision-making mechanism.

Risk may be defined as the likelihood that an undesirable result will occur or that a desired outcome will not be achieved. Risk is an appropriate way to describe an unknown or uncertain situation regarding a process or event. If something is to happen for sure, there is no uncertainty and therefore no risk. How to handle risks effectively has always been a priority for policymakers, researchers, and engineers.

The mathematical processes and understandings that led to our current perceptions of risk began to develop as the foundation of modern civilization from the mid-seventeenth century. The story of the transition from belief to calculated probability is gracefully explained in "Against the Gods, The Remarkable Story of Risk" (Bernstein, 1996). Yet the inherent uncertainty of the processes was recognized early on by some scientists, such as Leibniz. In 1703, Leibniz replied the Bernoulli's letter about applying the mathematics and probability to games of chance: "Nature has established patterns that result from the reversal of events, but most of the time". This captures the main idea that some variation in frequency is predictable, at least approximately.

In short, the challenge addressed in this thesis is to effectively deal with risks in large engineering projects with the Bayesian Belief Network, while always recognizing the impossibility of truly predicting the future to eliminate all risks.

1.1. Project Risk Management

One of the main motivations in project management is to increase the probability of success of projects. Risks are inevitable in the projects carried out and almost all projects are exposed to risks. Organizational policies to optimize investments and risks to minimize the possibility of failure are called risk management. The project manager has the responsibility to ensure that the impact of risks is minimized.

Risk management focuses on predicting what may not go according to plan and putting tasks into action to reduce uncertainty to a tolerable level. Risk can be perceived as positive (opportunities) or negative (threats). Risk is the potential for a situation or event to affect the achievement of certain objectives (Weaver, 2008).

Project risk is defined by the Project Management Institute (PMI) as “an uncertain event or condition that, if it occurs, has a positive or negative effect on a project’s objectives” (www.pmi.org). Therefore, Project Risk Management (PRM) is a method for identifying, assessing, measuring, monitoring and reporting for possible risks that may jeopardize performance and objectives of the project (Figure 1.1).



Figure 1.1: Risk Management cycle (Çakmak, 2021).

Project risk management exposes the dynamic nature of project work by identifying and managing emerging risks and reflecting new insights in current risk analysis. The first step in PRM is identification. This is the first step in the risk management process because one cannot resolve a risk if the risk is unknown. There are many ways to get the project risk identified like brainstorming, interviewing with experienced people, etc. After the risks are identified, their assessment is carried out in the second step. Risk analysis is usually done on a qualitative or quantitative basis. The risks are then classified according to different criteria. As soon as the source of the biggest risks in project management and which needs to be addressed quickly becomes clear, corrective action is taken in step three. It is important to monitor both the measures taken and the current situation in project risk management. This is important to ensure that risk responses remain effective, fast and efficient. The status of the risks and their expected impact and probability of occurrence should be constantly monitored in step four. In the last step, risks and the realization of the project should be controlled dynamically throughout the project life cycle. The sudden increase in risks may endanger the feasibility of the project. Therefore, all information that may be relevant to risks should be evaluated. Internal risks were identified as risk factors that influence how a project performs. A well designed PRM infrastructure drives the achievements of the project's operational performance, with guaranteed quality, deadlines met, costs not exceeded, etc. (Grant & Pennypacker, 2006). The Project Management literature also shows that if the PRM infrastructure is well designed, it reduces the performance failures of projects, especially cost overruns, which is a type of project risk (Besner & Hobbs, 2008).

1.2. Bayesian Belief Networks

Cause-effect diagram and influence diagram are some of the graph-based methodologies that can be used in the analysis of risks in PRM. In addition, diagrams are useful in modeling conditional probability relationships between risks and in handling complex problems. However, establishing these relationships is not as easy as it seems and requires more complex analyzes to be performed. Because of these drawbacks, the diagram approach has not been widely applied to project risk management (Han & Diekmann, 2001; Lyons & Skitmore, 2004; Raz & Michael, 2001; Simister, 1994).

Bayesian belief network is a graphical model that identifies causal relationships between a set of variables and presents probabilistic relationships between them (Heckerman, 1997). A Bayesian belief web can be a suitable methodology for project risk management with systematic and integrated processes, as it easily creates a cause-effect diagram.

Bayesian Belief Network is a powerful tool for knowledge representation and reasoning under conditions of uncertainty (Cheng et al., 2002). It also visually presents probabilistic relationships between a set of variables (Heckerman et al., 1995a). It is applied to real-world problems such as automated vision, software risk management, diagnosis, and production control (Heckerman et al., 1995b). Bayesian belief network has many advantages such as suitability for small and incomplete datasets, combination of different information sources, explicit handling of uncertainty, and support for decision analysis (Uusitalo, 2007).

1.3. Purpose Of Thesis

This paper proposes a way to overcome this risk by focusing on a major project performance failure and a framework, namely Bayesian Belief Networks. This general theory of knowledge views probability as a tool for weighing one's belief that about a generic direct cause and to compare these beliefs with empirical data. When several causes explain the same effect, a network of causes can be constructed from which the most convincing causal paths can be identified by applying Bayesian inference. Bayesian Networks (BNs) are valuable tools for creating, displaying and analyzing causal models that explain an effect for many reasons and feeding data to them. Because of their focus on beliefs, individual knowledge, expertise, and data independent of these elements, BNs are adapted to the current context of information technology us. This explains why BNs are used in many fields, including Project Management.

1.4. Hypothesis

Building on the general ideas outlined in the previous sections, we will try to contribute to the field of risk management in projects by addressing the following research question:

How can we methodologically create BNs to improve Project Risk Management on large projects? Through the analysis of historical data and expert knowledge of major engineering projects in the construction industry, the proposed method and model will take PM's applications as input and the expected cost/time out risk as output. Our proposed BN is intended to assist PM professionals in determining which approach should be followed to improve PRM. The computational results are based on data from a construction project in Somalia.

The thesis is organized as follows: At chapter 2 literature review is conducted. The literature review mainly consists of project management literature based on risk assesment, and Bayesian belief networks.

The Bayesian Belief Network model development is explained at chapter 3 in detail. Risk assessment approach and knowledge acquisition methods are also explained in this chapter. The model variables, assumptions, and key performance indicators are also explained.

An application of project risk management procedure using a Bayesian belief network is discussed at chapter 4. All parameters are based on a real-life construction project data. The computations are run using retrieved data from this project and then, the obtained solutions are compared with the current situation. The summary of this study and the interpretation of the results are presented in the last chapter.

