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Causes of variation orders in the Egyptian construction industry: Time and cost impacts

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Causes of Variation Orders in the Egyptian Construction Industry: Time and Cost Impacts

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Abstract

Variation orders are of great significance in any construction project. Variation orders are defined as any change in the scope of works of a project that can result in an addition, omission, or even modification. This research introduces the variation orders that occur during construction in Egypt. The literature review involves a comparison of causes of variation orders in Egypt with Tanzania, Nigeria, Malaysia and the United Kingdom. A classification of occurrence of variation orders due to owner related factors, consultant related factors and other related factors are signified in the literature review. These classified events that lead to variation orders gathered from the literature review are introduced in a survey with 19 events to observe their frequency of occurrence, and their time and cost impacts. The survey data is obtained from 87 participants that included clients, consultants, and contractors. The number of participants in the survey is an acceptable representation of the population.

A database of 42 scenarios is created that is used to develop an experts system model to help assist project managers in predicting the frequency of variations and account for a budget for any additional costs and minimize any delays that can take place. Two additional experts with more than 25 years of experience are given the expert system model to verify that it is working effectively. The model is then validated on a residential compound that was completed in July 2016 to prove that the model actually produces acceptable results.

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Chapter 1: Introduction

1.1 Background

Egypt's construction industry is one of the biggest and most booming in the Middle East and North Africa (MENA) region. The Egyptian construction industry regained growth momentum since 2011, and the growth rate is anticipated to further increase during the next five-year period (2016-2020) as a result of Egypt undergoing various investments in commercial, residential, industrial, energy and infrastructure projects (Timetric, 2016).

Construction Projects involve a vast amount of resources and money. The careful monitoring and control of these resources is essential for the success of these projects. One of the most important aspects of construction projects that should be properly managed, to achieve the careful monitoring and control of project's resources, is the change/variation process. Change is inevitable in construction projects and can have a major influence on the project deliverables and thus the project stakeholders. The influence of variation orders can be positive or negative whether on the deliverables or the stakeholders, yet it is a crucial aspect that has to be managed thoroughly as it can enormously affect the success of a project.

Variation orders are of great importance for both the contractor and the client. The client's main objective is to have the project completed in the required duration and within budget. The contractor usually, on the other hand, focuses on extending the project duration and claiming for additional costs. The larger the number of variation orders in a project, the higher the possibility that they can affect both time and cost (Charoenngam et al., 2003).

Variation orders have been found to be one of the most common causes leading to disputes in construction projects. Well-managing variation orders can decrease disruptions, delays, and cost over-run in a project.

1.2 Variation Order

A variation order is a change in the scope of works of a project that can result in an addition or an omission from the overall volume of work. It observes that a change exists without the need to issue a new contract (Hester et al., 1991). This change is issued as an official document stating the associated change and agreed upon between the client and the contractor. Upon agreement, this document becomes part of the project's contract documents.

Variation orders can occur due to many reasons such as changes within the scope of work and contract documents. Variation orders can result in project cost overrun and delays, as well as many other negative impacts such as affecting project performance, quality, health and safety (Arain et al., 2004). Factors such as the complexity of the project, procurement method and nature of the project affect the occurrence of variations. However, these factors differ from one project to another (Mohamed et al., 2001).

Variation orders are significant contributors to cost overruns and time delays in construction projects; therefore, studies are being conducted to mitigate these variations.

1.3 Problem Statement

With the construction industry expanding in Egypt, projects are getting more innovative and complex. The more complex the project is, the more likely it is time and cost sensitive.

Studies in the literature observe the causes of variation orders related to the client, consultant and other related factors. Since the construction industry covers a wide spectrum of project types, the type and magnitude of the effect of variation is dependent on the nature of the project. This then leads to complications in predicting variations that can occur during a project and its effect on time and cost without a systematic model. Therefore, it is essential to develop a model that helps predict the frequency of variation occurring and its effect on time and cost based on the type, nature, and size of the project.

1.4 Research objectives and scope

The main objective of this research is to predict the effect of variation orders that could occur during the execution of different types of projects, and their associated time and cost impacts in the Egyptian construction industry through developing an expert system model. The above objective of the research is performed through the following:

1. Create a database to obtain different scenarios for different project types in Egypt.
2. Classify the variation orders that can occur during the project construction in Egypt with their effect on time and cost.
3. Develop a model that predicts the frequency of variation orders, and their effect on time and cost for different scenarios.
4. Verify the model is working coherently
5. Validate it on a real case study.

1.5 Research Methodology

The research objective will be pursued through a number of structured steps that form the methodology of this research; including:

1. A literature review will be established to obtain the list of variations that can occur due to client, consultant and other related factors.
2. A database through a distribution of surveys to obtain different scenarios for different project types, cost, procurement methods and contract type.
3. A model to address the different scenarios obtained in the database.
4. Analysis of variances (ANOVA) for each scenario in the database.
5. Alternative scenario if the scenario fails to accept the null hypothesis.
6. Validation and verification of the model.

Figure 1 represents a flowchart for the research sequence.

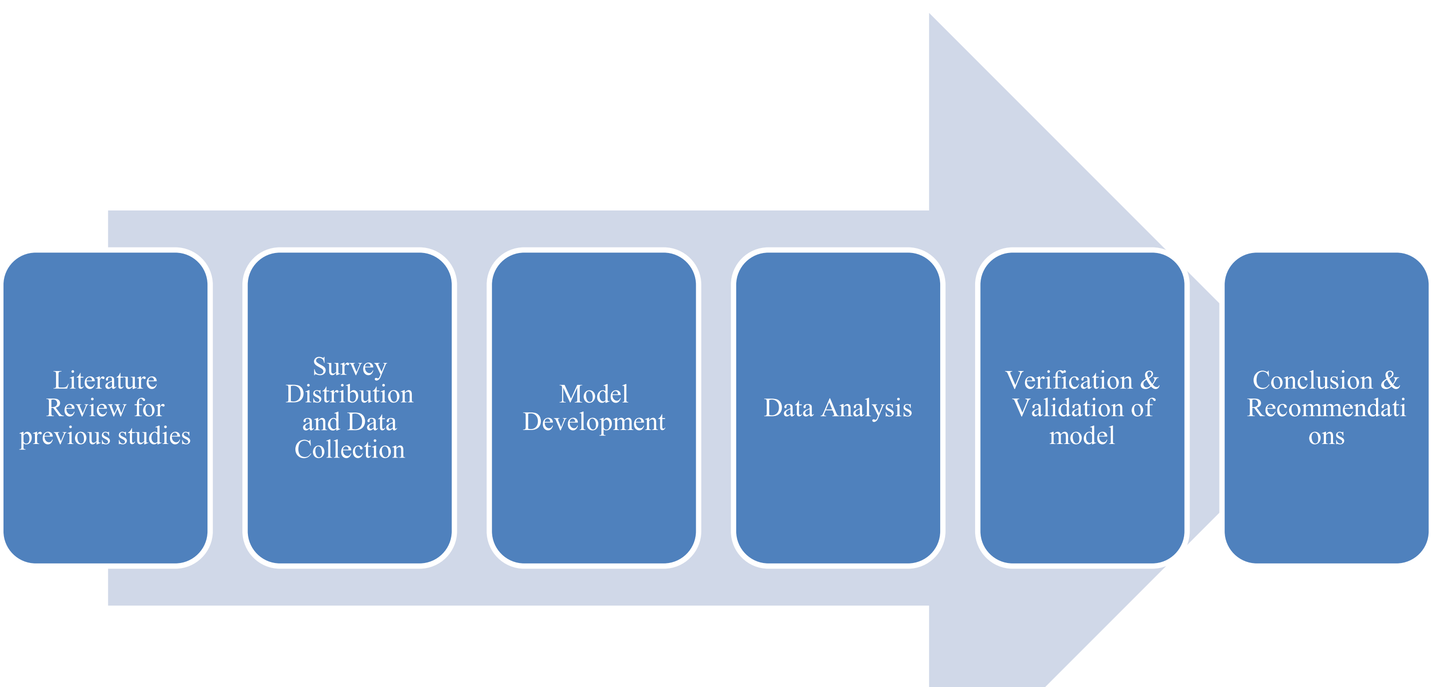

Figure 1: Research Sequence

1.6 Thesis Organization

1. Chapter 1: An introduction providing background information regarding the research topic, along with the objectives and problem statement indicating the gap in the research that needs to be covered.
2. Chapter 2: Literature review representing previous research in similar topics and providing a list of variations that can occur in construction projects, as well as their impacts and ways to mitigate them.
3. Chapter 3: Survey distribution and data collection to gather the required data needed to construct a sufficient database.
4. Chapter 4: Model development expressing the techniques used to develop the model.
5. Chapter 5: Data analysis showing the expected prediction of the data output of the model. Verification of the model to check the model is working comprehensibly and a model validation is also applied for a real case study to ensure the model is working effectively on real life projects.
6. Chapter 6: Presents the conclusion attained from this research and presents recommendations for further studies in the existing study area.

Chapter 2: Literature Review

2.1 Overview

During the construction of projects, changes can occur and they are highly unavoidable. These changes take place when the scope of work differs from the original scope agreed upon in the contract. These changes can lead to time delays, increase in project cost budgets, quality defects and even disputes. Therefore, these changes have to be effectively managed in order to reduce the risk that might occur as a result of these changes such as arise to claims and disputes. s

2.2 Variation Orders

When the scope of agreed upon in the contract differs from the work performed then variation orders shall take place. Variations arise based on the project's size, duration and complexity. For instance, large complex projects require more observation from various people in order to mitigate and manage the changes that can occur during the construction of a project (Cox, 1997). There are numerous reasons why variation orders can occur and shall be discussed later on in this chapter.

2.3 Variation Order Clause

Each construction contract must have a variation order clause that allows for changes to scope of work to take place. This clause simply identifies the process at which the parties shall follow in order for the variation order to take place. It gives the Contractor a reasonable alteration to the contract price and schedule as a result of the variation that arose. In various contracts, a duration that the Owner shall provide the Contractor with the response regarding the submitted cost estimate and schedule can be included. The variation order clause also indicates the method of cost along with the associated time delays that the Contractor shall undertake while accessing the variation (Egan et al., 2012).

2.4 Classification of Variation Orders

Variation orders can be distinguished in various different classifications. According to Egan et al. (2012) and Cox (1997) both have classified variations into three main groups: Direct/ Owner Changes, constructive changes and cardinal changes.

Direct/Owner changes are referred to changes issued by the Client that may result in modifications to the contract or specifications. Constructive changes are changes that are required from the Contractor to perform extra work that is altered to the contract documents. Cardinal changes are changes that are required to be performed by the Contractor that are outside of the project scope.

Arain et al. (2005) similarly categorize variation orders into two groups: beneficial and detrimental. Beneficial variation is considered to be a variation that reduces time and cost, enhances quality, and simplifies the complexity of the project. Detrimental variations, on the other hand, as stated by Arain et al. (2005) are variations associated with reducing costs through substituting material and quality to lower and cheaper quality to meet the Client's financial problems. This, therefore, may negatively affect the project significance.

Motawa et al. (2007) categorizes variation orders as "radical change" or "gradual change" according to the level of difficulty of the project. Motawa et al. (2007) also classifies variation orders as “emergent change” or “anticipated change” based on whether the variations were planned or not.

Alsuliman (2009) classifies variation orders into five different groups: Owner-related variations (ORV), Consultant-related variations (CRV), Contractor-related variations (CTRV), Other variations (OV), and Combinations of causes (CC).

This thesis classifies variation orders into three main groups: Client related factors, Consultant related factors and other factors, as it is the most popular form of categorization and the simplest.

2.5 Causes of Variation Orders

Many researches have been conducted to organize the factors responsible for the causes of variation orders that take place during the construction process of a project.

According to statistics directed by Muhammed et al. (2015) state that client related factors contribute about 30% of the total causes of variation orders, while consultant and other factors contribute about 65% and 5% respectively.

2.5.1 Client Related Factors

1. *Inadequate project objectives:* Unclear communication of project objectives can cause difficulties and variations in a project. Project objectives should be understood among all parties in order to avoid numerous changes that can occur during the work process. Having an effective and efficient communication method can help achieve the overall project objectives (Ibbs et al., 1995).

2. *Change of scope:* During the construction of a project, the Client performs various change orders due to his lack of participation in the pre-tender phase and during the execution of the project. The Client is not much involved in the design and resources used in the project (Arain et al., 2004). Therefore, the implementation of the project is affected by issuance of variations.