2. LITERATURE REVIEW

After the Second World War, construction industries began to define the fundamentals of project management and discovered that quality performance and risk management are the basis of project management and are often used to help with challenging jobs. In a world where international competition is so intense, time and money are important requirements for organizations to deliver their projects to their customers faster and cheaper than their competitors. Most projects fail when it comes to cost and time. Because of this, most organizations need to improve the way they manage their projects, not only to meet their project goals, but also to make sure they're part of the cost, budget, and customer satisfaction equation. Research in recent years has shown that most projects fail within this framework. This makes it even more important to develop project management skills.

In a study conducted by Standish Group (1995), it was stated that 31% of the projects were decided to be canceled before they were completed, and 53% of the projects exceeded the allocated budget by 189%. In addition, the report shows that out of every 100 projects started, 94 need to be redone and one-third of the projects reviewed fall behind schedule by up to 300%. Only 16% of the projects were completed on time and within budget.

The main goal of project risk management is to find, assess, and control risks that could affect the success of a project. Measuring a project's success is hard because it can change from one phase to the next and different people have different ways of judging project's success. Project management has evolved over time and a lot has been learned, used and improved about planning engineering projects. Methods that used to work may not work now due to changes in technology and the complexity of completing projects. The project management community is concerned about its lack of historical foundation (Söderlund & Lenfle, 2013).

Project crises occur when several unlikely, mismanaged risks arise unexpectedly, or when a major risk has an immediate negative outcome.

A crisis is a great danger that causes the project manager to make critical choices. The definitions of "risk" and "crisis" have a close resemblance, and both can have their roots in an internal or external risk. Risks may or may not develop at some point in the near future, but a crisis always comes as a surprise and might take place at any moment. Furthermore, during crises, a leadership is critical that can push the necessary modifications in the project management process (Alves et al., 2021).

Since 1920s, management literature has talked about uncertainty and how it relates to project risks (Geraldi et al., 2011). Most decision making are made with a lot of uncertainties (Cooper & Herskovits, 1991). Risk evaluation is one the most important factors in project risk management and it determines the ability of project managers to get rid of threats (Motaleb & Kishk, 2014). According to Simon Jackson (2002), team working and individual skills are the foundation of success in any project.

The success of the projects is determined by not exceeding the budget and timeline (Baccarini & Archer, 2001). For a project to be successful, the management team must frequently monitor the project by collecting the latest project data and comparing it to the original project schedule (Hartono et al., 2015).

Research conducted in April 2007 found that the most significant risks were design change, design manpower, and raw material supply as internal risks, while the most significant external risk was the exchange rate (Lee et al., 2009). A survey conducted in Somalia in 2022, it was found that the most significant risks were project monitoring, unskilled workers, delayed raw material and budget overrun as internal risks, while the most significant external risks were security problems and the exchange rate (Shueib, 2022). In both of these researches internal risks were the risks that affected the performance of a project.

The best way to avoid project risk is to ensure that effective communication is present among the project team. Mostly project managers fail to keep all the necessary people on the same page (Cervone, 2006). This study suggests using project tracking system to improve collaboration. Within the project tracking system, it is important to have project strategies and its risks. Project tracking helps learn from the past as it allows project managers to record the findings of risk assessment. This type of tracking often becomes helpful later in the project or in future projects.

When used well, effective communication may get rid of mistakes, helps manage uncertainty and will enable individuals perform better as a team. (Clarke, 1999).

Fairley (1994) laid out the steps of the project risk management process as; identify the risk factors, figure out the probability of occurrence and the effects they will have on the project, develop strategies to reduce the identified risk, observation of risk factors, have a backup plan, manage crisis and finally recover from the problem.

Willumsen et al. (2019) concentrated on the control of risk to add value to the project. In this article, a review of the literature and an empirical study were done to add value to the project. Interview questions with experts and qualitative analysis were done as a part of an empirical study. The study reveals that stakeholder's point of view is an important factor on the success of the project. The results show that different risks need to be understood better based on how stakeholders see them. This adds more value to the risk management process.

Osunsanmi et al. (2020) discussed the importance of adopting Construction 4.0 technology, known as the fourth industrial revolution. With Construction 4.0 technology, it is possible to improve how projects are designed, managed and assisted in decision making. Construction 4.0 concept is rarely used in today's construction works. Yet not enough people in the construction industry know how to deal with risks, which means money, time, quality etc. causing losses.

2.1. Project Risk Management

Risk management has been chosen as one of the main areas of Project Management and the authors have suggested that organizations that manage and control their projects well place greater value on risk analysis tools (Raz & Michael, 2001).

Lessard and Miller (2001) have shown that it is very difficult to determine early on how to direct and manage the risks involved in large construction projects. They also stated that when risks are "internal", that is, specific and controllable, classical risk management techniques are recommended for minimizing risks. When risks are specific but uncontrollable, the right solution is to shift or divide those who use contracts or financial markets.

Torres (2014) stated that statistical control helps organizations to minimize the risks of failure and improve the process. This method helps to learn from past projects and without statistical control, progress is not possible. Deming (1982) claimed that the application of statistical techniques to manage process performance will increase efficiency and minimize losses.

Vergopia (2008) believes that the first of the three most important causes of project failure are a lack of communication between many stakeholders, while the other two are a lack of resource and activity planning and a lack of quality control. The author also stated that projects completed on time, within budget, and to specifications are generally successful.

Traditional project management models focus on meeting two goals: time and budget (Gayatri et al., 2013; Shenhar, 2015; Das & Ngacho, 2017). According to this approach, projects can be successful if they can manage these goals. Yet statistics show that the vast majority of projects fail. In later studies, project success began to be measured in a different way. For example, according to Hartono et al. (2015), project monitoring is considered as the most critical activity that must be properly controlled by management to ensure the success of a project.

According to Demirkesen and Ozorhon's (2017) study, it shows that integration management is necessary in the management of projects. In this study, a survey was conducted to obtain information from 121 projects and 22 of them were conducted in the form of face-to-face interviews. In this study, structural equation modeling (SEM) was used to validate the framework and test the hypothesis to see if there is a link between integration and performance and to check whether better integration management can lead to better project management performance. The results of this study show that integration management has a great impact on the performance of the project and there is a great link between the two. Looking at the previous studies reveals that there is a gap in the research literature and the impact of integration management needs to be emphasized more. The author shows that the success of the project depends on how well the integration management is, such as knowledge integration and supply chain integration. By using integration management process projects, you are more likely to achieve customer satisfaction and avoid budget overruns.

The success of project management usually depends on the ability to estimate the project cost when it is completed (Narbaev & Marco, 2014). To reduce the chance of risk, Jasiukevicius and Vasiliauskaite (2015) suggest that personal experiences and subjective judgments are still the most effective and widely used risk management strategy.

Mir and Pennington (2014) believe that project efficiency (achievement of schedule and financial goals) is the most important factor in the success of a project. But often organizations focus on customer satisfaction and financial success. Compared to project efficiency, other factors may be more important to an organization's success. This is because if financial success is achieved, it makes sense for both clients and project team members to be happy and benefit. So, in the long run, not meeting budget and deadlines may not be so important.

For the risk management process, every risk should be evaluated and the right steps should be taken to prevent it. The success of the project can be jeopardized if the risks are not well managed. Risks often change as the project progresses; as the old disappear, new ones emerge. Because risk management is an ongoing process, it is always important to re-evaluate risks.

In the above-mentioned studies, all these researchers have different opinions and perspectives. However, for most projects, performance is evaluated against project schedule and budget, and additional elements may be considered. Each organization needs to identify project success based on its strategic objectives. According to Project Management Institute risk management might have a positive or negative impact on the project (PMI, 2013).

Due to the lack of knowledge about risk management in the construction industry, this topic is not very popular. Risk management should be used from the start of a construction project because knowing where the risk comes from will help to better deal with it. Although there are many studies on construction risk, cost overruns, timeouts, quality issues etc. There are still major risks such as (Sharma & Gupta, 2019).

In this study, 10 main risk areas in construction risk management were identified and these are lack of available funds, design errors and poor engineering, inadequate site management and supervision, contract risks, changes in laws and regulations, extreme weather conditions, unexpected changes in the rate of inflation, natural disasters, inadequate security measures and modifications to the scope of the project.

Time management is very important in construction projects. Estimating the probability of time overruns can play a crucial role in the success of construction projects. There is a saying, “We cannot manage what we cannot measure”. Project managers need to understand and measure the probability of timeout before they can make the necessary adjustments (Luu et al., 2009). The survey conducted in this study mentions that two-thirds of respondents confirm that they often encounter construction delays. The data from this survey were collected to analyze the mean value statistically. According to the data, contractors and consultants ranked “owner's financial woes” as their top priority. To avoid time overruns, this study recommends that contractors understand their responsibilities to provide materials on time and be financially prepared for this obligation.

For Muneeswaran et al. (2018) inadequate schedule is the most critical risk that leads to future problems in any construction project. According to Kwak and Stoddard (2004) main lessons learned from project risk management are:

- Identifying risks is the most important part of risk management, but it is frequently done wrong.
- All projects must allocate enough resources throughout planning phase of the project in order to properly prepare for risk management process.
- Project managers must have full control of the all the main positions to participate the process
- A risk driver may affect all aspects of risk (cost, scheduling, technical, etc.) and the overall outcome can be miscalculated.
- Quicker, nicer, cheaper and other efforts to be more competitive make risks worse.

2.2. Bayesian Belief Network

There are many graphic-based methodologies in the literature such as cause-effect diagram, influence diagram, and bayesian network that can be used in the analysis of risks in PRM. Establishing conditional probability relationships between risks is not as easy as it seems and requires further analysis (Lyons & Skitmore, 2004).

Bayesian belief network is a graphical methodology that identifies causal relationships between a set of variables and models probabilistic relationships between them (Heckerman et al., 1995a). Bayesian belief networks are more efficient than other classifiers because they define joint conditional probability distributions. Bayesian belief network support the graphical structure of causal relationships to which learning can be applied.

Bayesian belief network is a useful tool in the analysis of quick-response decisions, especially when little or incomplete data is available, as it easily generates a cause-effect diagram. Therefore, it is a suitable methodology for project risk management despite some drawbacks. In short, Bayesian network is a useful tool for knowledge representation and reasoning in uncertain situations (Cheng et al., 2002).

A BBN is represented by two components, including a directed acyclic graph and a set of conditional probability tables. Each node in the directed acyclic graph defines a discrete or continuous random variable (Horný, 2014).

There are many well-known applications in the literature in which BBN is used to model the problem. One of them is genetic linkage analysis, such as mapping genes on a chromosome. In addition, classification and learning capabilities of Bayesian belief networks are utilized in many application areas such as computer vision, file and text analysis, image restoration and stereo vision, decision support systems, and sensitivity analysis (Heckerman et al., 1995b). Qazi et al. (2015a, b) suggest using BBNs to build a model to better manage risk in large engineering projects and to predict the probability of project completion or cancellation. Another study reviewed the applications of BBNs to water resource management (Phan et al., 2016).

A systematic synthesis has also been made on the application of BBNs in considering spatial factors, water areas and climate change impacts to identify gaps in the

application of BBNs in the field of environmental modelling. The methods used to develop and validate BBN models in different decision-making contexts are also examined in this study. After reviewing previous research, decision-making contexts are discussed in terms of four main types of decisions: directive, strategic, tactical and operational. They concluded that integrated modeling tools are required to enable decision makers to understand the dynamic process based on feedback and to address the uncertainties inherent in dynamically complex systems. Also, validation of dynamic process models before their results are included in BBNs is important to increase the validity of BBNs.

There are many benefits such as creating or improving Bayesian belief networks with the help of expert opinions (Yet et al., 2014). After the network is built, their accuracy can be increased by adding new data to the model (Sanchez et al., 2020).

Another real-world application of the Bayesian belief network is from the Korean shipbuilding industry (Lee et al., 2009). In this study, a survey analysis is performed and various risk factors are acquired from field experts. Project risks between large and medium-sized shipbuilding companies were also compared. According to this study, the general main risks in both large and medium-sized shipbuilding companies were design change as internal risks, supply of design manpower and raw materials, and exchange rate as external risk. The main limitation of this study is the reliance on an expert survey to construct the Bayesian belief network and the consequent great effort in data collection.

In summary, in all of the above-mentioned studies, project performance is evaluated against the project schedule and budget in general. Some additional elements may also be considered depending on the organization's strategic objectives. One of the main objectives in project management is to increase the probability of success of projects and meet the project's deadline. There are many methodologies and policies to optimize investments and minimize the possibility of failure in the literature. One of them is the Bayesian Belief Network which can be used in the analysis of risks in project risk management.

Despite some drawbacks, BBN is one of the most suitable analysis tools for risk analysis since it can establish conditional probability relationships and can identify causal relationships between a set of variables.

In this study, a general framework to estimate the impact of risks on project performance was developed. It uses Bayesian networks to formalize project management experts' knowledge and to extract knowledge from a database. A real-life case from Somalia is used to demonstrate how the method can be applied to reduce the risk of project budget/completion time overrun on a project in the construction industry.