3. *Substitution of material:* According to Chappell et al. (1996), change orders for material substitution have impacts on the construction process of the project. Material

substitution change orders can occur due to various reasons including financial problems requiring substituting the material with a lower quality in order to reduce cost. Another reason would be that the construction site requires more competent material. Change orders associating with material substitution can then affect equipment, labor, time and cost. Therefore, it is required to have a proper management material process with a well-established specifications, storage and installation.

4. *Financial problem:* Clough et al. (1994) and Ibbs et al. (1995) state that client's financial problems are one of the most important reasons that causes time delay in projects. This is to due to financial issues arising from inflation, sudden price changes and unacceptable claims, affecting the client's cash flow. This then leads to changes in scope as the Client aims to reduce the project cost, impacting the implementation of the project.

5. *Change of Schedule:* Clients often change the schedule of the project that indicates cost and schedule consequences for the Contractor's resources as a result of the change that occurred during execution of the project (O'Brien, 1998).

6. *Unilateral decisions:* Clients can perform unilateral decisions without observing the consequences that can go behind these decisions. These decisions can sometimes be difficult to implement, affecting the projects time and cost (El-Sadek, 2016)

7. *Clients do not perform decisions in the correct time:* Decisions regarding the work process must be made in the correct timing to ensure project achievement. Memon et al.

(2014) stated that the incapability to perform the decisions at the correct time can affect the project schedule and costs, resulting in a variation orders taking place.

2.5.2 Consultant Related Factors

1. *Error and omission:* As indicated by Arain et. al (2004) and Assaf et.al (1995), a project having problems with the design or inadequate details in the design would significantly affect the work progress and the project time schedule.

2. *Design complexity:* Design drawings can be often difficult to execute if the project is complex, therefore, a procurement method of Design-Build method should be chosen in order for the contractor to be involved during the design stages. Difficult designs are addressed through various method statements according to the complexity of the design which requires more time and cost (El-Sadek, 2016).

3. *Change in design:* These change orders on behalf of the consultant occur to various reasons. One was mentioned by Arain et al. (2004) was due to improvement in designs naturally occurring during project construction. Fisk (1997), on the other hand, mentions that the occurrence of change orders in a project is highly possible due to projects starting before the completion of the final design. Other reasons at which changes in design occur are that engineer consultants perform technical design changes involving mechanical, electrical and plumbing changes while architect consultants perform structural changes that then cause important change impacts on the project.

4. *Conflicting contract documents:* A project having several contract documents may

produce misunderstanding in conveying the project scope. This is due to the fact that the contract documents may not be properly coordinated among all parties, therefore, impacting the project. One of the impacts could involve time delays as a misunderstanding in one of the contracts can easily affect the schedule of the other contracts documents involved. So in order to have an effective execution of the project, the contract documents must be properly managed among the parties and with other contracts in the project (CII, 1986).

5. *Insufficient design:* Fisk (1997) states that insufficient designs can be a common cause for change orders in a construction project, affecting time schedule and leading to a cost increase.

2.5.3 Other Related Factors

1. *Differing site condition:* Assaf et al. (1995) clarifies that delays can occur due to physical condition of the project differing from which have been mentioned and stated by the consultants in the contract documents. Differs in site conditions include: rock existence, soil conditions, and various other reasons. These site conditions can lead to increase in costs, time delays and even claims if the contractor represents mistaken contract documents. These differing site conditions can be avoided through effectively evaluating the site before beginning of construction. One of ways to manage time and cost impacts is to ensure the correct time and economic study has been conducted through the addition of a contingency to reduce and cover the impacts to account for any unforeseen conditions.

2. *Lack of co-ordination among parties:* Lac of co-ordination among consultants, client and contractor leads to misunderstanding of the contractor in selection of equipment, material and labor during the execution of the project. These coordination problems can severely affect the project if not dealt with at early stages and effectively managed by all parties (Arain et. al., 2004).

3. *New government regulation:* As indicated by Arain et al. (2004), project designs should follow specific codes and regulations according to the government organizations at which the project is performed in. However, changes in laws can severely impact the project, affecting project construction design. Delays can also occur if the project design does follow the government organizations, affecting the project's completion

date.

4. *Weather Conditions:* Changing weather conditions can have significant impacts on the project construction specifically productivity as it results in project delays. These weather conditions include snow, wind, rain and severe hot and cold weathers. Contractor must take into accounts models for forecasting the weather in order to minimize any delays that can occur (O'Brien, 1998).

5. *Value Engineering:* It is a process of replacing the existing materials with an alternative material achieving the same quality, but with a lower cost. This process involves improving the project function and costs, however, it involves a high risk of initiating various change orders (Dell, 1982). Usually, the value-engineering process should be performed during the design phase of the project.

6. *Safety Considerations:* The construction project must be executed in a safe environment following safety regulations and secure working conditions for all employees. However, if this is not properly managed, accidents can occur impacting the project schedule. Regular safety checks, accident avoidance, safety training for employees and process of dealing with emergencies are procedures that should be effectively managed to maintain a safe and secure project implementation (Clough et al., 1994).

7. *Required labor skills unavailable*: Projects that have difficult technology necessities require specific know-how and skills by the labor. Complex designs and method

statements need extreme professional skilled labor to implement these designs and perform all the required modifications and tests. However, if the project has a shortage of skilled labor, then this may result in occurrence of variation orders, affecting the project time and cost (Arain et. al., 2004).

2.6 Causes of Variation Orders in Egypt and other countries

Studies were conducted in various countries across the world to observe the common variations that occur during projects. These studies were carried out in low-income economies, lower middle-income economies, upper middle-income economies and high-income economies. A comparison between Egypt and a country in each income economy category is presented in table 1 below.

According to World Bank (2016) using World Bank Atlas method, GNI per capita were calculated to determine the economy of the country. Gross Nation Income (GNI) represents the average income corresponding to a country's inhabitants. It is calculated through dividing the country's final income per year in dollars by the country's population. Countries with GNI per capita less than $1,005 are considered as low-income economies. Lower middle-income economies have GNI per capita ranging between $1,006 and $3,955, while countries with GNI per capita ranging between $3,956 and $12,235 are considered as upper middle-income economies. Lastly, countries with GNI per capita above $12,235 are considered as high-income economies.

A collection of studies has been carried out in Gaza, Uganda, Malaysia and the UK for comparison with Egypt to obtain the top ten causes of variations. The reasons these countries were picked for comparison was due to their income economy category. A country was picked to reflect each of the four income economy categories. Egypt has GNI per capita of $2,450 ranking as a lower middle-income economy. Nigeria is slightly higher than Egypt with a GNI per capita of $3,230. Tanzania was used for comparison as it lies in the low-income economy category with a GNI per capita of $900. Malaysia has an upper middle-income economy with a GNI per capita of $9,850 and the UK as a high-income economy with a GNI per capita of $42,390 (World Bank, 2016). Table 1 represents the comparison of the top five variations among the five countries as various references included only the top five variations rather than top 10 variations.

Table 1: Comparison between Egypt and other countries

Rank	Tanzania (Mhando et al., 2017)	Nigeria (Ijaola & Iyagba, 2012)	Egypt (El-Sadek, 2016)	Malaysia (Memon et al., 2014)	United Kingdom (Keanne et al., 2010)
1	Design discrepancies	Owner instructs additional works	Client instructs additional works	Unavailability of equipment	Errors and omissions
2	Weather conditions	Owner instructs modification to design	The contractor uses the grey areas in the contract to request variations	Poor workmanship	Little involvement in design from contractor
3	Change of plans or scope	The contractor uses the gray areas in general conditions and request variations to the contract	Continuous change in project schedule	Design complexity	Inadequate project objectives
4	Differing site conditions	Natural growth of the project was not anticipated at the design stage	Conflicts between contract documents	Change in schedule	Poor design
5	Inadequate working drawings	Owner fails to make decision or review documents	Lack of coordination among project parties	Impediment to prompt decision making process	Conflicts between contract documents

2.6.1 Tanzania

Tanzania has the lowest-income economy among Nigeria, Egypt, Malaysia and the UK. The top five causes of variations in Tanzania are: design discrepancies, weather conditions, change of plans or scope, differing site conditions and inadequate working drawings. Two of the top five causes of variations can be linked to Tanzania's location: weather conditions and differing site conditions. Tanzania shares event number one design discrepancies with Egypt's event number three conflict in contract documents, as they are both of similar issue.

2.6.2 Nigeria

Nigeria has a lower middle-income economy as Egypt and its five main reasons for variations are: owner instructs additional works, owner instructs modification to design, the contractor uses the gray areas in general conditions and request variations to the contract, natural growth of the project was not anticipated at the design stage and owner fails to make decision or review documents. Nigeria shares the top three events with Egypt.

2.6.3 Egypt

The top five causes of variations in Egypt are: client instructs additional works, the contractor uses the grey areas in the contract to request variations, continuous change in project schedule, conflicts between contract documents, and lack of coordination among project parties. Egypt has the same top cause of variation as Nigeria, and also shares event number two with Nigeria; however, ranked as third in Nigeria. Egypt has the same cause of variation as number four in Malaysia and number five in United Kingdom. Though, they are ranked as events number three and four respectively in Egypt.

2.6.4 Malaysia

Malaysia has an upper middle-income economy and its five main causes of variations are: unavailability of equipment, Poor workmanship, design complexity, change in schedule, and impediment to prompt decision making process. Despite the fact that Malaysia has an upper middle-income economy, yet it faces problems regarding unavailability of equipment and poor workmanship, leading to these reasons as being the top two causes of variations in Malaysia. Malaysia's third event design complexity can be linked with Egypt's fourth and fifth events. Change in schedule is a shared event between both Malaysia and Egypt.

2.6.5 United Kingdom

United Kingdom has as a high-income economy and the highest among Tanzania, Nigeria, Egypt and Malaysia (World Bank, 2016). The five main causes of variations in UK are: errors and omissions in design, little involvement in design from contractor, inadequate project objectives, poor design, and conflicts between contract documents. UK shares event number four with Tanzania and event number five with Egypt.

2.6.6 Overall Comparison

There is no clear similarity between all five countries, meaning that the events that lead to variations can vary from one country to another. However, some countries share few events with another country. For instance, owner requesting additional work appears as a top cause of variation in both Nigeria and Egypt yet did not appear in as a main cause in Tanzania, Malaysia and UK. Nonetheless, the most common cause of variations among all five countries is related to design.

2.7 Impacts of Variation Orders

Assaf et al. (2006), CII (1995), Hester et al. (1991), Fisk (1997) and O'Brien (1998) have all highlighted about the impact of variation orders on a construction project. These variation orders can have a massive and numerous impacts on an ongoing project.

1. *Progress Impact:* One of the most significant impacts of variation orders is time delay. And, often time delays, may result in a cost increase (Assaf et al., 2006).

2. *Cost:* Variation Orders can have an impact on cost as well. Therefore, construction projects should account for a contingency percent to take into consideration any variation orders that may take place during the construction of the project (Assaf et al., 2006).

3. *Quality degradation:* Quality of work within a project can be affected by the amount of variation orders issued during the project. High issuance of variations can easily affect the quality of work due to the fact that contractors are cutting costs in order to compensate for losses, leading to reduction in quality (CII, 1995).

4. *Productivity degradation:* Variation orders are directly proportional with productivity degradation as they lead to work disruptions. These work disruptions result in delays and repetition of work since it is associated with labor productivity as it can simply demotivate all employees working within the project. Productivity degradation can result in increase in cost budgets. These increases in cost budget are a result of

employees working for long periods and working overtime to compensate for time delays (Hester et al., 1991).

5. *Procurement delay:* O'Brien (1998) states that as a result of variation orders arising within a project can often lead to procurement delays as these variation orders may require new resources, new materials, particular equipment or revised procurement requests for the ongoing construction projects.

6. *Logistics delays:* It is significantly possible that some variation orders may be established on the need of new materials, tools and equipment, leading to logistics delays (Hester et al., 1991).

7. *Damage to firms' reputations:* Variations can lead to claims and disputes; and these disputes can be predicted to damage the firm's reputation that may as well lead to problems reaching bankruptcy (Fisk, 1997).

8. *Poor safety conditions:* Variations can have a huge impact on the safety within a construction project as these variations can lead to changes in material, equipment and the construction method itself that would then require additional observation and safety procedures (O'Brien, 1998).

2.8 Management of Variation Orders

Due to the fact that variation orders are highly unavoidable during the construction of a project along with their possible impacts on time, cost, productivity and quality. Several approaches have been considered in managing variation orders.

One of the approaches to manage variations is to produce a well-coordinated and communicated system between the project team as mentioned by Charoenngam, et al. (2003) through the use of Internet technology as it can be accessed anywhere with no obligation of having specific time and location. Chan and Yeong (1995) second that the project team must have a good communication and teamwork between each other. Chan and Yeong (1995) state that managing orders must be conducted through having an effective change management system that is performed by the gathering of forms mentioned in the contract. A clear timeline and dates must accompany this change management process.