3. METHODOLOGY

Bayesian Belief Networks are probabilistic graphical models that establish causal relationships between variables and present probabilistic relationships between them. Developing these connections isn't simple and takes extensive analysis. BBNs require an excessive reliance on expert knowledge for BBN model construction.

Despite the disadvantages of the diagram approaches mentioned, using BBN it is possible to implement a feedback loop for risk management, establish a cause-consequence relationship visually, and provide conditional probability estimates of risks. A project risk management framework based on BBN was derived and applied to the tackled construction project in Somalia.

3.1. Bayesian Belief Network Models

BBN is a framework tool that uses direct acyclic graphs (DAGs) to express a broad range of variables. DAG is a straight graph composed entirely of verticals and edges (also known as arcs). The arcs extend from the primary node to a minor node. The validity of a BBN is determined by the causal variables and the mutually exclusive relationship between the two. BBNs are an extremely valuable tool for understanding how incidents depend on each other and assigning probabilities to them. Their ability to build joint conditional probability distributions makes them more efficient and suitable than other networks. BBNs need expert knowledge, organized data, and causal understanding.

BBNs are an effective method for representing and reasoning knowledge in the face of uncertainty. Expert's knowledge, judgment, or beliefs may be mapped to unbiased data with the use of BBNs, which are powerful modeling tools. BBN offers several advantages, including being good for small and incomplete datasets, collecting information from various sources, highlighting uncertainty, and helping with decision analysis (Table 3.1).

Table 3.1: The strengths and weaknesses of Bayesian Belief Network (Sanchez et al., 2020)

No	Strengths	Weaknesses
1	The network may be built or refined with the help of experts' opinions (Yet et al., 2014).	Variables that are continuous must be discretized. (Uusitalo,2007). Because it is stated in terms of conditional probabilities in the output node, the prediction of performance is uncertain.
2	The network may be built or improved using data.	
3	Different circumstances may be shown by them.	
4	Once the network is built, they may raise their accuracy by putting new data into the system, which has dynamic learning.	
5	Using a retro propagation study, they may examine the value of non-performance reasons (Yet et al., 2014).	
6	Criteria values may be represented by them as nodes in a network, each with its own identity.	
7	No big amounts of information are required.	

Most BBN models are developed using expert knowledge and case studies. The most common form of reasoning used by BBNs was a prediction, which looked at outcomes like cost overrun, performance, and workplace accidents (Hon et al., 2022).

Hon et al (2022) noted research holes in already published articles, such as an excessive reliance on expert knowledge for BBN model construction, and a lack of recommendations for BBN model development.

Several recommendations are proposed such as investigating the effectiveness of Bayesian techniques in construction management and how they interact with other methods to improve construction management difficulties and creating an automated data extraction approach.

According to Chen and Pollino (2012), it is possible to develop and apply BBNs for a wide variety of uses, including the following:

- Improving system knowledge
- Collaborative modeling
- Knowledge acquisition
- Generating new or storing new information and knowledge
- Prediction
- Exploration and analysis of possible outcomes
- Tradeoff analysis
- Providing information and enabling management and decision making
- Identifying any gaps in both knowledge and data

Bayesian Belief Network is composed of both qualitative and quantitative sections. The qualitative part of BBN is also named (structural learning) it is a graphic representation of variable independence using DAG common in statistics, machine learning, and artificial intelligence societies.

The quantitative component of a BBN, also known as parameter learning, determines dependence connections as joint conditional probability distributions among variables by making use of the qualitative component's cause and side-effect relationships as well as the information related to the variables.

There are two techniques for modeling, namely semantic modeling and Bayesian modeling. Semantic modeling is based on ideas from project management maturity analysis, whereas Bayesian modeling is used to represent the actions necessary for the construction of a real causal structure. The accuracy of BBN is estimated to be above 90 percent.

3.2. Proposed Risk Management Framework

Risk reductions may be evaluated using these risk management techniques. The steps of the procedure are listed below and explained in the following sections:

1. Risk classification and identification
2. Risk assessment for a Bayesian Belief Network
3. A Bayesian Belief Network construction
4. Risk control
5. Risk reassessment

3.2.1. Step 1: Risk Classification and Identification

In this step, risks affecting the project, and risk elements are classified. Furthermore, the impact of risks on projects was determined using various sources such as literature review, expert survey, and historical data. Although risk classifications have been done in many ways in the past, they have mostly focused on a single risk element. An interview survey is conducted and after interviewing an expert a total of 8 major risk factors were chosen associated with a construction project in Somalia as shown in Table 3.2.

Table 3.2: The main risks related to the construction project in Somalia

D_i	Drift Factor	Remark
D1	Placing the wrong person in control of the situation.	Internal
D2	Unexpected security problems such as explosions	External
D3	Major tax problems caused by corruption	External
D4	Lack of safety for workers and lack of emergency plan in such cases	Internal
D5	Labor shortage and a difficulty in finding a quality labor	Internal
D6	Exceeding budget	Internal
D7	Exceeding timetable	Internal
D8	Delayed raw materials	External

According to Sheriff and Badawy (2021) major critical risks related to construction of the administrative projects are as follows:

- Bribery and fraud
- Company's financial problems
- Unexpected circumstances
- Structural damage
- Faulty material installation
- Rework procedure

- Ineffective communication
- Health and safety risks
- Issues in design
- Delayed payments

Previous studies presented different strategies when dealing with construction projects, but most studies performed general construction project analysis which resulted in many gaps in these studies.

Each construction risk type such as risks in highways and bridges should be separately studied. Risks are divided into internal and external. Internal risks are elements a company can control, such as product risk, process, and resource quality. External risks are risks that can't be controlled like laws, changes in currency, safety, and inflation. Each risk factor is separated into internal or external.

Risk classifications have evolved throughout time. Edwards and Bowen (1998) provided an extensive classification of risks associated with land-based construction projects by using natural (such as climate and geological systems) and human (such as social, governmental, financial, health, managerial, and technical).

3.2.2. Step 2: Risk Assessment for a Bayesian Belief Network

At this point, the risk level of each risk item discovered in Step 1 is assessed. According to the International Standard, Risk assessment helps people understand what risks are, what causes them, what their effects are, and how likely they are to happen. This helps make decisions about:

- What the best course of action is in the given situation
- How to increase the likelihood of opportunities
- Whether it's necessary to address the risk
- Making a decision between options that have different risks
- Risk treatment options should be ranked in order of importance

Risk assessment helps people who make decisions and those who are responsible better understand the risks that could keep them from meeting their goals.

The risk assessment approach may be selected based on 16 criteria, as stated by Habtamuabie and Borking (2012), cost, outside influences, contract, management structure, ability to adapt, complexity, accuracy, potential risk, organizational size, and organizational security philosophy, reliability, usefulness, suitability, validity, creditability, and automation.

3.2.3. Step 3: The Development of a Bayesian Belief Network

It is possible to design BBN in 2 ways: manually or automatically, both have their advantages and disadvantages (Horný, 2014).

3.2.3.1. Manual Construction

To build a Bayesian Belief Network manually, it is necessary to have prior expert knowledge about the underlying topic and collect data from an expert. First, DAG is constructed, and then a conditional probability distribution is assessed for each node of the graph. However, there are still arguments about which type of probability distribution fits best in the construction industry (Khodakarami and Abdi, 2014). When using BBN modeling, one of the benefits is that the network may be simply adjusted and updated to suit the problem although it does require some knowledge of probability.

In general, the most popular steps of manual construction are given below (Lucas et al, 2004):

1. Selection of relevant variables
2. Identifying the connections between the variables
3. Identifying qualitative, probabilistic, and logical constraints
4. Probability assessment
5. Sensitivity analysis and evaluation

Bayesian Belief Network is tested in construction project in Somalia. Below are the primary stages used to build a BBN model:

Stage 1: Selection of Bayesian Belief Network in Manual Construction

In our case, BBN was built using Netica software. To manually construct a model, it is necessary to gather all data from an expert.

The network is typically shown as a graph, which consists of a collection of nodes and arrows connecting them and the arrows indicate the causal linkages that exist between the probabilistic variables (Figure 3.1).

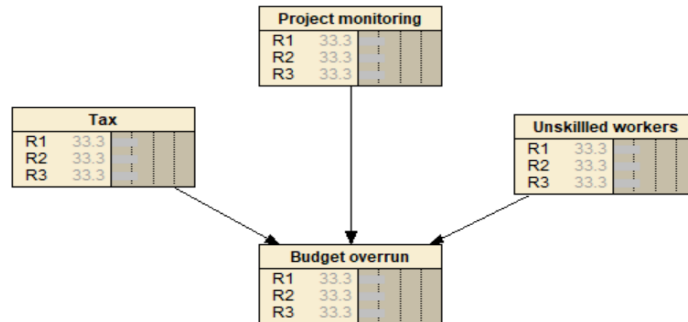


Figure 3.1: Example of Bayesian Belief Network

The nodes that represent the beginning of the line are known as the parent nodes. Parent nodes do not have an arrow pointing inward. The remaining nodes, those that are connected to them by arrows pointing inward, are the child nodes. To confirm that the calculations are carried out correctly, it is required to define probabilities for each node (Khodakarami & Abdi, 2014).

Stage 2: Organize the Database

As previously stated, the network is built with the help of an expert; however, data may be collected without any processing being done. For an accurate result, every single incorrect value must be removed. BBN is a kind of model that is reliant on data.

BBN, in contrast to machine learning (which is based only on data), provides the opportunity to question humans about the root causes that come from the problem they are trying to solve. This is different from machine learning, which only looks at data even though BBNs can be constructed only from expert's derivation or data learning, applications benefit greatly from combining the two (Chen and Pollino, 2012). Bayesian Belief Network can be built using different software including genie and Netica.

Stage 3: Set the Target Node

The target node represents where the project is immature such as costs overruns. Modeling the target node's number of states is challenging. All these important targeted nodes should be clear enough to produce accurate results.

According to Akaike's information criterion (AIC) and Bayesian information criterion (BIC), the target nodes should have four different arrows to represent four different levels of cost overrun risk to maintain accuracy and precision (Akaike, 1974).

3.2.3.2. Automatic Learning

Unlike manual construction, automatic learning doesn't need knowledge from experts. Bayesian Belief Networks can be simply learned automatically from databases using experience-based algorithms that are often built into the software. Although automatic learning is very helpful it also can be a problem because it makes more demands on the data.

The negative part about automatic learning is that it puts more demands on the data and most automatic learning algorithms don't work if there are any missing data in the dataset.

If there are gaps in the data, the missing information must be imported or estimated from other sources. Also, there needs to be enough data to meet the requirements of the algorithm for estimating the conditional probability distribution in a reliable way. For manual construction, it is presumed that the conditional probability distribution is already known. (Horný, 2014). The development of network structure and the calculation of conditional probability distribution are both necessary steps in automatic learning.

3.2.4. Step 4: Risk Control

Risk control measures are steps made to eliminate, avoid, or minimize the occurrence of recognized risks. One of the most significant risks in projects is the control of the budget and schedule. Most studies found that project success depends on how well the budget and timetable are controlled (Shueib 2022, Gayatri et al., 2013; Shenhar, 2015; Das & Ngacho, 2017). Proper mismanagement of these two risks causes major problems for the stakeholders involved (Gazi & Dikmen, 2021).

Estimating how much a project will cost is a common difficulty for project managers. These decades have seen a growth of approaches to cost risk analysis because of developments in computing power and the accessibility of simulation software.

Unfortunately, simulation-based approaches have theoretical and practical limits and cannot simulate complicated cause-and-effect interactions between variables. When estimating a project's budget, it's important to account for multiple sources of uncertainty (Khodakarami & Abdi, 2014).

There have been many failures in project management, especially with regard to cost overruns. The strength of BBN is used to estimate cost overrun and other causes (Mansfield et al.,1994). As a result, we can:

- Explain uncertainties about each cost item and the project's overall cost using detailed probability distributions.
- Analyze cost item dependencies using causal and conditional linkages.
- Gain knowledge from data to ensure that forecasts are as accurate as possible.

According to Mansfield et al. (1994) major cost overruns are as follows:

- In appropriate contract management
- Strategies of financing and payment for finished projects
- Modifications to site conditions
- Limitations in supplying materials
- Importing goods and plants
- Changes in design
- Choosing the wrong sub-contractors and suppliers

3.2.5. Step 5: Risk Re-assessment

In Step 4, risk items that are needed to be controlled are selected. Project risk reassessment involves finding new and reassessing existing risks. It is then combined with collaboration to reduce the likelihood of bad consequences and to raise awareness. The odds of risk projects are estimated in Step 4. In this phase risks that are no longer in danger to the project is removed.

4. IMPLEMENTATION AND RESULTS

In this study, we aimed to figure out how likely it is a construction project will go wrong. In our case, we focused on a construction project in Somalia. The survey was made by interviewing an expert who was the construction manager, and all the necessary data was provided by a field expert. The planned duration of the construction was 6 months, but the project was completed in almost 8 months. One of the reasons is delayed raw materials. Delayed raw materials occur because most materials are imported from outside the country.