A variation order process was introduced by Krone (1991) that helped managing variation orders. This process' main technique is to observe the daily changes that occur during the construction process. The Contractual analysis technique (CAT) proposes that the early indication of a variation and recommending strategies results in effectively obtaining a well-controlled management and avoiding any claims that can occur. On the other hand, Stocks and Singh, (1999) introduced functional analysis concept design (FACD) that is its main aim is to decrease the number of variation orders that occur during construction projects. Many authors observe this method as an effective technique that can reduce the overall project costs.

Similarly, Harrington, et al. (2000) presented a theoretical model for the change management organization framework that consisted of seven phases as follows:

1. Clarify the project
2. Announce the project
3. Conduct the diagnosis
4. Develop an implementation plan
5. Execute the plan
6. Monitor progress and problems
7. Evaluate the final results

However, each model introduced has its own advantages and disadvantages. One might be suitable to one project, yet may be unfitting for another.

Chapter 3: Survey Distribution & Data Collection

Variation orders are inevitable in any construction project. Project managers need to predict the variation orders that may occur in their assigned projects, along with their time and cost impacts. Managers also need to account for these changes and develop an effective and comprehensive change control process to properly manage variations and limit their impact on both time and cost of the project. As mentioned in the previous chapter, variation orders may have negative impacts on the project along with time and cost impacts.

The literature review is conducted to help attain the most commonly occurring variation orders that can be caused by the client, consultant and other related factors. Then, a model is developed to help assist project managers in predicting the variations and their impacts that can occur during the construction phase based on the type, size, duration, procurement method, and contract type of the project.

3.1 Survey Distribution

3.1.1 Survey

Surveying includes various techniques, one of which is questionnaires. Questionnaires are one of the efficient and most popular techniques as they save time compared to other techniques such as face to face or phone interviews. Questionnaires have a higher reliability especially when conducting it over a divergent sample.

Questionnaires can be either performed electronically through Internet or physically through distribution of hardcopies of the questionnaire. Internet is a great option as currently almost every engineer can have access to the Internet; therefore, it is quicker to distribute the surveys. Furthermore, it is easier to analyze the questionnaire online than through hardcopies.

The survey in this research paper was distributed via email to engineers working in various projects in the construction field. It was also collected in the same manner via email.

3.1.2 Survey Creation

The main aim of the survey is to gather as much and as divergent data as possible about different projects to enrich the database with different scenarios. The survey is created in a manner that its responses are used in the model as a database source.

In order for this to happen, the survey is created in a simple way for the user to follow and fill it out. The survey was also distributed to people with varying experience in the construction industry in Egypt; Employers, Consultant, and contractors. The survey first starts with gathering data about the user through a structural manner. Structured questions involve having number of choices for the user to choose from. These kinds of questions are simpler for the user to answer and require less time to fill out. Below is an example of structured question: What is your field of expertise?

- Client representative
- Consultant
- Contractor

This survey requires an engineer to fill it out, and particularly an engineer that has worked with variation orders. However, the more experienced the engineer filling out the survey, the more weight will be allocated for the answers in the further development of the database and model.

The second section of the survey consists of two parts, the first part is structured questions and the second part is more stimulating as it involves a matrix that requires the user to rate his choice. For instance, the frequency of the variation order arising will be a choice between 1-5, where 1 is being the least occurring event and 5 being the most occurring event. Below is an example:

Please select a rating to the variations that occur during the construction of your project:

- Inadequate project objectives 1 2 3 4 5

Following the frequency of the event, the user will then be asked to rate the variation order's time and cost impacts. This section will be repeated again in the survey for the user to input his recent two projects that he worked on if possible.

An assessment will be held for all the expertise and an average for all the answers will be conducted to obtain the frequency of event arising within a project, and their time and cost impacts.

3.1.3 Survey Architecture

As mentioned before, the survey was distributed among clients, consultants and contractors. The questions in the survey were designed to collect answers to form input to the model.

The first section of the survey consists of structured questions regarding the background of the engineer filling out the survey. It is based on having a number of choices, and selecting the most suitable answer. The first section questions are:

1. What is your field of expertise?
   - Client representative
   - Consultant
   - Contractor

2. What is your current position?
   - Employee with no supervisory position
   - Supervisor
   - Middle Management
   - Top Management

3. What is your work specialization?
   - Design
   - Project Management
   - Cost Management
   - Construction Supervision

4. Years of experience

   - Less than 5
   - 5-10
   - 11-15
   - 16-20
   - 21-25
   - More than 25

The second section of the survey is regarding the two most recent projects the user has worked on. This section is divided into two parts; the first part consists of structured questions regarding the most recent project the user has worked on. The questions are:

5. What kind of project are you assigned on?

   - Retail
   - Residential
   - Commercial/Administrative
   - Industrial
   - Healthcare
   - Heavy Construction
   - Infrastructure
   - Other (Please specify):

6. What is the approximate value of the project?

   - Less than $10,000,000
   - Less than $50,000,000

- Less than $100,000,000
- More than $100,000,000

7. What is the procurement method for this project?
   - Traditional (Design-bid-build)
   - Design Build
   - Construction Management
   - Engineer-Procure-Construct
   - Public-Private Partnerships
   - Other (Please specify):

8. What type of contract is used in this project?
   - Lump Sum or Fixed Price
   - Re-measured or Unit price
   - Cost-plus fee
   - Cost-plus fee with a Guaranteed Maximum Price
   - Other (Please specify):

The second part in the second section is a matrix that involves 19 events that to lead variations related to the client, consultant and other factors that were gathered from the literature review. The reason those 19 events were specifically selected to be used in the survey is that it was found out through the literature review that these constitute common events leading to variation orders in projects in Egypt. The selection of a number of 19 events to be included in the surveys was totally arbitrary based on previous studies.

Below is the list of the events used in the survey:

1. Inadequate project objectives (Ibbs et al., 1995)
2. Change of scope (Arain et al., 2004)
3. Substitution of material (Chappell et al., 1996)
4. Financial problem (Clough et al., 1994) and (Ibbs et al.,1995)
5. Change of Schedule (O'Brien, 1998)
6. Unilateral decisions (El-Sadek, 2016)
7. Clients do not perform decisions in the correct time (Memon et. Al., 2014)
8. Error and omission (Arain et al., 2004) and (Assaf et al., 1995)
9. Design complexity (El-Sadek, 2016)
10. Change in design (Arain et. al., 2004) and (Fisk, 1997)
11. Conflicting contract documents (CII, 1986)
12. Insufficient design (Fisk, 1997)
13. Differing site condition (Assaf et al., 1995)
14. Lack of co-ordination among parties (Arain et. al., 2004)
15. New government regulation (Arain et al., 2004)
16. Weather Conditions (O'Brien, 1998)
17. Value Engineering (Dell, 1982)
18. Safety Considerations (Clough et al., 1994).
19. Required labor skills unavailable (Arain et al., 2004)

The matrix consists of three divisions. The first division is the frequency of variations that occur during a project and the user is required to give a rating for (1 being the least and 5 being the max). So for instance, if the user choses 3 for a selected variation, then this mean this variation occurs 60 percent of the time.

The second and third divisions in the matrix are similar as the user choses the most suitable answer regarding variation's effect on time and cost. The user is required to select from various percentages on how much the variation will impact the time and cost. For example, the user can select that variations that occur due to change of scope had 10-30% cost impact and no time impact.

The expected outcome of this survey to obtain the probability of variation types that may occur during the construction of a project and their time and cost impacts in different project types with various costs, procurement types and contract types.

3.1.4 Demographics of the Surveys

Table 2 represents the sample size of the people who filled out the survey. The number of surveys distributed was 102 and the total number of people who completed the survey was 87. A sample size equation was used to determine the adequacy of the sample size; whether it is representative of the population or not.

$$\text{Sample Size} = \frac{\frac{z^2 . p(1-p)}{e^2}}{1+\frac{z^2 . p(1-p)}{e^2 N}}$$

N = Population size

e = Margin of Error (as a decimal)

z= Confidence Level (as a z-score)

p = Percentage Value (as a decimal)

The sample size corresponds to the completed responses from the survey distribution. The population size (N) refers to the total number of surveys distributed that is 102 surveys. A desired confidence level of 95% was used to determine how reliable the results. Z-score refers to the number of standard deviations a given proportion is away from the mean. The z-score is corresponding to 95% confidence level is 1.96. Margin of error refers to the percentage of expected results in order to reflect the population size. A small margin of error means a closer result to the confidence level; therefore, a 5% margin of error is used. A percentage value of 50% was used to assume a normal distribution in calculation to correspond to an optimum sample size.

$$80.56 = \frac{\frac{1.96^2.0.5(1-0.5)}{0.05^2}}{1+\frac{1.96^2.0.5(1-0.5)}{0.05^2.102}}$$

The sample size that needs to be surveyed was 81. However, the actual number of respondents was 87; meaning that the sample size is an acceptable representation of the population.

More than half of the respondents had experience of more than 10 years (60%); which gives reliable results. The remaining 40% of the respondents were either juniors or middle management.

Table 2: Demographics of Respondents

Sample Size	87
Number of Projects	144
Years of experience 10+ or more	39%
Years of experience 25+ or more	21%

Figure 2 shows the participants that contributed in the survey, where half of the participants worked in a consultant firm and the other half either worked for contracting companies or client firms. The work specializations of these participants were design, project management, cost management and construction supervision. Figure 3 represents the different types of projects that the participants worked on. The top two project types that the participants worked on are residential and commercial/administrative projects at 30% and 27% respectively. This concludes that more than half the participants worked in these two types of projects while the remaining participants worked on retail, healthcare, industrial, infrastructure and heavy construction projects.

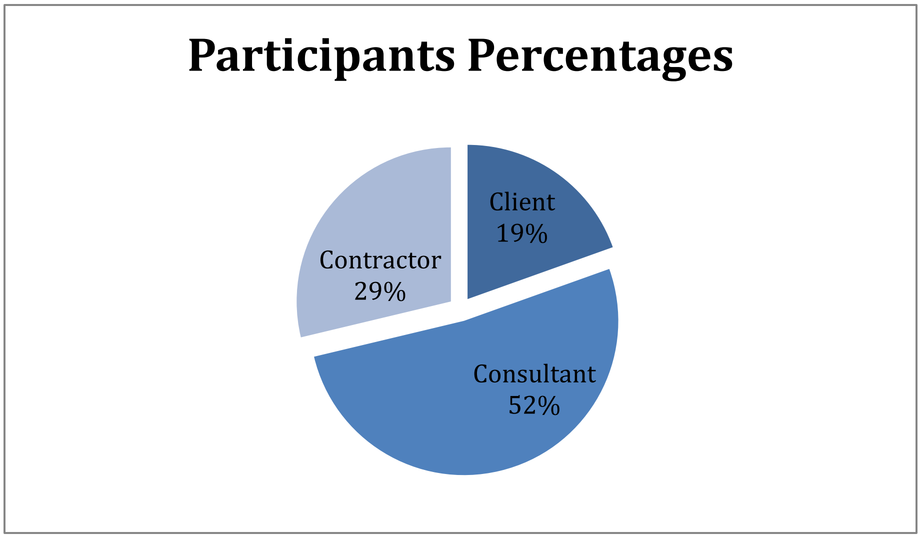

Figure 2: Participants percentages

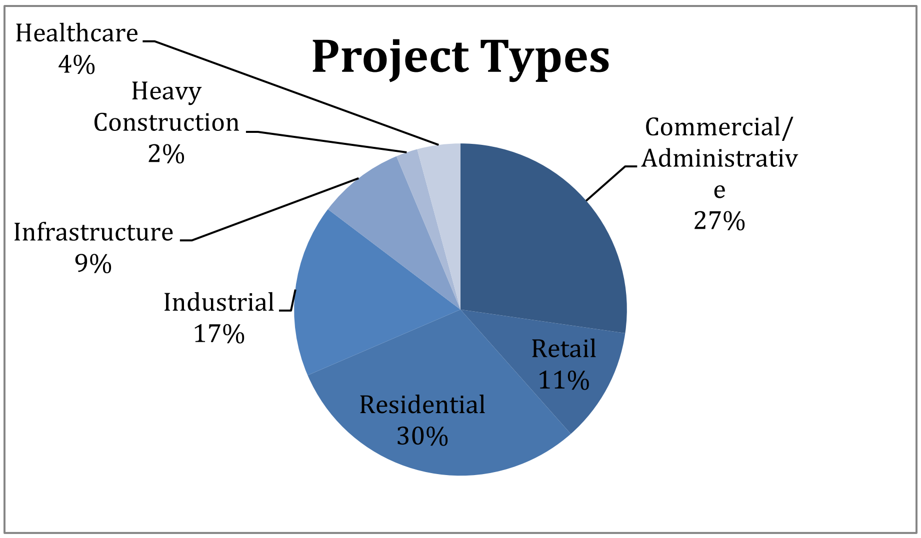

Figure 3: Project Types

Figure 4 represents a statistical categorization of projects' values for the 144 projects; 30% of the projects the participants have worked on had a value of more than $100,000,000 and 21% had a value between $50,000,000 and $100,000,000. This means that more than half the participants have worked on mega projects in Egypt. The remaining percentage is distributed among the other project values of less than $10,000,000 and less than $50,000,000 at 25% and 24% respectively.