Risks were divided into internal and external risks. The main internal risks were unskilled workers, delayed raw material, budget overrun, and exceeding timetable while the most significant external risks were security problems and exchange rate. Internal risks were the risks that affected the performance of the project.

Main findings related to the construction project include:

- *Labor shortage:* Whenever a worker is lost, it was very difficult to find a replacement with the same requirements which resulted in time loss.
- *Poor safety management:* The safety of the workers has been very poor there was no such thing as wearing a helmet and there were times where there has been a fall that caused injuries and there was no emergency plan in such cases.
- *Tax officers:* Usually, you pay your taxes to the district but officers from other regions come to ask for another tax and demand to stop the project until another tax is paid which also delayed the project.
- *Appointing the wrong employees:* Some workers didn't understand much about their field and made some mistakes during their daily activities and the person in charge did not follow up and is responsible for ignoring the safety of the workers.
- *Security problems:* such as explosions near the construction area.
- Not putting the right person in charge.
- Overoptimistic instincts (time, cost).

As a result of these problems in the project, customers have constantly demanded improvements in PM, and an urgent improvement in project management is recommended.

In order to overcome these obstacles in PM, the following requirements have been identified:

1. Each member should have a minimum of ten years of experience in PM.
2. Each member is required to participate in at least 2 courses related to the advancement of PM.
3. Certificate from project management institute.
4. Experience in handling difficult moments in the project.

A framework for risk management of a construction project in Somalia was derived according to the process steps detailed below and applied to the on-hand project in Somalia.

4.1. Stage 1: Construction of Bayesian Belief Network

First, an interview survey is conducted about the main risks of the chosen construction project, and then we select source nodes. The source nodes do not have arrows pointing at them. The nodes below them in the hierarchy are called child nodes. Then one decides the cause-and-effect relationship. Each node has probabilities of risks R1, R2, and R3. R1 is the lowest risk and R3 is the highest.

BBN is a valuable tool that may be used in a variety of situations that need a mix of data and expert knowledge to be solved. Hon et al. (2022) believe there is a lot of reliance on expert knowledge for BN model construction. BBNs can be built using different softwares including Genie and Netica. In our implementation, the network is built using Netica.

4.2. Stage 2: Organize and Structure the Database

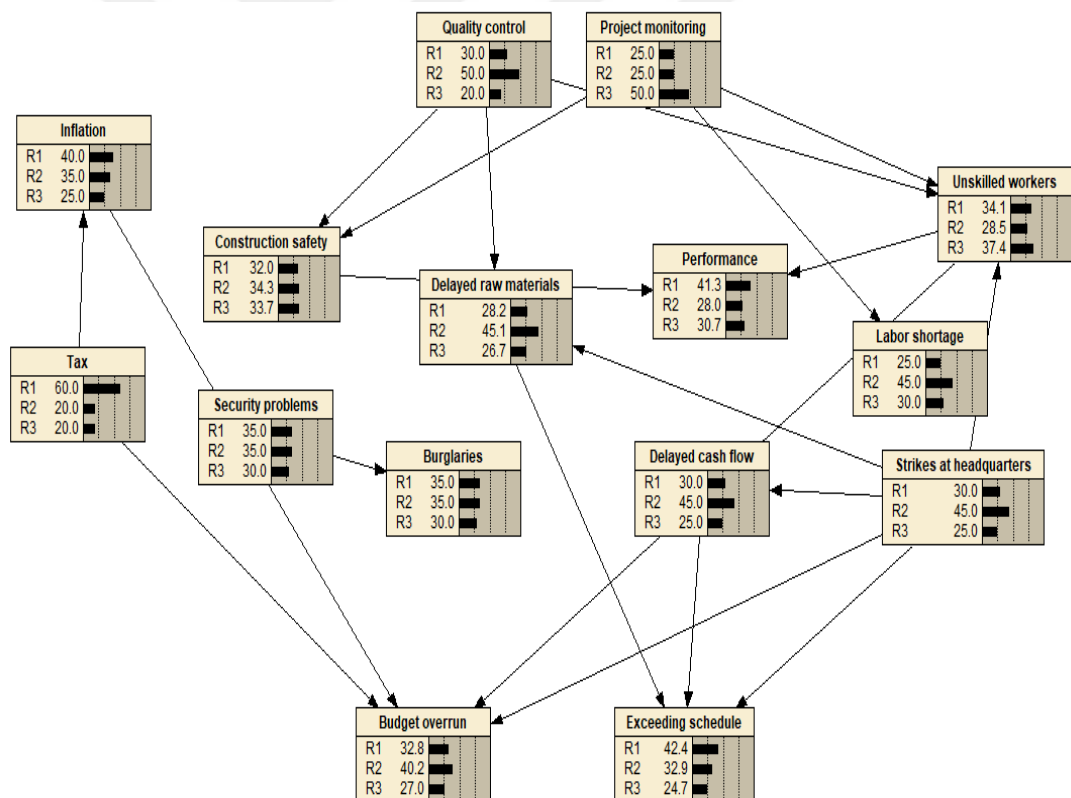
When using a Bayesian Belief Network, data may be collected without any processing being done, but it must be clear, and every single incorrect value must be removed. The nodes in the network represent the key risks in the construction project and the arrows indicate the causal linkages that exist between the probabilistic variables.

There is a possibility that inaccuracy that occurs from experts up to 5% can have a 2% effect on the accuracy of the network (Sanchez et al., 2020).

4.3. Stage 3: Set the Target Node

At this stage, the accuracy of the database is evaluated. The target node indicates the slow progress of the project's implementation due to critical elements of the project such as cost overruns. Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) require the target node to have four states to indicate four different levels of cost overrun risk levels for accuracy and precision, meaning there should be four different arrows pointing at the target node.

In this last step, Bayesian Belief Network is tested by applying it to the case study. The results of the case study conducted in Somalia in 2022 are shown in Figure 4.1.



Activa

Figure 4.1: A Bayesian Belief Network for a construction project in Somalia

This network is built using Netica software. After interviewing an expert, the main risks related to the construction project are given as seen in the figure. R1, R2, and R3 indicate the risk levels of each node. After that probabilities are assigned to each risk level. The target node indicates where the project is immature. This network is chosen because of its effectiveness and accuracy which exceeds 90 percent.

4.4. Discussion

In this study, we developed a framework that was centered on the operational performance of a project in Somalia. The reason for the delays is discussed such as cost overrun and exceeding timetable as well as the elements that were responsible for causing it. Bayesian Belief Network is applied on a construction project in Somalia. Netica software is then used to identify and understand the reasons of these delays as well as the causes.

Since BBN construct joint conditional probability distributions, they are more suitable than other networks in terms of efficiency. They represent graphical methods that identify causal linkages and describe probabilistic relationships between variables. Up to 5% expert error may reduce network accuracy by 2%. BBNs test accuracy is over 90%. The target node should have four arrows pointing at them to maintain accuracy and precision. The obtained BBN was applied, and it showed that it is relevant, useful, and accurate and the overall the quality of BBN is very good.

This case and the model that is used do not mean that it is a general BBN that shows a list of variables that cause deviation and how they affect each other that can be used on any project. Engineering projects may have different features. The structure of the network and the weights may also be affected by the situation (for example, there may be different causes of deviation).

The primary goal of this BBN in this study is not to give a general BBN that presents a list of variables that sometimes causes deviation element which can apply to any project and as previously stated the scope of the BBN is very tight. Engineering project features may vary according to the industry sector. There are related situations that steers the design of the network such as the cause of different drifts.

According to the findings of this research, the usage of BBN is still a useful testing method that produces successful results, but it is restricted to a certain set of reasons. The network is built with the help of experts providing all the necessary information.

Lack of agreement about project management is shown in the literature and authors have different opinions about the main importance of project management but in most projects, performance is measured based on budget and duration. Depending on the organization's strategic objectives, other factors may also be considered.

The usage of project tracking system is recommended to promote collaboration. Project tracking helps PM Managers learn from the past by recording risk assessment results. This type of tracking becomes beneficial later in the project.

According to Standish Group 31% percent of projects were canceled before completion, while 53% of projects went over budget by 189%. Out of every 100 projects started, 94 need to be redone, and one-third go behind schedule by up to 300%. Only 16% of the projects were completed on time and within budget.

As previously indicated, traditional project management focuses on not exceeding budget and timetable but the results of the construction project in Somalia show that it has failed to meet these two goals.

The project's budget was exceeded by 114,9%. The causes of budget overruns include tax, corruption, inflation and unskilled workers. With more experienced labors, exceeding budget could have been avoided by around 4%.

The project's timetable was exceeded by 33.3%. The major reasons that caused to exceed schedule were delayed raw materials, explosions near by and delayed cash-flow. For example, in our bayesian network the probability of exceeding schedule in risk level 3 is 24.7%. if delayed in cash-flow had not occurred, the delay could have been reduced to 21%.

5. CONCLUSION

The main purpose of project risk management is to find, evaluate and control risks that may affect the success of a project. Measuring the success of a project is difficult because it can change from one stage to the next, and different people evaluate the success of a project differently. Project crises occur when several unlikely, mismanaged risks arise unexpectedly, or when a major risk encounters an adverse outcome. A crisis is a great danger that causes the project manager to make critical choices.

In general, the performance of the project is generally evaluated against the project schedule and budget. Some additional elements may also be considered, depending on the strategic objectives of the organization. One of the main goals is to increase the probability of success of projects and meet the project deadline. There are many methodologies and policies in the literature to optimize investments and minimize the possibility of failure. Despite some disadvantages, Bayesian Belief Networks (BBNs) is one of the most suitable analysis tools for risk analysis because it can establish conditional probability relationships and determine causal relationships between a number of variables.

Bayesian Belief Networks are a type of probabilistic graphical model that can be used to represent and reason about uncertain events and their dependencies. In the context of construction project risk management. A BBN can be used to model the various risks that a project may encounter and the relationships between those risks.

In a BBN, each risk is represented as a node in a directed acyclic graph (DAG). The edges between nodes represent the dependencies between risks. For example, if one risk (e.g., bad weather) is known to increase the probability of another risk (e.g., delays in construction), there would be a directed edge from the bad weather node to the delays in construction node.

The probabilities of the risks can be estimated using historical data, expert judgment, or other sources of information.

These probabilities can be used to update the beliefs about the risks as new evidence becomes available during the course of the project. This process of updating beliefs is known as Bayesian inference.

By modeling the risks and their dependencies in this way, a BBN can help project managers identify the key risks that are most likely to impact the project and take appropriate action to mitigate or manage those risks. It can also be used to evaluate the potential outcomes of different risk management strategies and choose the most effective one.

There are several alternative approaches to risk management in construction projects that can be used in addition to or instead of BBNs. Some of these approaches include:

1. *Decision tree analysis*: This involves creating a tree-like diagram that represents the possible outcomes of a series of decisions or events, along with the probabilities of each outcome occurring. Decision tree analysis can be used to evaluate the potential outcomes of different courses of action and choose the one that is expected to have the best outcome.
2. *Monte Carlo simulation*: This involves using computer software to simulate the risk management process under a wide range of different scenarios. The software generates random values for the probabilities of the risks based on probability distributions specified by the user. The results of the simulation can be used to understand the possible outcomes of different risk management strategies.
3. *Expert judgment*: This involves seeking the advice and opinion of experts in the field, such as experienced project managers or risk management professionals, to identify and evaluate the risks that a project may face.
4. *Risk matrix*: A risk matrix is a simple table that is used to classify risks based on their likelihood and potential impact. Risks are plotted on the matrix according to their likelihood and impact, and are then prioritized based on their position on the matrix (Qazi & Dikmen, 2021).

Each of these approaches has its own advantages and limitations, and the best approach to use will depend on the specific needs and circumstances of the project. BBNs may be particularly well-suited for projects that involve complex dependencies and uncertainties, but other approaches may be more appropriate in other cases.

In this study, we aimed to develop a BBN based framework that will enable the prediction of the delays that may occur in the project and to take a course of action by considering the possible risks in the risk management of construction projects. A real case from Somalia is used to demonstrate how this method can be applied to reduce the risk of project budget/time to completion in construction projects.

Bayesian Belief Networks can also be used to answer what-if questions in the risk management of construction projects. One way to use BBNs to answer what-if questions in the risk management of construction projects is to use the network to perform sensitivity analysis. Sensitivity analysis involves varying the probabilities of the risks in the BBN and observing how the changes affect the overall probability of certain outcomes or events.

For example, suppose a project manager wants to know how the probability of project delays would be affected if the probability of bad weather occurring increased. To answer this question, the project manager could use the BBN to calculate the probability of project delays under different scenarios in which the probability of bad weather is varied.

This type of analysis can be useful for identifying which risks have the greatest impact on the project and for evaluating the potential effectiveness of different risk management strategies. It can also help project managers understand the uncertainties and dependencies that are most important to consider when making decisions about how to mitigate or manage risks.