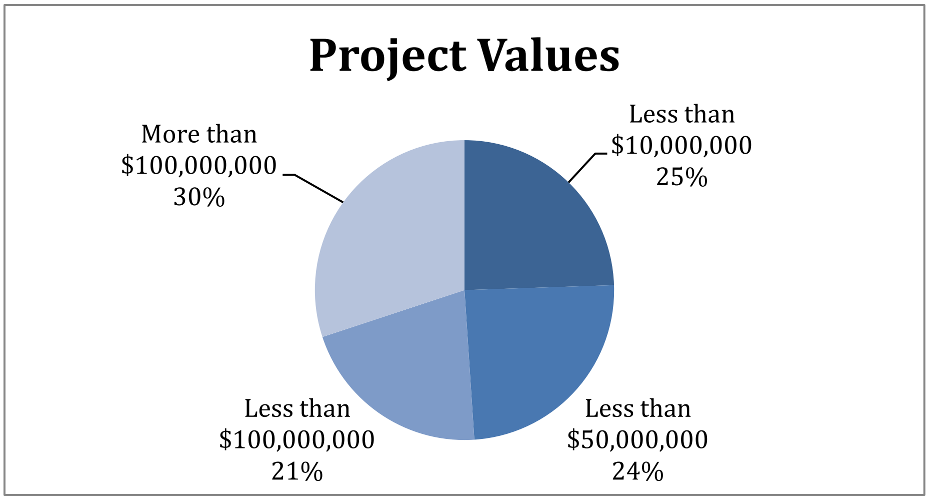

Figure 4: Project values

Figure 5 shows the procurement methods that the participants used during their projects. 63% of the projects that the participants worked on used traditional (design-bid-build). This shows that this is the most common procurement method used in Egypt which is also known as the general contracting project delivery. The remaining procurement methods all contribute to 37% of the total projects.

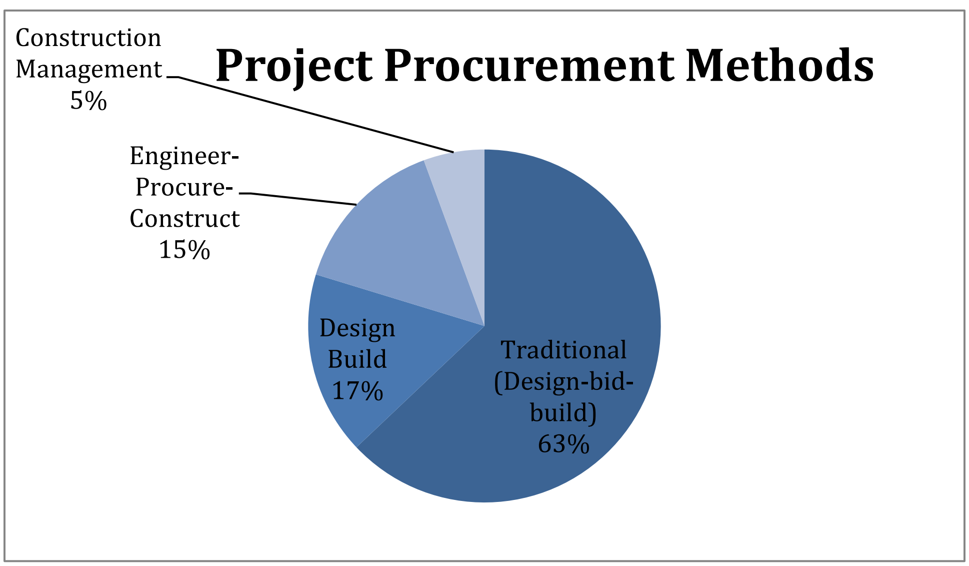

Figure 5: Project procurement methods

Figure 6 represents the project types used in the projects worked on by the participants. Almost two thirds of the projects used lump sum or fixed price contracts. This contract type is mostly common here in Egypt as it has the lowest risk on the client since the client knows the final cost of the project before the work has begun and commits to an agreed-upon project scope. Following this, 34% of the projects the participants worked on used re-measured or unit price contracts, leaving cost-plus fee with guaranteed maximum price with only 6% of the total projects. This shows that Egypt is more familiar and biased towards using lump sum contracts.

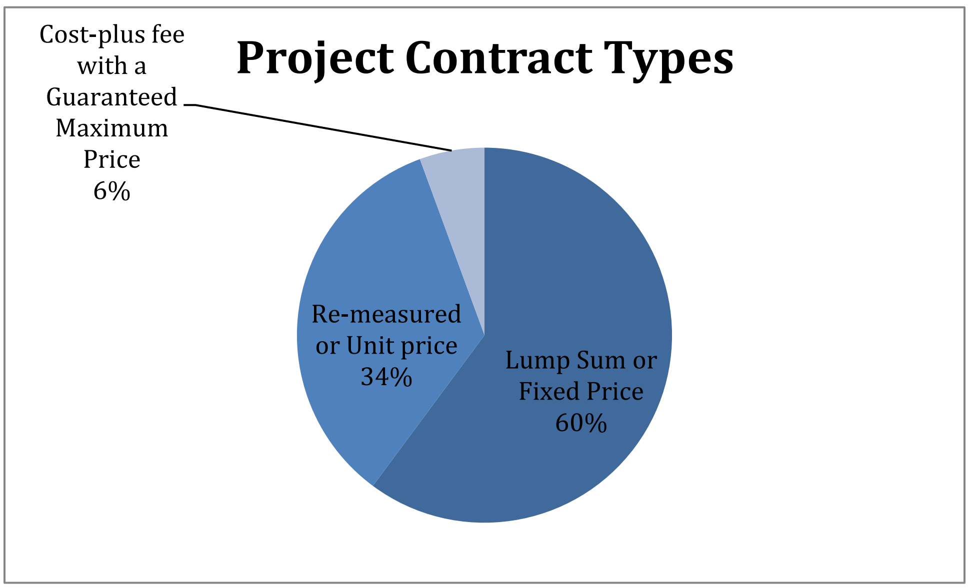

Figure 6: Project contract types

Figure 7 shows a distribution of durations of projects the participants worked on: 31% of the projects had duration of 24-36 months and 28% were more than 36 months. This shows that almost 60% of the projects surveyed in Egypt had duration of more than two years.

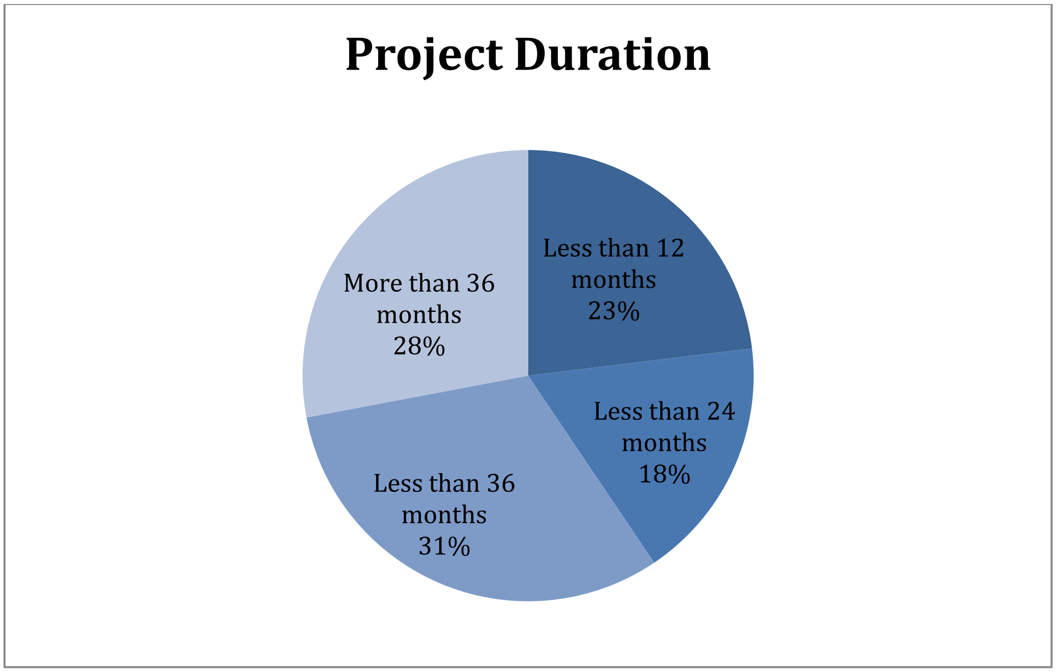

Figure 7: Project duration

3.2 Data Collection

A sufficient database is required to develop the model. The database shall contain different scenarios of projects' types, size, value, duration, procurement rout, and contract type. The database shall also contain the common variations occurred in each scenario and their associated cost and time impact. The development of the database required data collection that is performed through distribution of surveys.

3.2.1 Database

The following results were obtained after the distribution of the surveys. The responses were effective for the expert system expert system model as a total of 87 surveys were collected, resulting in a total number of 144 projects being analyzed. The data gathered for the 144 projects were then gathered in one single combined database.

Project No.	Field of Expertise	Current Position	Work Specialization	Years of Experience	Involved in Variation Process	Projects Worked on					
						Project Type	Value	Procurement Method	Contract Type	Project Duration	Survey Reference
1	Consultant	Supervisior	Cost Management	11-15	Yes	Residential	Less than $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	1
2	Consultant	Supervisior	Cost Management	11-15	Yes	Infrastructure	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	24 - 36 months	1
3	Consultant	Middle Management	Design	Less than 5	Yes	Retail	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	24 - 36 months	2
4	Contractor	Employee with no supervisory position	Cost Management	Less than 5	Yes	Commercial/Administrative	More than $100,000,000	Construction Management	Lump Sum or Fixed Price	24 - 36 months	3
5	Contractor	Supervisior	Construction Supervision	5-10	Yes	Residential	More than $100,000,000	Engineer-Procure-Construct	Re-measured or Unit price	More than 36 months	4
6	Contractor	Top Management	Cost Management	More than 25	Yes	Retail	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	5
7	Contractor	Top Management	Cost Management	More than 25	Yes	Residential	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	5
8	Contractor	Middle Management	Project Management	Less than 5	Yes	Residential	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	6
9	Consultant	Middle Management	Project Management	Less than 5	Yes	Industrial	Less than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	6
10	Consultant	Employee with no supervisory position	Cost Management	5-10	Yes	Residential	Less than $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	7
11	Consultant	Middle Management	Design	11-15	Yes	Industrial	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	8
12	Consultant	Middle Management	Design	11-15	Yes	Commercial/Administrative	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	8
13	Consultant	Middle Management	Project Management	Less than 5	Yes	Residential	Less than $100,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	More than 36 months	9
14	Consultant	Supervisior	Cost Management	5-10	Yes	Commercial/Administrative	More than $100,000,000	Traditional (Design-bid-build)	Cost-plus fee with a Guaranteed Max	More than 36 months	10
15	Contractor	Employee with no supervisory position	Cost Management	Less than 5	Yes	Retail	Less than $100,000,000	Construction Management	Cost-plus fee with a Guaranteed Max	24 - 36 months	11
16	Contractor	Supervisior	Project Management	Less than 5	Yes	Residential	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	12
17	Contractor	Supervisior	Project Management	Less than 5	Yes	Residential	Less than $100,000,000	Design Build	Re-measured or Unit price	24 - 36 months	12
18	Consultant	Middle Management	Project Management	Less than 5	Yes	Commercial/Administrative	Less than $10,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	Less than 12 months	13
19	Consultant	Middle Management	Project Management	Less than 5	Yes	Residential	Less than $10,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	Less than 12 months	13
20	Consultant	Middle Management	Project Management	5-10	Yes	Commercial/Administrative	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	14
21	Consultant	Middle Management	Project Management	5-10	Yes	Commercial/Administrative	Less than $10,000,000	Design Build	Lump Sum or Fixed Price	Less than 12 months	14
22	Consultant	Middle Management	Project Management	11-15	Yes	Commercial/Administrative	Less than $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	15
23	Consultant	Middle Management	Project Management	11-15	Yes	Residential	Less than $50,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	12 - 24 months	15
24	Contractor	Employee with no supervisory position	Cost Management	Less than 5	Yes	Commercial/Administrative	Less than $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	16
25	Contractor	Employee with no supervisory position	Cost Management	Less than 5	Yes	Commercial/Administrative	Less than $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	24 - 36 months	17
26	Client representative	Middle Management	Project Management	5-10	Yes	Commercial/Administrative	Less than $10,000,000	Design Build	Lump Sum or Fixed Price	Less than 12 months	18
27	Client representative	Middle Management	Project Management	5-10	Yes	Commercial/Administrative	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	18
28	Client representative	Employee with no supervisory position	Project Management	5-10	Yes	Residential	Less than $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	19
29	Client representative	Employee with no supervisory position	Project Management	5-10	Yes	Healthcare	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	24 - 36 months	19
30	Consultant	Employee with no supervisory position	Cost Management	Less than 5	Yes	Residential	Less than $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	20
31	Client representative	Employee with no supervisory position	Project Management	Less than 5	Yes	Commercial/Administrative	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	21
32	Client representative	Employee with no supervisory position	Project Management	Less than 5	Yes	Commercial/Administrative	Less than $10,000,000	Design Build	Lump Sum or Fixed Price	Less than 12 months	21
33	Consultant	Middle Management	Cost Management	5-10	Yes	Commercial/Administrative	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	22
34	Consultant	Middle Management	Cost Management	5-10	Yes	Industrial	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	24 - 36 months	22
35	Consultant	Supervisor	Cost Management	11-15	Yes	Retail	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	23
36	Consultant	Supervisor	Cost Management	11-15	Yes	Commercial/Administrative	Less than $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	23
37	Client representative	Employee with no supervisory position	Cost Management	16-20	Yes	Residential	Less than $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	24
38	Client representative	Employee with no supervisory position	Cost Management	5-10	Yes	Residential	Less than $50,000,000	Design Build	Lump Sum or Fixed Price	12 - 24 months	24
39	Contractor	Employee with no supervisory position	Project Management	16-20	Yes	Residential	Less than $50,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	12 - 24 months	25
40	Contractor	Middle Management	Cost Management	5-10	Yes	Residential	Less than $50,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	12 - 24 months	26
41	Contractor	Middle Management	Cost Management	16-20	Yes	Residential	Less than $50,000,000	Design Build	Lump Sum or Fixed Price	12 - 24 months	26

Figure 8: Extract from the database

Figure 8 is an extract from the database that represents the output of the surveys. The first five columns show the participants' general background: field of expertise, current position, work specialization, years of experience and their involvement in variation orders. The following four columns reflect data about the project the participant has worked on: project type, project value, project duration, procurement method and contract type.

Chapter 4: Model Development

A model was developed to help assist clients and project managers predict variations that can occur during the construction of a project. It helps in accounting for a contingency for both cost and time.

Figure 9 represents a flowchart of the general logic behind the model. The details of the flowchart will be explained later on in this chapter.

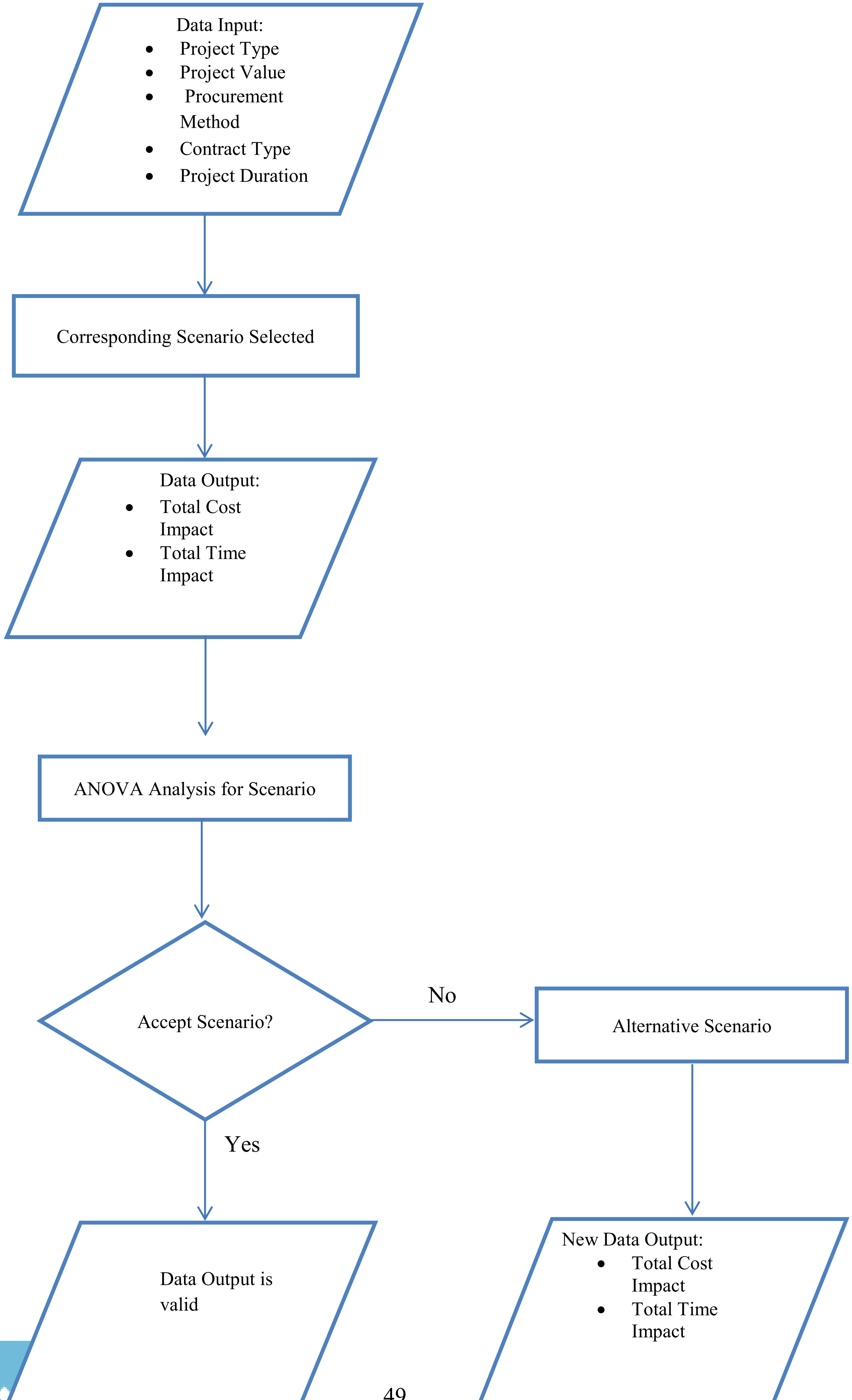

Figure 9: Flowchart of the general logic behind the model

4.1 Scenarios Creation

A database was created from the distribution of the surveys. This database was then used to group each individual project type; project value, procurement method, contract type and project duration in order to create a unique scenario. So for instance, if the user picked the retail as a project type, less than $10,000,000 as project value, design-build as procurement method, less than 24 months as project duration and lump sum as contract type, then this is a unique scenario. However, changing any of previous mentioned data will result in another distinctive scenario. So if the user picked the same previous mentioned data, yet changed the contract type from lump sum to re-measured, it will then result in another scenario.

Nevertheless, not all the possible scenarios had been mentioned as the scenarios are only based on the data gathered via the surveys. Therefore, there is a possibility that there is a scenario that does not exist due to the fact that none of the 87 participants worked on such kind of scenario before. This demonstrates that the only mentioned scenarios are the ones the participants worked on in Egypt.

4.2 Calculation of Time & Cost Impacts

Each of the scenarios was investigated separately. Every single project within the database involved a survey reference for simplicity when assessing the scenario.

The following equations were used in the model:

Average of the frequency of event occurring, or Average time impact, or Average cost impact

$$= \frac{\Sigma Values\ from\ all\ Surveys}{Total\ number\ of\ Surveys} \quad (1)$$

The surveys corresponding to each individual scenario were used as an input to determine the average of the frequency of event occurring, average time impact and average cost impact. The average of the three parameters was calculated through Equation (1).

$$Average\ Cost\ Score = Average\ Frequency\ of\ event\ occurring\ x\ Average\ Cost\ Impact \quad (2)$$

Equation (2) represents the average cost score for each variation occurring. It is calculated through multiplying average frequency of event occurring by average cost impact that had been previously calculated in Equation (1).

$$Total\ Cost\ Impact = Project\ Value\ x\ \Sigma Average\ Cost\ Score \quad (3)$$

Equation (3) represents the total cost impact on the project. It is calculated through multiplying the project value by the summation of the average cost score. Project value is obtained through the user data input. The summation of the average cost score is calculated by adding up all the average cost scores that had been previously calculated in Equation (2) for all the 19 events that lead to variation occurrence.

$$Average\ Time\ Score = Average\ Frequency\ of\ event\ occurring\ x\ Average\ Time\ Impact \quad (4)$$

Equation (4) represents the average time score for each variation occurring. It is obtained similarly as average cost score but through multiplying average frequency of event occurring by average time impact which had been previously calculated in Equation (1).

$$Total\ Time\ Impact = Project\ Duration\ x\ \Sigma Average\ Time\ Score \quad (5)$$

Equation (5) represents the total time impact on the project that is obtained similarly as total cost impact. It is calculated through multiplying the project duration by the summation of the average time score. Project duration is obtained through the user data input. The summation of the average time score is calculated by adding up all the average time scores that had been previously calculated in Equation (4) for all the 19 events that lead to variation occurrence.

4.3 Analysis of Variance (ANOVA)

For each scenario of the 42 scenarios, analysis of variances (ANOVA) has been used. The terminology "analysis of variance" is based on an approach that uses variances to observe whether the means are the same or vary. ANOVA is a statistical method that is used to test the hypothesis of two or more means that are the same. This statistical method assumes that the data to be normally distributed and have equal standard deviations.

There are three types of ANOVA analysis: one-way ANOVA, two-way ANOVA with replication and two-way ANOVA without replication. One-way ANOVA is applied for data collection where only one dependent variable is near to the common mean. In other words, one-way ANOVA is used when studying if any statistical difference occurs between the means of three or more unrelated groups. However, this approach could not be applied in this model will not be useful as approach relies on

$$H_0=\mu_1=\mu_2=\mu_3=\mu_k \qquad (6)$$

$$H_1=\mu_1\neq\mu_2\neq\mu_3\neq\mu_k \qquad (7)$$

Equation 6 represents that the null hypothesis for one-way ANOVA, it states that all the means are the same. Equation 7 represents the alternative hypothesis where the means are not the same where:

μ= group mean

k= number of groups

On the other hand, two-way ANOVA is applied for data collection from two groups for two independent variables converging near the common mean. Two-ANOVA with replication is applied when there is repeated measure; for instance, an observation has been conducted on the same individual more than once.

The null hypothesis for the two-way ANOVA with replication tests three tests. The first test states that the means of data grouped by one independent variable are equal. The second test states the means of data for the other independent variable is equal. The third test states that there is no interaction effect occurring between the two independent variables. The interaction effect here means that the effect of one independent variable depends on the other independent variable.

The null hypothesis for the two-way ANOVA without replication tests two tests. It tests the same first two tests as the two-way ANOVA with replication. However, it does not test for interaction effect.

In this model, two-way ANOVA without replication has been applied. This approach was selected out of the two other approaches due to the fact that the variations being analyzed are independent of one another. Each scenario has three two-way ANOVA without replication being applied for each of the following parameters: frequency of events, cost impact and time impact.

The main observation was based on the columns as to detect the variances among the submitted surveys corresponding to each scenario. This was conducted to know whether there was a significant difference between the answered surveys of the same scenario or not.

Chapter 5: Data Analysis, Verification & Validation

5.1 Data Analysis

5.1.1 User Input

The user in the model selects a scenario for any project type, project value, procurement method, contract type and project duration for any project he would like to predict the frequency of variations that can occur along with their time and cost impacts. All three parameters mentioned above have to accept the null hypothesis in order for the scenario the user input gets accepted.