In addition to sensitivity analysis, BBNs can also be used to perform other types of what-if analysis, such as scenario analysis or risk simulation. These approaches involve considering multiple possible combinations of risks and their probabilities, and can be used to evaluate the potential outcomes of different risk management strategies under a range of different circumstances.

5.1. Main Contributions

The main contributions of this research are listed below:

- Derived a BBN-based framework to improve Project Risk Management in large construction projects.
- The main risk factors were determined by the analysis of historical data and field expert knowledge of engineering projects in the construction industry.
- Our BBN-based model is intended to assist PM professionals in determining and handling critical risks to meet project terms. While internal risks are a greater risk factor than external risks, some external risks such as massive corruption and exploitation in the immediate environment have also been found to have a major impact on construction.
- Our proposed method for risk management was applied in a small/medium-scale construction project in Somalia, and the results were analyzed.
- A free-license software was used to create the BBN model. With the experience gained thanks to the use of this software, the ability to analyze the risk factors of larger-scale construction projects or projects in different fields has been gained.

5.2. Limitations and Recommendations

One of the main limitations of this study is that it included a relatively small sample size of experts interviewed to gather information. Another important limitation is the reliance on an expert survey to create the BBN. A model such as the Netica software relies heavily on expert knowledge and there may be a lack of expert advice for developing a BBN model.

Previous studies have presented different strategies when handling construction projects, but most studies have done general construction project analysis resulting in many gaps. Therefore, as a result of this study, it was concluded that it would be more appropriate to examine each type of construction risk separately, such as risks on highways and bridges.

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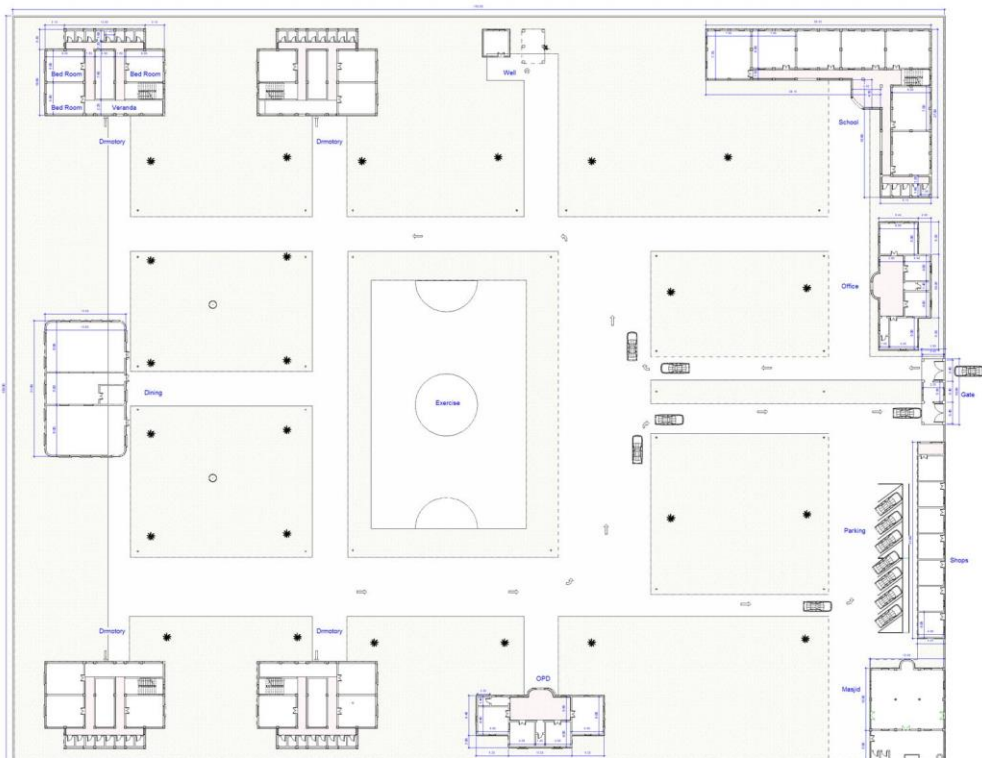
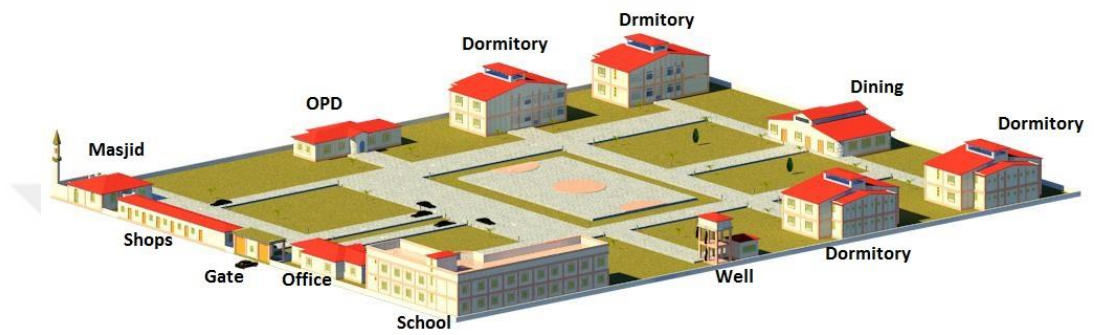
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APPENDICES

APPENDIX A: Sketch of the Construction Project in Somalia



APPENDIX B: Budget and Expenditure Items

BOQ					
No	Materials	Unit	QTY	Rate \$	Amount\$
1	Cement	Bags(50KG)	25150	8.50	213,775.00
2	Iron For Cement Concrate	Load(100Kg)	1500	85.00	127,500.00
3	Wood	M3	100	385.00	38,500.00
4	Playwood	No	2320	5.00	11,600.00
5	Ceiling	No	805	8.00	6,440.00
6	Nail	Kg	2120	1.50	3,180.00
7	Wire Iron	Kg	1520	1.50	2,280.00
8	Stone	Load(4M3)	470	110.00	51,700.00
9	Sand	Load(4M3)	300	120.00	36,000.00
10	Agregate	Load(4M3)	350	200.00	70,000.00
11	Hard Sand	Load(6M3)	400	100.00	40,000.00
12	Blocks	No	155000	0.80	124,000.00
13	Doors & Windows	M2	485	250.00	121,250.00
14	Floor Tiles	M2	6450	8.00	51,600.00
15	Electric	sum			7,000.00
16	Paint	sum			12,000.00
17	WC	sum			9,500.00
18	Sub - Total	sum			926,325.00
19	Libor	sum			324,213.75
20	Total in us \$				1,250,538.75