However, if the scenario the user inputs is rejected; then an alternative scenario will be selected. The alternative scenario is selected due to the fact that the original scenario has unreliable results as there were variances in the corresponding surveys conducted within that scenario. The alternative scenario is not the exact same scenario; it is someway similar and closer to the original scenario to what the user wants under the same circumstances. The alternative scenario will include the same project type, project duration and project value; yet will change the procurement type or contract type or both.

5.1.2 Scenarios Creation

Upon creation of the database, grouping them was the following step. The 144 projects resulted in a total number of 42 scenarios being created.

Table 3: Database scenarios

Project Type	Value	Procurement Method	Contract Type	Project Duration	Scenario No.
Commercial/Administrative	Less than $10,000,000	Design Build	Lump Sum or Fixed Price	Less than 12 months	1
Commercial/Administrative	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	2
Commercial/Administrative	Less than $10,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	Less than 12 months	3
Commercial/Administrative	$50,000,000 - $100,000,000	Construction Management	Cost-plus fee with a Guaranteed Maximum Price	24 - 36 months	4
Commercial/Administrative	Less than $100,000,000	Design Build	Lump Sum or Fixed Price	24 - 36 months	5
Commercial/Administrative	$10,000,000 - $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	6
Commercial/Administrative	$50,000,000 - $100,000,000	Engineer-Procure-Construct	Re-measured or Unit price	24 - 36 months	7
Commercial/Administrative	$50,000,000 - $100,000,000	Construction Management	Lump Sum or Fixed Price	24 - 36 months	8
Commercial/Administrative	More than $100,000,000	Traditional (Design-bid-build)	Cost-plus fee with a Guaranteed Maximum Price	More than 36 months	9
Commercial/Administrative	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	10
Healthcare	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	11
Healthcare	More than $100,000,000	Design Build	Lump Sum or Fixed Price	More than 36 months	12
Heavy Construction	More than $100,000,000	Engineer-Procure-Construct	Lump Sum or Fixed Price	More than 36 months	13
Industrial	Less than $10,000,000	Design Build	Lump Sum or Fixed Price	Less than 12 months	14
Industrial	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	15
Industrial	Less than $10,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	Less than 12 months	16
Industrial	$10,000,000 - $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	17
Industrial	$50,000,000 - $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	24 - 36 months	18
Industrial	$50,000,000 - $100,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	24 - 36 months	19
Industrial	More than $100,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	More than 36 months	20
Industrial	More than $100,000,000	Engineer-Procure-Construct	Re-measured or Unit price	More than 36 months	21
Infrastructure	$10,000,000 - $50,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	12 - 24 months	22
Infrastructure	$10,000,000 - $50,000,000	Design Build	Lump Sum or Fixed Price	12 - 24 months	23
Infrastructure	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	24
Infrastructure	More than $100,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	More than 36 months	25
Residential	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	26
Residential	Less than $10,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	Less than 12 months	27
Residential	$10,000,000 - $50,000,000	Design Build	Lump Sum or Fixed Price	12 - 24 months	28
Residential	$10,000,000 - $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	29
Residential	$10,000,000 - $50,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	12 - 24 months	30
Residential	$50,000,000 - $100,000,000	Design Build	Re-measured or Unit price	24 - 36 months	31
Residential	$50,000,000 - $100,000,000	Design Build	Lump Sum or Fixed Price	24 - 36 months	32
Residential	$50,000,000 - $100,000,000	Engineer-Procure-Construct	Lump Sum or Fixed Price	24 - 36 months	33
Residential	$50,000,000 - $100,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	24 - 36 months	34
Residential	More than $100,000,000	Engineer-Procure-Construct	Re-measured or Unit price	More than 36 months	35
Residential	More than $100,000,000	Engineer-Procure-Construct	Lump Sum or Fixed Price	More than 36 months	36
Residential	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	37
Retail	Less than $10,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	Less than 12 months	38
Retail	$10,000,000 - $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	39
Retail	$50,000,000 - $100,000,000	Construction Management	Cost-plus fee with a Guaranteed Maximum Price	24 - 36 months	40
Retail	More than $100,000,000	Engineer-Procure-Construct	Lump Sum or Fixed Price	More than 36 months	41
Retail	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	42

Table 3 shows the 42 scenarios grouped from the database. The top two project types used in the scenarios were residential and commercial/administrative at 12 and 10 scenarios respectively. This shows that these scenarios involving these two project types are the most commonly applied in Egypt. Other scenarios involving project types such as healthcare and heavy construction contributed to only a total of 3 scenarios out of the total 42 scenarios. This shows these scenarios involving these project types are less common applied in Egypt.

The top two common projects used in the scenarios involve a procurement method of a traditional (design-bid-build) with lump sum contract type and traditional (design-bid-build) with a re-measured contract type at 13 and 10 scenarios respectively. This indicates that these scenarios are the most commonly applied in Egypt. On the other hand, there are less common projects applied in Egypt such as a project having a procurement method of a design-build with a re-measured contract type or a project having a construction management procurement method with a lump sum contract as each project contributes to only one scenario out of the 42 scenarios in the database.

5.1.3 Calculation of Time & Cost Impacts

For each scenario, averages of frequencies of variation event, time and cost impacts were calculated.

Table 4: Average frequencies, time and cost impacts for each individual scenario

		Frequency of Event					Effect on Cost					Effect on Time				
		Survey 14	Survey 18	Survey 21	Average Frequency		Survey 14	Survey 18	Survey 21	Average Cost		Survey 14	Survey 18	Survey 21	Average Time	
	Client Related Events															
1	Inadequate project objectives	1	1	2	1.00	0-20%	3	3	2	3.00	0-10%	3	1	3	2.00	0-10%
2	Change of scope	3	2	2	2.00	20-40%	4	3	3	3.00	0-10%	3	3	2	3.00	0-10%
3	Substitution of material	2	2	2	2.00	20-40%	4	3	3	3.00	0-10%	2	1	3	2.00	0-10%
4	Financial problem	1	4	1	2.00	20-40%	2	3	2	2.00	No Impact	1	3	1	2.00	0-10%
5	Change of Schedule	2	3	1	2.00	20-40%	2	3	2	2.00	No Impact	3	4	1	3.00	0-10%
6	Unilateral decisions	1	3	1	2.00	20-40%	2	3	2	2.00	No Impact	1	2	1	1.00	No Impact
7	Clients do not perform decisions in the correct time	3	5	1	3.00	40-60%	3	3	3	3.00	0-10%	2	3	3	3.00	0-10%
	Consultant Related Events															
8	Error and omission	1	1	2	1.00	0-20%	3	3	3	3.00	0-10%	1	2	2	2.00	0-10%
9	Design complexity	2	1	2	2.00	20-40%	2	3	2	2.00	No Impact	1	1	3	2.00	0-10%
10	Change in design	4	1	1	2.00	20-40%	5	3	3	4.00	10-30%	4	2	3	3.00	0-10%
11	Conflicting contract documents	1	1	2	1.00	0-20%	2	2	2	2.00	No Impact	1	1	2	1.00	No Impact
12	Insufficient design	4	1	3	3.00	40-60%	3	2	3	3.00	0-10%	2	2	3	2.00	0-10%
	Other Related Events															
13	Differing site condition	1	2	2	2.00	20-40%	2	3	3	3.00	0-10%	3	1	2	2.00	0-10%
14	Lack of co-ordination among parties	1	2	3	2.00	20-40%	2	2	2	2.00	No Impact	1	3	3	2.00	0-10%
15	New government regulation	3	3	3	3.00	40-60%	2	4	3	3.00	0-10%	1	1	1	1.00	No Impact
16	Weather Conditions	1	1	2	1.00	0-20%	2	2	2	2.00	No Impact	1	1	1	1.00	No Impact
17	Value Engineering	2	4	2	3.00	40-60%	1	1	1	1.00	Cost Saving	3	3	1	2.00	0-10%
18	Safety Considerations	1	1	4	2.00	20-40%	2	2	2	2.00	No Impact	1	1	4	2.00	0-10%
19	Required labor skills unavailable	1	1	4	2.00	20-40%	2	2	2	2.00	No Impact	1	1	3	2.00	0-10%

Table 4 is conducted for scenario number one. The rows represent the variations that can occur during the project, while the columns represent the surveys that contributed to this scenario. Table 4 shows that 3 surveys were conducted for this scenario and an average has been calculated for each parameter. However, the number of surveys being assessed in each scenario differs according to the number of surveys undergoing this specific scenario. This table has been repeated for each of the 42 scenarios and results have been calculated. Each scenario had to have a minimum of 3 surveys in order to achieve reliable results.

Table 5: Average Frequency score, cost score and time score for each individual scenario

		Frequency of Events	Effect on Cost	Effect on Time
Client Related Events		Av. Frequency Score	Av. Cost Score	Av. Time Score
1	Inadequate project objectives	0.30	0.05	0.05
2	Change of scope	0.30	0.20	0.20
3	Substitution of material	0.50	0.20	0.05
4	Financial problem	0.50	0.00	0.05
5	Change of Schedule	0.70	0.00	0.05
6	Unilateral decisions	0.30	0.00	0.00
7	Clients do not perform decisions in the correct time	0.50	0.05	0.05
Consultant Related Events				
8	Error and omission	0.50	0.05	0.05
9	Design complexity	0.50	0.00	0.05
10	Change in design	0.50	0.05	0.20
11	Conflicting contract documents	0.50	0.00	0.05
12	Insufficient design	0.50	0.00	0.05
Other Related Events				
13	Differing site condition	0.30	0.05	0.05
14	Lack of co-ordination among parties	0.30	0.00	0.05
15	New government regulation	0.50	0.20	0.20
16	Weather Conditions	0.50	0.00	0.05
17	Value Engineering	0.70	-0.20	0.00
18	Safety Considerations	0.50	0.00	0.05
19	Required labor skills unavailable	0.30	0.00	0.00

Table 6: Total cost and time impacts for scenario

Cost Impact	$22,500,000.00	
Time Impact	7.00	Months

Table 5 represents the average frequency scores, average cost scores and average time scores corresponding to each variation occurring. Table 6 represents the total predicted cost and time impacts for that scenario. Tables 5 and 6 have been conducted for each of the 42 scenarios.

5.1.3 Analysis of Variance (ANOVA)

Two-way ANOVA without replication has been used to analyze the results of the surveys. It has been used to test whether the null hypothesis has been accepted or fail to accept (rejected).

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Inadequate project objectives	3	4	1.3333333	0.333333333
Change of scope	3	7	2.3333333	0.333333333
Substitution of material	3	6	2	0
Financial problem	3	6	2	3
Change of Schedule	3	6	2	1
Unilateral decisions	3	5	1.6666667	1.333333333
Clients do not perform decisions in the correct time	3	9	3	4
Error and omission	3	4	1.3333333	0.333333333
Design complexity	3	5	1.6666667	0.333333333
Change in design	3	6	2	3
Conflicting contract documents	3	4	1.3333333	0.333333333
Insufficient design	3	8	2.6666667	2.333333333
Differing site condition	3	5	1.6666667	0.333333333
Lack of co-ordination among parties	3	6	2	1
New government regulation	3	9	3	0
Weather Conditions	3	4	1.3333333	0.333333333
Value Engineering	3	8	2.6666667	1.333333333
Safety Considerations	3	6	2	3
Required labor skills unavailable	3	6	2	3
Survey 14	19	35	1.8421053	1.140350877
Survey 18	19	39	2.0526316	1.608187135
Survey 21	19	40	2.1052632	0.877192982

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	15.333333	18	0.8518519	0.614195362	0.864580992	1.89862196
Columns	0.7368421	2	0.3684211	0.26563598	0.768207819	3.259446306
Error	49.929825	36	1.3869396			
Total	66	56				

Figure 10: Two-way ANOVA without replication for frequency of events occurring

Figure 10 represents the output of the two-way ANOVA without replication analysis. The first output table represents the summary of variations that occur during that specific scenario. The *count* column represents the total number of surveys submitted in that scenario which in that case is three. The *sum* column represents the sum of the three surveys submitted at each variation. The *average* column represents the average of the three surveys and the *variance* column represents the variance among the three surveys. The terminology of variance is used here to determine how far the surveys are spread out of their mean. However, this is repeated with the surveys where the *count*, *sum*, *average* and *variance* are calculated for all variations as well.

The second output table represents the sources of variation for the rows which in that case are all the variations that can take place during the project and the columns which are the surveys submitted for that scenario. The first column *SS* refers to the sum of squares which is a mathematical approach that is used to define the distribution of the data collected. This is basically calculated through obtaining the total sum of the squares of the differences from the mean.

The second column *df* refers to the degrees of freedom at which corresponds to the number of values input that is free to differ. The *df* is calculated through subtracting 1 from the total number of values submitted. For instance, if three surveys are submitted, then the corresponding *df is* two.

The third column *MS* refers to the mean squares which is an approximation of the population variance. This is calculated through the dividing the corresponding sum of squares by the degrees of freedom.

The fourth column refers to the *F-test* which is named so after Sir Ronald Fisher. An F-statistic has been conducted for each hypothesis which is a statistic test for F-test. The *F* statistic is a ratio that has been calculated through dividing the corresponding *MS* by MS_{Error}.

The fifth column refers to the *p-value* that represents the probability that is used to determine the significance of the results. It is used as an indication to accept or reject the null hypothesis. The smaller the p-value, the stronger the evidence that the null hypothesis should be rejected.

The sixth column F_{crit} refers critical value for the F-distribution. In order to get the F_{crit}, the following need to be identified: probability level, the numerator degrees of freedom, and the denominator degrees of freedom. Alpha is used at 0.05 as a default in this model. It refers to 95 percent confidence level that is the level of significance for the hypothesis test. In this case, F_{crit} is obtained through F-distribution tables for p=0.05 significance level.

The following conditions need to be satisfied to accept the null hypothesis or in other words, fail to reject the null hypothesis. These conditions state that there is no significant difference among the results.

- $F\text{-}value < Fcrit$
- $P\text{-}value > 0.05$

However, if the following conditions are satisfied, then there is a significant difference in the results, and therefore, reject the null hypothesis.

- $F\text{-}value > Fcrit$
- $P\text{-}value \leq 0.05$

The main focus in this study of two-way ANOVA without replication analysis is on the columns where an assessment of variance on the surveys has been conducted. The following results have been attained:

- $F = 0.26564 < Fcrit = 3.2594$, and
- P-value = 0.76820 > 0.05

The above conditions satisfy the acceptance of the null hypothesis, showing that the results are not different from each other. It also indicates that the alternative hypothesis is weak, and therefore, cannot reject the null hypothesis as the means of the results are the same.

The following previous conditions of accepting or rejecting the null hypothesis have been assessed for the time and cost impacts as well for each individual scenario.

5.1.4 Accept/Reject the Scenario

Each scenario of the 42 scenarios has three two-way ANOVA without replication analysis conducted for each of the three parameters: frequency of events, cost impact and time impacts.

Table 7: Accept/Reject the null hypothesis (H_0) of scenarios

Scenario No.	Project Type	Value	Procurement Method	Contract Type	Project Duration	Frequency of Event (H_0)	Effect on Cost (H_0)	Effect on Time (H0)	Accept/Reject Scenario
1	Commercial/Administrative	Less than $10,000,000	Design Build	Lump Sum or Fixed Price	Less than 12 months	Accept	Accept	Accept	**Accept**
2	Commercial/Administrative	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	Reject	Reject	Reject	**Reject**
3	Commercial/Administrative	Less than $10,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	Less than 12 months	Reject	Reject	Reject	**Reject**
4	Commercial/Administrative	$50,000,000 - $100,000,000	Construction Management	Cost-plus fee with a Guaranteed Maxim	24 - 36 months	Accept	Accept	Reject	**Reject**
5	Commercial/Administrative	Less than $100,000,000	Design Build	Lump Sum or Fixed Price	24 - 36 months	Accept	Accept	Accept	**Accept**
6	Commercial/Administrative	$10,000,000 - $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	Accept	Accept	Accept	**Accept**
7	Commercial/Administrative	$50,000,000 - $100,000,000	Engineer-Procure-Construct	Re-measured or Unit price	24 - 36 months	Accept	Accept	Accept	**Accept**
8	Commercial/Administrative	$50,000,000 - $100,000,000	Construction Management	Lump Sum or Fixed Price	24 - 36 months	Accept	Accept	Accept	**Accept**
9	Commercial/Administrative	More than $100,000,000	Traditional (Design-bid-build)	Cost-plus fee with a Guaranteed Maxim	More than 36 months	Reject	Accept	Reject	**Reject**
10	Commercial/Administrative	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	Accept	Accept	Accept	**Accept**
11	Healthcare	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	Accept	Accept	Accept	**Accept**
12	Healthcare	More than $100,000,000	Design Build	Lump Sum or Fixed Price	More than 36 months	Accept	Accept	Accept	**Accept**
13	Heavy Construction	More than $100,000,000	Engineer-Procure-Construct	Lump Sum or Fixed Price	More than 36 months	Accept	Accept	Accept	**Accept**
14	Industrial	Less than $10,000,000	Design Build	Lump Sum or Fixed Price	Less than 12 months	Accept	Reject	Accept	**Reject**
15	Industrial	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	Accept	Accept	Accept	**Accept**
16	Industrial	Less than $10,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	Less than 12 months	Reject	Accept	Accept	**Reject**
17	Industrial	$10,000,000 - $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	Accept	Accept	Accept	**Accept**
18	Industrial	$50,000,000 - $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	24 - 36 months	Accept	Accept	Accept	**Accept**
19	Industrial	$50,000,000 - $100,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	24 - 36 months	Accept	Reject	Reject	**Reject**
20	Industrial	More than $100,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	More than 36 months	Accept	Reject	Accept	**Reject**
21	Industrial	More than $100,000,000	Engineer-Procure-Construct	Re-measured or Unit price	More than 36 months	Accept	Accept	Accept	**Accept**
22	Infrastructure	$10,000,000 - $50,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	12 - 24 months	Reject	Reject	Accept	**Reject**
23	Infrastructure	$10,000,000 - $50,000,000	Design Build	Lump Sum or Fixed Price	12 - 24 months	Accept	Accept	Accept	**Accept**
24	Infrastructure	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	Accept	Reject	Accept	**Reject**
25	Infrastructure	More than $100,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	More than 36 months	Accept	Accept	Accept	**Accept**
26	Residential	Less than $10,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	Less than 12 months	Accept	Accept	Accept	**Accept**
27	Residential	Less than $10,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	Less than 12 months	Reject	Accept	Accept	**Reject**
28	Residential	$10,000,000 - $50,000,000	Design Build	Lump Sum or Fixed Price	12 - 24 months	Accept	Accept	Accept	**Accept**
29	Residential	$10,000,000 - $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	Reject	Accept	Accept	**Reject**
30	Residential	$10,000,000 - $50,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	12 - 24 months	Reject	Reject	Reject	**Reject**
31	Residential	$50,000,000 - $100,000,000	Design Build	Re-measured or Unit price	24 - 36 months	Accept	Accept	Accept	**Accept**
32	Residential	$50,000,000 - $100,000,000	Design Build	Lump Sum or Fixed Price	24 - 36 months	Accept	Accept	Accept	**Accept**
33	Residential	$50,000,000 - $100,000,000	Engineer-Procure-Construct	Lump Sum or Fixed Price	24 - 36 months	Accept	Accept	Accept	**Accept**
34	Residential	$50,000,000 - $100,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	24 - 36 months	Reject	Reject	Reject	**Reject**
35	Residential	More than $100,000,000	Engineer-Procure-Construct	Re-measured or Unit price	More than 36 months	Accept	Accept	Accept	**Accept**
36	Residential	More than $100,000,000	Engineer-Procure-Construct	Lump Sum or Fixed Price	More than 36 months	Reject	Accept	Reject	**Reject**
37	Residential	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	Reject	Reject	Reject	**Reject**
38	Retail	Less than $10,000,000	Traditional (Design-bid-build)	Re-measured or Unit price	Less than 12 months	Accept	Accept	Accept	**Accept**
39	Retail	$10,000,000 - $50,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	12 - 24 months	Accept	Accept	Accept	**Accept**
40	Retail	$50,000,000 - $100,000,000	Construction Management	Cost-plus fee with a Guaranteed Maxim	24 - 36 months	Accept	Accept	Accept	**Accept**
41	Retail	More than $100,000,000	Engineer-Procure-Construct	Lump Sum or Fixed Price	More than 36 months	Accept	Accept	Accept	**Accept**
42	Retail	More than $100,000,000	Traditional (Design-bid-build)	Lump Sum or Fixed Price	More than 36 months	Reject	Reject	Reject	**Reject**

Table 7 shows the null hypothesis for each of the three parameters. The scenario is either accepted or rejected. All three parameters must accept the null hypothesis in order for the scenario to be accepted. However, if one of the parameters fails to satisfy this condition, or in other words is rejected, then the scenario as a whole is rejected.

5.2 Model Verification

Model verification is a procedure that is conducted on the model to ensure that the model is working effectively and producing the required results. The model is based on data gathered from Egypt. Nevertheless, the model can be applied any other country, yet the database in that case will need to be updated according to that specified country through the distribution of surveys.

The model was given to two professionals with more than 25 years of experience to test that the model is working coherently and give comments, if any.

5.1.1 Expert One

The expert selects the scenario that needs prediction for variation orders occurrence and their time and cost impacts. The first expert chose the following as their data input for the model:

- Commercial/Administrative
- More than $100,000,000
- Traditional (Design-bid-build)
- Lump sum or fixed price
- Project Duration: 12 - 24 months

Upon user selection, the model then predicts the variations that can occur during that specified project along with the time and cost impacts.

Table 8: Results for expert one

		Frequency of Event	Effect on Cost	Effect on Time
Client Related Events				
1	Inadequate project objectives	40-60%	0-10%	0-10%
2	Change of scope	60-80%	10-30%	0-10%
3	Substitution of material	0-20%	0-10%	10-30%
4	Financial problem	0-20%	0-10%	0-10%
5	Change of Schedule	20-40%	10-30%	30-50%
6	Unilateral decisions	0-20%	No Impact	0-10%
7	Clients do not perform decisions in the correct time	20-40%	0-10%	0-10%
Consultant Related Events				
8	Error and omission	60-80%	0-10%	0-10%
9	Design complexity	20-40%	0-10%	0-10%
10	Change in design	20-40%	10-30%	0-10%
11	Conflicting contract documents	40-60%	0-10%	0-10%
12	Insufficient design	20-40%	0-10%	0-10%
Other Related Events				
13	Differing site condition	40-60%	0-10%	0-10%
14	Lack of co-ordination among parties	20-40%	No Impact	No Impact
15	New government regulation	20-40%	0-10%	0-10%
16	Weather Conditions	20-40%	No Impact	0-10%
17	Value Engineering	40-60%	No Impact	No Impact
18	Safety Considerations	20-40%	No Impact	No Impact
19	Required labor skills unavailable	0-20%	No Impact	No Impact

Table 9: Calculated time and cost impacts for expert one

Cost Impact	$29,000,000.00	
Time Impact	5.00	Months

Table 10: Accepted scenario for expert one

Accept/Reject Scenario	Accept

Table 8 represents the results for expert one. It shows that the model worked successfully showing the required results. The results state the prediction of variations that can occur in the project along with their time and cost impacts. Table 9 shows the calculation of the time and cost impacts in accordance with the original cost and duration. It indicates that expert one needs to account for almost 29% additional costs and 21% time delay. Table 10 states that this scenario is accepted and the results are confident. Nevertheless, if the scenario is rejected, an alternative scenario is chosen for the user.

5.2.2 Expert Two

Another expert was given the model to test and the following data was chosen as his input for the model:

- Infrastructure
- $10,000,000 - $50,000,000
- Traditional (Design-bid-build)
- Re- measured or Unit price
- Project Duration: 24 – 36 months

Table 11: Results for Expert Two

		Frequency of Event	Effect on Cost	Effect on Time
Client Related Events				
1	Inadequate project objectives	20-40%	0-10%	0-10%
2	Change of scope	40-60%	10-30%	30-50%
3	Substitution of material	60-80%	30-50%	30-50%
4	Financial problem	40-60%	10-30%	10-30%
5	Change of Schedule	60-80%	0-10%	30-50%
6	Unilateral decisions	20-40%	No Impact	0-10%
7	Clients do not perform decisions in the correct time	20-40%	No Impact	30-50%
Consultant Related Events				
8	Error and omission	40-60%	Cost Saving	No Impact
9	Design complexity	80-100%	30-50%	More than 50%
10	Change in design	60-80%	10-30%	10-30%
11	Conflicting contract documents	20-40%	No Impact	0-10%
12	Insufficient design	80-100%	10-30%	10-30%
Other Related Events				
13	Differing site condition	40-60%	No Impact	0-10%
14	Lack of co-ordination among parties	80-100%	10-30%	More than 50%
15	New government regulation	40-60%	0-10%	0-10%
16	Weather Conditions	20-40%	No Impact	No Impact
17	Value Engineering	60-80%	Cost Saving	No Impact
18	Safety Considerations	40-60%	No Impact	0-10%
19	Required labor skills unavailable	0-20%	No Impact	No Impact

Table 12: Rejected scenario for expert two

Accept/Reject Scenario	Reject

Table 11 shows the results for the scenario for expert two. However, as shown in Table 12, the scenario is rejected. Therefore, an alternative scenario has been chosen. Table 13 represents the alternative scenario provided by the model. The alternative scenario includes the same project type and project value, yet changes the procurement method or contact type or both. The model then states the prediction of variation orders and their impacts for the alternative scenario as shown in Table 14.

Table 13: Alternative scenario for expert two

Alternative Scenario				
Project Type	Value	Procurement Method	Contract Type	Project Duration
Infrastructure	$10,000,000 - $50,000,000	Design Build	Lump Sum or Fixed Price	24 - 36 months

Table 14: Results for alternative scenario for expert two

Results for Alternaive Scenario

		Frequency of Event	Effect on Cost	Effect on Time
	Client Related Events			
1	Inadequate project objectives	20-40%	0-10%	0-10%
2	Change of scope	20-40%	0-10%	No Impact
3	Substitution of material	40-60%	0-10%	0-10%
4	Financial problem	20-40%	No Impact	No Impact
5	Change of Schedule	0-20%	Cost Saving	0-10%
6	Unilateral decisions	20-40%	No Impact	0-10%
7	Clients do not perform decisions in the correct time	40-60%	0-10%	10-30%
	Consultant Related Events			
8	Error and omission	40-60%	10-30%	10-30%
9	Design complexity	40-60%	0-10%	0-10%
10	Change in design	20-40%	0-10%	0-10%
11	Conflicting contract documents	40-60%	0-10%	0-10%
12	Insufficient design	60-80%	10-30%	0-10%
	Other Related Events			
13	Differing site condition	0-20%	0-10%	0-10%
14	Lack of co-ordination among parties	40-60%	0-10%	No Impact
15	New government regulation	60-80%	10-30%	No Impact
16	Weather Conditions	60-80%	0-10%	0-10%
17	Value Engineering	20-40%	No Impact	0-10%
18	Safety Considerations	0-20%	No Impact	No Impact
19	Required labor skills unavailable	0-20%	No Impact	0-10%

Table 15: Calculated time and cost impacts for expert two

Cost Impact	$18,000,000.00	
Time Impact	7.00	Months

Table 14 represents the alternative scenario for expert two. The alternative scenario suggested that the procurement method needs to be changed from traditional (design-bid-build) to design build. It also indicated that the contract type shall be changed from re-measured or unit price to lump sum contract. And accordingly, Table 15 represents the predictions of variation orders occurrence and their time and cost impacts for the suggested alternative scenario. Table 15 represents the calculations of the time and cost impacts that the expert needs to account for. Expert two needs to account for an approximate of 36% additional project costs and 19% time delay.

5.3 Model Validation

The model is validated on a case study for a residential compound in Cairo that has been completed in July 2016. The following data was obtained from the project:

- Type of project: Residential
- Original Project Value: 125 Million Egyptian Pounds ($6,9400,000)
- Final Agreed Amount: 153 Million Egyptian Pounds ($8,500,000)
- Procurement Method: Traditional (Design-bid-build)
- Original Project Duration: 14 Months
- Original Completion date: January 2016
- Actual Completion Date: July 2016
- Contract Type: Lump Sum Contract
- Number of Variation Orders Issued: 112
- Total Cost of Variation Orders: 28 Million Egyptian Pounds ($1,550,000)

The previous data was then used as an input for the model to predict the variations that can occur during the project and compare it to the actual data.

Table 16: Results for case study

		Frequency of Event	Effect on Cost	Effect on Time
	Client Related Events			
1	Inadequate project objectives	20-40%	0-10%	10-30%
2	Change of scope	40-60%	10-30%	10-30%
3	Substitution of material	40-60%	No Impact	No Impact
4	Financial problem	40-60%	0-10%	10-30%
5	Change of Schedule	40-60%	0-10%	0-10%
6	Unilateral decisions	40-60%	No Impact	0-10%
7	Clients do not perform decisions in the correct time	60-80%	0-10%	10-30%
	Consultant Related Events			
8	Error and omission	20-40%	0-10%	No Impact
9	Design complexity	40-60%	No Impact	0-10%
10	Change in design	40-60%	0-10%	0-10%
11	Conflicting contract documents	20-40%	No Impact	0-10%
12	Insufficient design	20-40%	0-10%	0-10%
	Other Related Events			
13	Differing site condition	0-20%	0-10%	0-10%
14	Lack of co-ordination among parties	40-60%	0-10%	No Impact
15	New government regulation	60-80%	0-10%	0-10%
16	Weather Conditions	60-80%	No Impact	No Impact
17	Value Engineering	20-40%	No Impact	No Impact
18	Safety Considerations	0-20%	No Impact	No Impact
19	Required labor skills unavailable	0-20%	0-10%	0-10%

Table 17: Time and Cost Impacts for case study

Cost Impact	$1,400,000.00	
Time Impact	6.00	Months

Table 16 represents the results for the project. The model predicts that the project can have an approximate of $1.4 Million cost impact and 6 months project delay due to variation orders arising during the construction phase of the project as shown in Table 17.

Comparing this to the actual data of the case study, the results are very near. The total cost of variations generated is extremely high which needs to account a budget for. The time impact as well is worrying as it contributes to almost 40% time delay of the total project duration.

Hence, if the project manager had used this model at the beginning of the project, he would have been able to predict the occurrence of variations and their time and cost impacts and account a contingency for these impacts.

Chapter 6: Conclusion, Limitations & Future Recommendations

6.1 Conclusion

Variation orders are very significant in any construction project. They can affect project duration, cost, productivity, quality as well as many other negative impacts.

A model was developed in this research to help predict the variations that can arise during the construction of a project and account for their time and cost impacts. The expert system model was conducted through gathering of 87 surveys of various participants that included clients, consultants and contractors. The surveys consisted of 19 events that were obtained from the literature review to determine the time and cost impact corresponding to each event. From the surveys gathered, 42 scenarios were created each having a unique project type, value, procurement method, contract type and project duration. The user inputs these project data and a scenario is selected to produce the output of the model representing time and cost impacts corresponding to the input data entered.

The model has been verified by two experts with more than 25 years of experience to observe that the model is working coherently. The model was also validated on a residential compound in Cairo to compare the output of the model to the actual data of the case study. The model showed proficient results.

The main objective of the model is to help assist clients and project managers in accounting for time and cost impacts that can occur due to variation orders before the commencement of the project. This model can be applied in any country as it depends entirely on the database that is created through the distribution of surveys.

There are various approaches that can be used to help manage variations. One approach is to make use of the Internet technology to create a well-coordinated and communicated system between the project team. Another is to monitor the daily changes that occur during the construction process.

6.2 Limitations

During the study, there were some limitations:

Firstly, after performing the verification and validation, the model showed alarming results with variations impact of more than 40% additional costs and time delays. This is due to the fact that many of these projects filled out by the respondents in the database were constructed during a time that witnessed devaluation of the Egyptian pound, introduction of value added taxes, increase in custom duties and increase in fuel prices. These projects experienced cost overrun by almost 25% only to these new government regulations in addition to the other variation impacts.

Secondly, due to the fact that some scenarios are rejected, the scenario needs to be changed as there is a variance in the survey database within that scenario. However, sometimes that scenario is the only option for the user, therefore, the procurement and contract types can't be changed.

Thirdly, the database has 52% participants that are consultants; therefore, the prediction of time and cost impacts is mostly based on Consultant's experience and background.

Fourthly, the model does not cover all the possible scenarios due to the fact that some scenarios are non-existent as they have not been mentioned by the respondents in the surveys.

Finally, the model can only be applied locally as all the data gathered is based only in Egypt.

6.3 Future Recommendations

1. Increase the number of respondents to cover all the "Non-Applicable" scenarios in the database and create reliable results for the rejected scenarios to become acceptable.
2. Add mixed use of project types, type of contracts and procurement methods. For instance, a project can have two types of contract within: re-measured and lump sum contracts.
3. Investigate a larger number of variations that can occur during a project.
4. Study an equal distribution of clients, consultants and contractors to obtain a database that fully cover all stakeholders of construction projects.
5. Study more techniques in management of variation orders.

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Appendices

Survey

I am currently performing my MSc. degree in Construction Engineering at the American University in Cairo (AUC). In order to complete this degree, a research is required to be accomplished in one of the industry related topics and submit a thesis. The chosen topic is "Causes of Variation Orders in the Construction Industry: Time and Cost Impacts". I would be grateful if you take 5 minutes of your time to complete this survey, as your cooperation is very significant.

1. What is your field of expertise?
   - Client representative
   - Consultant
   - Contractor

2. What is your current position?
   - Employee with no supervisory position
   - Supervisor
   - Middle Management
   - Top Management

3. What is your work specialization?
   - Design
   - Project Management
   - Cost Management
   - Construction Supervision
   - Other (Please specify):

4. Years of experience
   - Less than 5
   - 5-10
   - 11-15
   - 16-20
   - 21-25
   - More than 25

5. Are you involved in variation process?
   - Yes
   - No

If yes, please proceed with the rest of the questionnaire.

For the latest two projects you were involved in, please answer the following:

Project One:

9. What kind of project are you assigned on?
    - o Retail
    - o Residential
    - o Commercial/Administrative
    - o Industrial
    - o Healthcare
    - o Heavy Construction
    - o Infrastructure
    - o Other (Please specify):

10. What is the approximate value of the project?
    - o Less than $10,000,000
    - o $10,000,000 - $50,000,000
    - o $50,000,000 - $100,000,000
    - o More than $100,000,000

11. What is the procurement method for this project?
    - o Traditional (Design-bid-build)
    - o Design Build
    - o Construction Management
    - o Engineer-Procure-Construct
    - o Public-Private Partnerships
    - o Other (Please specify):

12. What type of contract is used in this project?
    - o Lump Sum or Fixed Price
    - o Re-measured or Unit price
    - o Cost-plus fee
    - o Cost-plus fee with a Guaranteed Maximum Price
    - o Other (Please specify):

13. What is the duration for this project?
    - o Less than 12 months
    - o 12 - 24 months
    - o 24 - 36 months
    - o More than 36 months

11. Please select a rating to the variations that occur during the construction of your project:

S/N	Event	Frequency of event occurring (1 being the least & 5 being the max)					Effect of event on project cost						Effect of event on project time				
		1	2	3	4	5	Cost Saving	No Impact	Up to 10%	10-30%	30-50%	More than 50%	No Impact	Up to 10%	10-30%	30-50%	More than 50%
Client Related Events																	
1	Inadequate project objectives																
2	Change of scope																
3	Substitution of material																
4	Financial problem																
5	Change of Schedule																
6	Unilateral decisions																
7	Clients do not perform decisions in the correct time																
Consultant Related Events																	
8	Error and omission																
9	Design complexity																
10	Change in design																
11	Conflicting contract documents																
12	Insufficient design																
Other Related Events																	
13	Differing site condition																
14	Lack of co-ordination among parties																
15	New government regulation																
16	Weather Conditions																
17	Value Engineering																
18	Safety Considerations																
19	Required labor skills unavailable																

If other, please specify:

Project Two:

12. What kind of project are you assigned on?
    - Retail
    - Residential
    - Commercial/Administrative
    - Industrial
    - Healthcare
    - Heavy Construction
    - Infrastructure
    - Other (Please specify):

13. What is the approximate value of this project?
    - Less than $10,000,000
    - $10,000,000 - $50,000,000
    - $50,000,000 - $100,000,000
    - More than $100,000,000

14. What is the procurement method for this project?
    - Traditional (Design-bid-build)
    - Design Build
    - Construction Management
    - Engineer-Procure-Construct
    - Public-Private Partnerships
    - Other (Please specify):

15. What type of contract is used in this project?
    - Lump Sum or Fixed Price
    - Re-measured or Unit price
    - Cost-plus fee
    - Cost-plus fee with a Guaranteed Maximum Price
    - Other (Please specify):

16. What is the duration for this project?
    - Less than 12 months
    - 12 - 24 months
    - 24 - 36 months
    - More than 36 months

17. Please select a rating to the variations that occur during the construction of your project:

S/N	Event	Frequency of event occurring (1 being the least & 5 being the max)					Effect of event on project cost						Effect of event on project time				
		1	2	3	4	5	Cost Saving	No Impact	Up to 10%	10-30%	30-50%	More than 50%	No Impact	Up to 10%	10-30%	30-50%	More than 50%
	Client Related Events																
1	Inadequate project objectives																
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14	Lack of co-ordination among parties																
15	New government regulation																
16	Weather Conditions																
17	Value Engineering																
18	Safety Considerations																
19	Required labor skills unavailable																

If other, please specify: