Delay Hierarchy Propagation Model

By

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ABSTRACT

Construction projects are always exposed to delay. Research has shown that most projects encounter delays and this problem is a global one. Previous research related to delays in construction projects have been dedicated to measuring and ranking the ***direct delays*** that have occurred. These types of delay are past delays and have already affected many aspects of the project's performance. This type of research is of the reactive type and handles delays after they have happened.

The objective of this research is to model the construction project delays that can be used to predict the level of delays that the project could face during its future life.

The proposed Delay Hierarchy Propagation Model (DHPM) is the first attempt to model delays in the construction project. This model is an innovative predictive approach to anticipate the future encountered delays before they become real. The model assumes that the direct delay is generated from earlier events or aspects that are found before the direct delay occurs; these events are called the ***root delay causes***. These root delay causes need to be analysed, measured and managed in order to prevent or mitigate the effect of a later direct delay in the project life. The direct delays were analysed by a cause-effect technique to extract a set of root delay causes. The model assumes that the root delay causes will influence the project resources supply rate. The resource shortage then leads to activity delay and, hence possible delay to the whole project.

The DHPM consists of two interrelated models: a Resource Shortage Possibility (RSP) model and the Predicting Project Delay model (PPD) model. The RSP model objective is to predict the possibility of resource shortage, whilst the PPD model objectives are to predict the project finish time and to define the critical areas for the project to delay using the output of the RSP model as input.

The RSP model was verified through interview questionnaires with a number of selected personnel from the construction industry. The Delphi method was used to enhance the questionnaire results. The RSP model calculations used a combination of fuzzy logic, analytical hierarchy process (AHP) and multi-attribute theory to obtain the model output. A prototype computer program was introduced. The prototype computer program was then tested on a real construction project. The application of the RSP model showed that it is viable.

The PPD model used probabilistic networking to predict the finish time of the project. The model introduced two new terms that can be used to define the most critical activities and the possible resource influence to delay. The comparison between PPD and the classical critical path method (CPM), programme evaluation and review technique (PERT) and Monte Carlo simulation revealed that the proposed model provides new information required to enhance delay management by project management staff.

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At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other university award without prior agreement of the Graduate Committee.

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Chapter 1

Introduction

1-1 Background

The Construction Industry is of a significant importance in the economic structure of most countries in the world. In 1993, the construction industry in the UK contributed £ 46.3 billion, which represented 8% of GDP (DoE, 1994) and it reached £ 65 billion in 2000 (AUDITOR, 2001). In 2003, the construction industry employed 6.6 % of Britain's total workforce and generated around 10% of its GDP (UKNA, 2004). The construction industry has similar values all over the world. For example, in the USA it contributes 10% of Gross National Product (GNP) (Clough and Sears 1994), in Italy 10% (Pietroforte and Bon, 1995), 5.5% of annual Indonesian gross domestic product (Langdon, 1994), 8% in Iranian GNP (MRU, 1994) and about 20% of the total non-oil gross domestic product of Saudi Arabia (Al-Jarallah, 1983). It is important therefore that the construction process is made as efficient as possible.

The construction process passes through three main phases; project conception, project design and project construction. Project conception is the recognition of the project need, which can be satisfied by a physical structure. The project design phase translates the primary concept into an expression of a special form which will satisfy the owner's requirements in an optimum economic manner. The construction phase is the final phase and creates the physical form that satisfies the conception and permits the realisation of the design, (Shtub, et al 1994).

The construction process is controlled by complicated legal contracts and involves complex relationships on several organisational levels. In a general sense there are three functional entities involved in the development, design and construction of a project, all of which combine to make the construction team. Firstly, there must be an owner/client to determine the project needs. Secondly, a designer who can articulate those needs in a technically competent way and within the limitation of the owner's resources. Thirdly, there should be a contractor (constructor) to articulate a project strategy with respect to time and cost and to manage the construction endeavour through to its successful completion. A good working relationship - including efficient communications - between these three functional entities is essential to a well-executed project. Figure 1-1 outlines these relationships between the three entities based on the traditional competitive bid strategy (Osama, 1996).

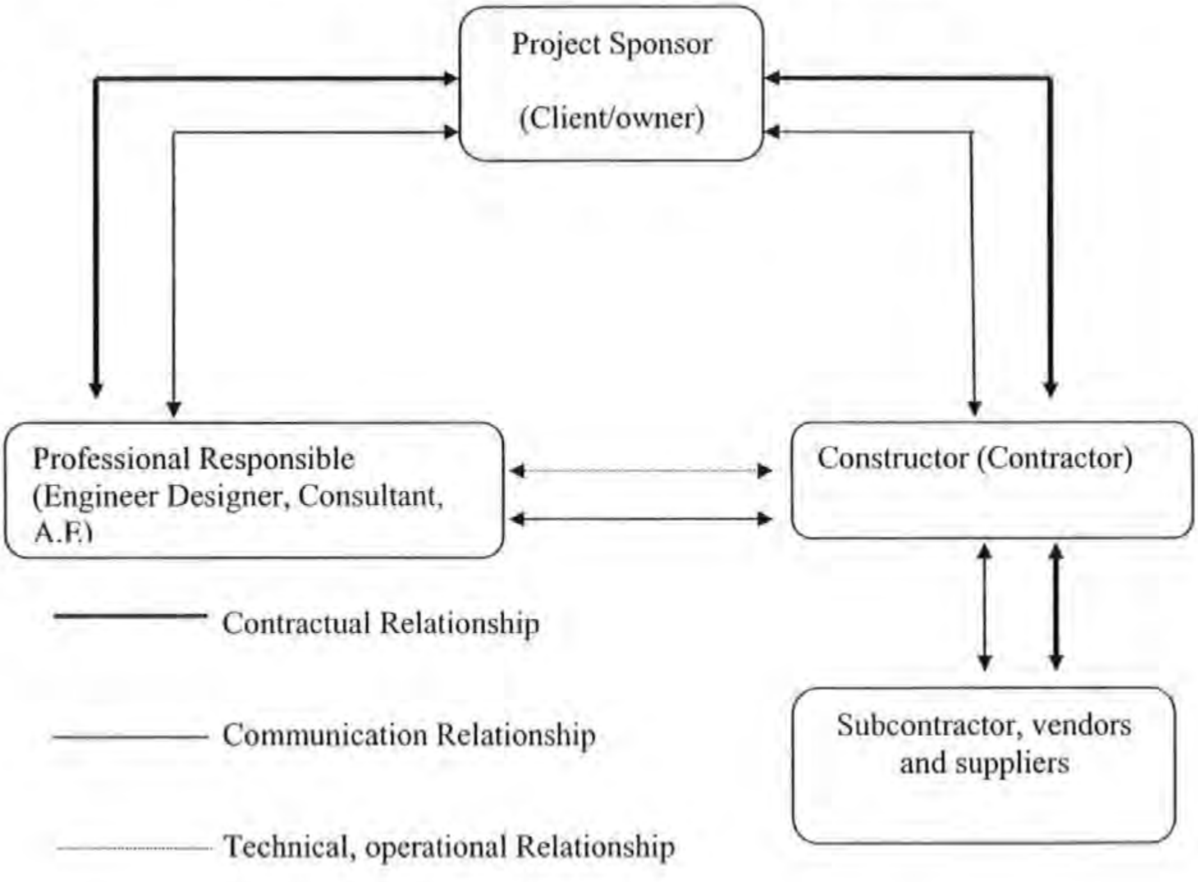


Figure (1-1) Essential Construction Project Parties Relationships (Osama, 1996)

The construction industry is particularly subjected to risks more than other business sectors because of the complexity of construction projects and location of production. The construction process is one of the few processes in which the product is built in an open environment and is subject to various weather conditions and other environmental factors which affect labour as well as equipment productivity. Moreover, a construction project must be designed and executed by integrating the efforts of a large number of different organisations and individuals, all of them have different often conflicting, priorities and objectives (Boussabaine and Duff, 1996).

Because of the dynamic feature of the construction project through its life, it is very sensitive to any risks that it encounters during the project construction period. These construction risks lead to many consequences; project delay, cost overrun, owner dissatisfaction and sometimes a cancelled project (Callahan, et al 1992).

Finishing the construction project in the pre-agreed and predefined period is one of the main objectives of construction management (Clough et al, 2000) and the success of completing projects on time is one of the indicators of the construction industry efficiency (NEDO, 1993). Any recorded delay occurring within the project will affect the efficiency of project success.

The delay of project completion is one of the major problems in construction that often leads to costly disputes and acrimonious relationships between parties involved (Al-Khalil and Al-Ghafly, 1999).

1-2 Construction Project Delay Problem Statement

In the UK, the construction industry has had a significantly poor record with respect to the completion of projects on time over a long period of time (NEDO, 1983). In 1980 UK NEDO reported that one in six UK public sector construction projects overran by more than 40% of the original duration. The average time overrun for UK Government construction projects for the period 1993-1994 was 23.2% (HMSO, 1995).

Onyango (1993) found that 52% of all UK construction projects ended up with a claim of some type. The largest causes of claims were post-contract changes by the owners (25%), different site conditions from those stated in the tender documentation (18.6%) and unfulfilled duties by the engineers/ architects (14.6%). Project delay was the basis of many of these claims.

This poor time completion performance is also well known as an international problem. World Bank (1990) figures showed that for the 1627 projects completed between 1974 and 1988 the overrun varied from 50% to 80% of the original duration. In Canada, Semple (1994) showed that over 70% of high rise building in Western Canada experienced time over-run. In Australia, the results of a survey of 400 completed building projects showed that only one contract in eight was completed on or before the date originally expected and the overall average extra time taken exceeded 40% of the original (Kaka and Price, 1991).

In the developing countries, the problem may be worse; Arditi et al's (1985) survey of 258 public projects in Turkey showed that 44% overran from the original duration. Al-Ghafly (1995) found that the percentage of delayed projects in Saudi Arabia varied from 35% to 84%.

As described above, the problem of delays in construction projects is significant and an international problem. Therefore, research into the causes of delays and attempts to mitigate their effects is a valid and worthwhile effort. It is essential to predict major delay sources before constructing a project so that project parties can manage these delay sources and apply proactive procedures to prevent these delays (Zayed and Kalavagunta, 2005).

Therefore there is a need to better understand the science of how delays occur in order to model delays.

It is important to note that the delays reported in the above literature are ***real or direct delays*** that actually occurred on the project. It is proposed that these ***direct delays*** are the outcomes of some earlier events that later become real or direct delays. These earlier events have been given the term "***root delay causes***". It is important to understand what these earlier events are in order to properly manage the ***real or direct*** delays experienced on site. The study of delays in construction should search for these earlier events or the ***root delay causes*** as these causes will affect the generation of all the project's future direct delays.

These root delay causes should be measured or assessed before or shortly after the project start.

In "Rethinking Construction, 1998", Egan stressed the need for changing the construction process to enable improvement. In his model, which is known as "5-4-7" model, he put one of the annual targets for work change improvement is increasing predictability. Figure 1-2 shows the Egan Model. The 5-4-7 model also proposed that one of the processes that should be improved to achieve this target improvement was "project implementation".

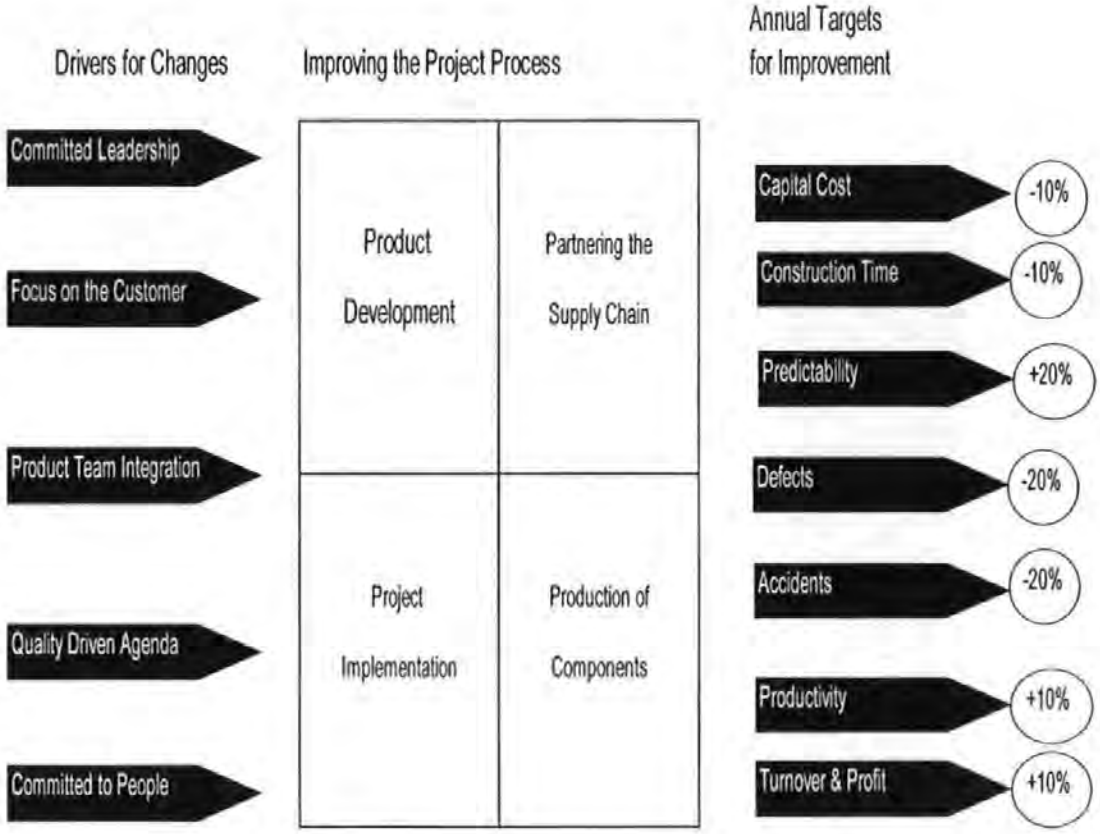


Figure (1-2) 5-4-7 Model for year on year improvement targets (Egan, 1998)

Therefore there is a need to better understand the science of delays in order to model delays in construction projects. The model should be generic and can be applied for any type of project delivery systems. The model should answer these questions: why does delay occur, what is the probability of delay occurring, and what are the most important sources of delays? The model should also encourage team integration and improve the predictability of the project delay problems. This research is an attempt to model and analyse the delays in construction project and answer these questions.

1-3 Research Objectives

The objectives of this research is to understand the root delay causes of the construction project, to model the construction project delays and then to expect the level of delays that the project can face during its life. The following are the specific objectives for this research:

1- To study the sources of delays in the construction industry.
2- To analyse these delays and understand their root causes.
3- To build a generic model to predict delays in the construction project.
4- To predict the most critical sources of delay

1-4 Thesis Outline

Chapter 1: Introduction

This chapter contains a description of the construction industry in general and the problem statement for delays in construction projects. Research objectives are defined and scope of research presented.

Chapter 2: A Review of Delay Related Research

This chapter presents the previous research works regarding construction delays. The definition of delays in construction and the effects of delays in construction projects are presented. Research to measure causes of delays are listed and analysed. It is noted that all of these delays are ***real or direct*** delays. The direct delays from past research are gathered and these direct delays are then listed.

Chapter 3: A Proposed Approach to Model Delay in Construction Projects

This chapter defines the assumptions that will be used as the basis to model the construction delays and the methodology required to achieve the research objectives. The delay model and the steps to conduct the research are presented. The proposed model is called Delay Hierarchy Propagation Model (DHPM). This model consists of two interrelated models; Model A: Resource Shortage Possibility (RSP) model and Model B: Predicting Project Delay (PPD) model. The objective of the RSP model is to estimate the possibility of a resource shortage that will lead to delay. Resource shortage is based on a predefined set of criteria that can be assessed before or shortly after the project start. The objective of the PPD model is to predict the probable project finish date and to define the critical sources for project delay. The research methodology then presented.

The research methodology defines the academic steps that required to achieve the research objectives. The steps start by defining the direct delay causes from analysing previous research work results. Then extracting the root delay causes by individual analysis for the direct delay causes. These root delay causes are the bases for the proposed DHPM. The proposed model is then verified by asking construction personnel about the model thoughts. A computer prototype program is proposed to get the outputs values of the proposed model. Testing for the proposed prototype computer program in a real project is then applied.

Chapter 4: Root Delay Causes and Root Delay Cause' Indicators

The direct delays that are listed in chapter 3 are then analysed to extract their root delay causes. Cause-Effect technique is used to extract these root delay causes. In a real project, the root delay causes affect the direct delay to be occurred. To evaluate the root delay causes before or shortly after the project start, root delay causes indicators are found. For each one of the root delay causes, there are many indicators that can be used to measure and assess the root delay causes.

Chapter 5: Verification of Delay Hierarchy Propagation Model (DHPM)

In this chapter the DHPM thoughts and basis are verified. An interview questionnaire was used to verify the model by interviewing selected number of construction personnel. The Delphi method was used to maintain high significance of collected data. Two rounds of the interview questionnaire were used. The statistical analysis of the collected data are then presented and analysed.

Chapter 6: Model A: Resource Shortage Possibility (RSP) Model

This chapter presents the details of the Resource Shortage Possibility (RSP) model. The objective of RSP mode is to estimate the possibility of resource shortage based on a predefined set of criteria that can be assessed before or shortly after the project start. The model uses the multi-attribute theory, fuzzy logic theory and Analytical Hierarchy Process (AHP) to build this model. A background of multi-attribute theory, fuzzy logic theory and Analytical Hierarchy Process (AHP) is presented. Details of the RSP model and algorithm formation are presented using Matlab® fuzzy toolbox. To test the prototype program, a workshop questionnaire is designed to collect data from construction project sites then a workshop is conducted in one of the construction sites.

Chapter 7: Model B: Predicting Project Delay (PPD) Model

This chapter demonstrates the basis for Model B: Predicting Project Delay (PPD) Model. The model is theoretically predicts the probability of project delay if the resource shortage is occurred. This model is based on the stochastic techniques in planning and scheduling. A background of planning and scheduling in general and the stochastic networking techniques is presented. Details for the model mathematical formulation are then presented. A numerical example is presented to apply the ideas of PPD model.

Chapter 8: Concluded Objectives, and Future Work

This chapter contains the concluded research objectives, contribution to academic science and future work.

Chapter 2

A Review of Delay Related Research

2-1 Introduction

In this chapter, the previous studies regarding delays in construction projects will be presented and analysed.

All the past studies regarding construction delays can be categorised into two main groups; the "delay claim analysis" and "delay causes measurement". Delay claim analysis depends on the application of the critical path method, CPM, networking to calculate the effect and responsibility of delays for use in litigation and dispute resolution (Bordoli and Baldwin, 1998). In other words, it deals with the delay as a past event and analyses the consequences to determine mainly cost damages and compensation. There will be other delays that do not lead to disputes, they may not be included.

Delay causes measurement deals with defining, measuring and ranking the main sources of delays in construction projects. The measuring is mainly obtained from the project personnel either from recorded documents or from their judgement that is built from their experience.

This research is concerned with modelling and predicating delays in a construction project such that it is more manageable and controlled; therefore the literature review will focus mainly on the construction delay causes and measurements.

This chapter has been set to four main sections: definition of delays in the construction industry, the effect of delays in project performance, presentation of the past research regarding delay causes measurement and a list of direct delays that results from past research work. This list of direct delays will be further analysed to obtain the root delay causes in chapter 4.

2-2 Definition of Delays in Construction Projects

The contract document must give a date for completion of construction works which becomes binding as the final completion date for the whole project. A construction project delay is defined as the time during which part of the construction project has been extended beyond what was originally planned due to unanticipated circumstances (Bramble and Challahan 1991) or the time overrun beyond project delivery date (Ahmed et al 2003). Kaming et al (1997) defined delay as the extension of time beyond planned completion dates traceable to the contractors.

The studies regarding the causes of construction delay (as will be presented later) identify the construction project delay as the additional portion of time that the construction project requires to finish more than originally estimated or contracted.

Delay causes in construction can be defined as those events that happen during the project life and lead to either (individually or combined) the project, or any part of it, taking more time to finish than the original estimate, (Challahan, et al 1992).

Based on the assumptions that are used in this research model, there are three more definitions that will be used in the model design; "***direct delays***", "***root delay causes***" and "***root delay causes' indicators***".

Direct delays are defined as the real or actual delays that occur and are documented in a construction project. This direct delay can be recognised and recorded by one or more parties in the construction project during the normal management process. This direct delay can be used a basis for claims from any party.

Root delay causes are defined as earlier events that develop to become direct delay. These root delay causes may be due to managerial, financial or specific project related factors.

Root Delay Causes' indicators are defined as the measures that are used to evaluate the root delay causes.

2-3 Effect of Delays on Construction Projects' Performance

Delays may occur in any part of the project. It may occur in an activity, section or the whole project. Delays in construction projects have many negative effects on project performance. The delay of project completion is one of the major problems in construction that often leads to costly disputes and acrimonious relationships between the involved parties (Al-Khalil and Algafly, 1996).

Delays that occur during a construction project will either extend the project duration or increase its cost or both. In addition, if completion is delayed the owner may lose out financially by not having the facility available when needed. The example of an offshore oil platform, the delay of project completion may result in loss in revenues of hundreds of million of dollars a week. The contractor may lose out by not having its own resources released to take on other works and may face the risk of paying penalty or liquidated damage or increasing costs due to additional payments of salaries, equipment hiring, financial interest (Yates, 1993).

Thompson and Perry (1992) stated that delays in the completion of construction projects could be the greatest cause for extra cost and loss of financial return and other benefits from a project. Moreover many authors stated that delays are the major causes of construction claims and disputes (Rubin et al, 1992; Riad et al, 1991 and Scott, 1993).

Delays in the construction project also have many other negative consequences. Labourers may regress along the learning curve if an activity is stopped. Rescheduling effort is required to resources management and redirect resources (Challahan, et al 1992). Delays in activity not only affect the activity performance, but also affect all the succeeding activities that have linkage to the delayed activity.

2-4 Studies to Evaluate Causes of Construction Delays

Many efforts have been made to define the causes of construction delays and evaluate their effects on total project delay. These studies are on a global scale.

All this research used a questionnaire based approach to collect information related to construction delays. This approach used questionnaires by either post or interview with respondents. The respondents were asked to either rank causes of delays or assess their level of influence on project delay.

Previous research used several different of similar terminologies related to delay causes. They used "delay factors", "delay source", "delay reasons" and "project problems" to state delay causes. As stated in section 1-2, these delay causes are the direct delays that cause delays in the construction project.

Twelve studies were recorded during the past three decades; these studies will be presented by defining the delays searched, the sample of participants and then main results are presented in Appendix A. At the end of this section, general comments for all past research work are presented.

2-4-1 Baldwin et al (1971)- USA

An early study was conducted by Baldwin et al (1971) who surveyed the causes of delays in the USA construction industry. A questionnaire was mailed to selected members of three groups of contractors, architects and engineers working in all the states.

The participants were asked to assess the level of importance of 17 predefined delay causes (the authors used the term delay factors). The level of importance had four levels; very important, important, minor important and has no importance.

In order to get a rank the delays' importance, the authors used "*severity index*". The "*severity index*" was calculated by adding up the very important and important responses only. The severity indices were used to rank the factors for each group of respondent.

The analysis of respondents from 244 contractors, 176 architects and 120 engineers revealed that the most important and most frequent causes of delays were:

- The weather conditions
- The problems resulting from subcontractors
- The shortage of labour supply

The authors used the *Rank Agreement Factor* (RAF) to evaluate the level of agreement between any two groups of respondents. This factor measures the absolute difference in participants groups ranking in the following way. If there are two groups of variables, group 1 and group 2 and for each group there is a rank, R_{i1} is the rank of the item i inside the group 1 and R_{i2} is the rank of item i inside the group 2.

Then the absolute difference of the ranks for the two groups ($D_i = R_{i1}-R_{i2}$) Where i= 1,2,...N number of items inside the group.

$$RAF = \frac{\left(\sum_{i=1}^{N} |R_{i1} - R_{i2}|\right)}{N} \quad \text{...(2-1)}$$

Where, (N) is the total number of items in the group.

The three groups agreed for the three top ranked causes of delays and there was good agreement among the three groups regarding the delay causes ranking.

The study causes and ranks are presented in Appendix A-1

In spite of the simplicity of data analysis used to rank the delay causes, the study formed a basis for estimating delay causes based on the perspective of the industry personnel. The *severity index* developed by the authors was used in many of succeeding studies across the world including Okpala and Aneikwu, (1988) in Nigeria and Waheed, (1994) in Egypt.

2-4-2 Arditi et al (1985)- Turkey

Arditi et al (1985) surveyed the reasons for the delays of completed public projects in Turkey in the period from 1976-1980. The authors mailed questionnaires to the members of public agencies and contractors who were involved in these finished projects. The participants were asked to select from a list of delay causes (the authors used the term delay reasons), the five most important causes of delays in the construction of public projects with which they were involved. These causes were related to the construction stage of project. Then they were asked to put them in order of importance from five for the most important delay cause to one for the least importance delay cause.

The results of this study revealed that the top three ranked causes of delays which are:

- Difficulties in obtaining construction materials,
- Contractors' difficulties in receiving monthly payments from public agencies
- Contractors' financial problems.

The study delay causes and rank is presented in Appendix A-2

The study used similar simple calculations as used by Baldwin to rank delay causes in public building projects.

2-4-3 Sullivan and Harris (1986) - UK

Sullivan and Harris (1986) discussed the most frequent causes of construction delays on large civil, building, energy and process engineering construction projects in the UK. Questionnaires were mailed to 13 large contractors, 3 owners and 4 consultants working for large projects in the UK. Participants were asked to estimate the frequency of occurrence of 16 predefined delay causes (authors used the term problems) that can lead to project delay. Frequency was out of 100. The authors used the mean values for each delay factor to get an absolute rank for problems leading to delays. The analyses revealed that the major causes of construction delays in large projects in UK were:

- Waiting for information
- Variation orders
- Ground problems
- Bad weather
- Unexpected physical services obstruction

The authors also compared these results with the causes on overseas large civil projects in which British contractors were working in.

The study of delay causes and ranks are presented in Appendix A-3

It should be noted that, no account was taken of different types of work, locations or contract strategies. Building type works may have a different for delay causes when compared to that of civil engineering projects.

2-4-4 Okpala and Aneikwu (1988)- Nigeria

Okpala and Aneikwu (1988) conducted a study to investigate the reasons of cost overrun and time overrun on projects in Nigeria.

A questionnaire of 20 causes that could create both delays and cost overrun (authors used the term of delay and cost overrun variables) was directed to 450 professionals of engineers, architects and quantity surveyors who were working in the Southern area of Nigeria. The questionnaire asked the respondents to assess the relative importance of each variable from four levels (very important, important, minor important and has no significant). 192 replies were collected.

The authors used the severity index to rank the variables and the *Rank Agreement Factor* (RAF) developed by Baldwin et al (1971) to define the level of coincide inside each group of respondents.

The analysis revealed that the three important delay causes as agreed by all parties were:

- Shortage of materials.
- Finance and payment for completed works.
- Poor contract management.

The level of agreement between group rankings was high between engineers and architects. That is not strange since they were working for almost the same work objectives.

The results of this study are represented in Appendix A-4
This study did not distinguish between the causes of cost overrun and time overruns (delays). The causes of time overrun may or may not cause cost overrun and vice versa.

2-4-5 Dlakwa and Culpin (1990)- Nigeria

Another survey of causes of delays in Nigerian public projects was conducted by Dlakwa and Culpin (1990). The study was also based on the results of a questionnaire analysis sent to many of the personnel in public projects; owners, consultants and contractors. The results revealed that the financial problems, either for contractor or owner were the most cause of delays for Nigerian public projects and there was a general consensus of the surveyed participants on this across groups.

Dlakwa and Culpin study results is presented in Appendix A-5

The comparison between (Okpala and Aneikwu) study and (Dlakwa and Culpin) shows that despite the both studies were conducted in Nigeria, the rank of delay causes was different. The difference of study location and the project type from public and private in (Okpala and Aneikwu) study and in public projects in (Dlakwa and

Culpin) study has excessive influence in delay causes ranking. While material shortage was the most frequent delay cause in the (Okpala and Aneikwu) study, material shortage does not have the same importance in the (Dlakwa and Culpin) study. It means that changing in project type, location and time can have excessive influence in the delay causes ranking.

2-4-6 Waheed, (1994)- Egypt

Waheed, (1994) studied the causes of delays in the Egyptian construction industry by using questionnaires to ask the participants their opinions of the relative degree of importance and frequency of predefined 15 delay causes. The participants were from public and private owners, civil and building projects. The author used the severity index that was developed by Baldwin et al (1971) to get the delay causes ranking. The results showed the most important causes of delays in the Egyptian construction industry as:

- Poor contractor management and unrealistic scheduling
- Lack of finance and payment of completed work
- Shortage of materials

The study results are presented in Appendix A-6

2-4-7 Assaf et al (1995)- Saudi Arabia

Assaf et al (1995) surveyed the causes of delays in large building projects in the Eastern Province of Saudi Arabia. The authors divided the causes of delays into 9 groups; financial, material, contractual relationship, changing design, governmental relationship, environmental, scheduling and controlling, manpower and equipment related causes of delays. These groups contain a total of 56 causes of delays (authors used the term factor of delay). Interview questionnaires were used to ask randomly selected contractors, architect and engineer firms (A/E) and owners related to large projects with a value of more than 100,000,000 SR ($ = 3.75 SR) in the Eastern Province of Saudi Arabia.

The authors asked the participants to evaluate the importance of the delay causes in a rank of 4 levels; very important, important, somewhat important and not important. An "*Important Index (I)*" was used to evaluate the relative importance of the delay causes as the following equation.

$$I = \frac{\sum_{i=1}^{4} Ai * Xi}{3} \qquad \text{...(2-2)}$$

Where: I = important index

Ai = 0,1,2,3 (0 for not important,...3 for very important)

Xi= Frequency for the i^{th} response

The rank of delay causes was based upon each delay cause importance index. To get a rank for the 9 groups of delay causes, a group index was calculated as the average of the delay causes importance indexes in each group. The groups ranked the financial group of delay causes as the highest and the environment group was ranked the lowest.

The major results of the Assaf et al study are presented in Appendix A-7 (A) for delay causes and rank of group of delay causes in A-7 (B).

2-4-8 Al-Khalil and Al-Ghafly 1999- Saudi Arabia

Al-Khalil and Al-Ghafly (1999) conducted another study in Saudi Arabia regarding the causes of delays for the Water and Sewage Authority (WSA) projects in two provinces in the Eastern region of Saudi Arabia. The questionnaire was sent to the owners' personnel, a selection of the contractors working in the WSA projects and the consultants classified in the WSA. Sixty causes of delays were identified. These delay causes were categorised into six major categories; owner administration, early planning and design, government regulations, site and environmental conditions, site supervision and contractor performance.

The questionnaire was answered by project department managers, branch managers, or chief engineers, most of whom had over 10 years of experience in this type of projects.

Al-Khalil and AlGafly (1999) used a new "*important index (II)*" to rank causes of delay. This *importance index (II)* is a combination of frequency average-used by Sullivan and Harris (1986), and severity index developed by Baldwin et al (1971).

Frequency index (FI) which is the average of delay causes frequency to occur. The *severity index (SI)* is the average severity of delay cause. The "*importance Index (II)* is calculated by these equations:

$FI = (Wif \ * \ Xi/n)$ ....(2-3)

$SI = (Wis \ * \ Xi/n)$ ....(2-4)

Where: *Wi* is the weight either for frequency or severity assigned to the *i*th option (4 to 1), and *Xi* is the number of respondents who selected the *i*th option, and *n* is the total number of respondents. Then the *importance index (II)* was computed to rank the delay causes.

$$II = \frac{SI * FI}{16}$$ ....(2-5)

The importance index for each of the delay categories which contain a number of delay causes was determined as the average of the importance indexes of all the causes in the category.

Among the most important causes found were:

- cash flow problems
- financial difficulties by the contractor
- difficulties in obtaining permits
- the requirements to select the lowest bidder without regard to pre-qualifications.

By comparing the two studies conducted in Saudi Arabia; Al-Khalil and Al-Gafly (1999) and Assaf et al (1995), it is noticed that the general economical and project delivery system have a remarkable effect on delay causes ranking and special project characteristics have their own effect on delay causes ranking.

2-4-9 Ogunlana et al (1996) – Thailand

Ogunlana et al (1996) studied the sources of delays in Bangkok, Thailand as an example from a fast-growing economy. The study was conducted on 12 high rise buildings of different end uses in Bangkok during a boom construction economy period. The data were collected by site interviews with project parties including contractors, consultants, owners and construction management teams and asking about the recorded delay causes. The authors defined 25 causes of delays and divided them into six groups based upon the responsible for delay; owner, designer, CM (construction management), inspector, contractor, resources suppliers and others. The study ranked the most recorded delay causes in the 12 projects as the following:

- Shortage of construction materials
- Incomplete drawings

- Material management problems
- Deficiencies of contractor organisation
- Shortage of site workers
- Slow response of designer
- Contractor deficiencies in co-ordination

The study focused on special type of projects (high rise building) and in only one city (Bangkok). The study results cannot be generalised for high rise building or fast tracking economy environment because of small sample size.

The study results and delay reasons used are presented in Appendix A-8

2-4-10 Shen (1997) – Hong Kong

Shen (1997) used a questionnaire to determine the causes of delays in Hong Kong. He sent 85 questionnaires to various contractors in Hong Kong. The questionnaire contained only eight general causes that lead to delay (author used term of risk causes leading to project delay). The average ranking the predefined eight causes as following:

- Insufficient or incorrect design information
- Variation in ground and weather conditions
- Subcontractors' manpower shortage
- Shortage of materials/ plant resources
- Poor co-ordination with subcontractors
- Poor accuracy of project programme
- Shortage of skills/techniques
- Abortive works due to poor workmanship

The study was concerned only with the factors that can be founded in the construction period and because of limited number of causes, this study was not detailed one.

2-4-11 Kumaraswamy and Chan (1998)- Hong Kong

Kumaraswamy and Chan (1998) surveyed the sources of delays in the construction industry in Hong Kong. A questionnaire of 83 pre-identified construction delay causes (author used the term of factors) was mailed to sample of participants in the Hong Kong construction industry including owners, consultants and contractors.

The 83 delay causes were classified into eight factors' categories as following:

1- Project related factors
2- Owner related factors
3- Design team related factors
4- Contractors related factors
5- Materials related factors
6- Labour related factors
7- Plant/ Equipment- related factors
8- External factors

The participants were requested to rate the significance rate of each of the delay causes and the group. The authors divided their sample of respondents into two categories; building projects and civil engineering projects.

The *relative importance index (RII)* was used to summarise the importance of each factor and factor category

$$RII = \frac{\sum w}{A * N} \quad \text{.........} \quad (2\text{-}6)$$

Where w = weighting as assigned by each respondent (5 for extremely significant,...1 for non significant), A = the highest value = 5 and N the total number of sample. This index is similar as that is used by Assaf et al (1995).

The analysis was conducted for the two types of projects (building projects and civil projects). *RII* value is calculated for the factor category by averaging the RII values for category elements. The contractor related, design time related and then labour related categories have the highest rank in the respondents prospective.

The *Rank Agreement Factor (RAF)* that was developed by Baldwin et al (1971) was used to evaluate the agreement level between any two respondent groups. The analysis revealed that there is a fair degree of agreement between owners and consultants and there is an apparent divergence in perspectives between owners and contractors.

The ten most significant factors for both civil and building projects are listed in Appendix A-9 (A), while the category ranking is shown in Appendix A-9 (B).

2-4-12 Frimpong et al (2003) Ghana

Frimpong et al (2003) conducted a study to determine the causes of delay and cost overrun in ground water construction projects in Ghana. They used a mailed questionnaire of predefined 26 causes of delays and cost overrun. The study sample consisted of owners, consultants and contractors. The participants were asked to define the priority scaling (1 = very low, 2 = low, 3 = medium, 4 = high, and 5 = very high). They used an equation to rank the causes similar to that used by Assaf et al (1995). The study revealed that the most important causes were:

- Monthly payment difficulties
- Poor contractor management
- Material procurement
- Escalation of material prices

The study did not distinguish between the causes of delays and cost overrun.
The study results are presented in Appendix A-10

2-4-13 List of Direct Delays

Table 2-1 shows the summary of the above mentioned previous research work in aspect of: method of data gathering and the method of delay ranking. All of these studies used the questionnaire (mailed or interview) technique to gathering data and used simple mathematical equations to get the delay ranking. As mentioned before all of these delay causes are direct delays recorded on the site. From this previous research on delays a list of direct delays will be gathered.

Table 2-2 represents a list of 53 direct delays gathered by analysing and rationalising the research work detailed before. Direct delays which have similar words or meaning are put under one definition. These 53 direct delays are categorised into 9 groups: preconstruction, material, labour, equipment, contractor, designer, owner, project and external related direct delays. This division is based on time of occurrence or responsibility.

2-5 General Discussion Regarding the Previous Research

All the previous research conducted to determine the causes of delay has been based upon gathering subjective data from construction industry personnel by asking them to use their own judgement about the causes of delays. The participants were also asked to rank or assess the importance of a set of predefined causes of delay. The research sampled three main groups as following:

1- Contractors or constructors group, which contains the participants who are working as a contractor or represented as one of the constructor party.

2- Owners group, which contains the participants who are working as an owner, owner, or public agencies.

3- Consultant or designer group, which contains participants who are working in a consulting office, design firm or architectural/ engineering office.

There are several outputs from the analysis of this previous research:

a) It is obvious that the three groups participating in this research had different objectives, and when they were asked to determine the causes of delays, they often blamed the other group. This statement was proven from all previous studies. Many of these studies focused in determining the level of agreement of the participants' group in ranking the delay causes. A certain consensus between owners and consultants is noticed because of closeness of their objectives, while there is little consensus between contractor and owner.

The groups' difference in perceptions may be influenced by:

- The wording of the delay causes in questionnaire and this might affect of an increase in 'buck passing' by the different groups.
- It is suggested that the apparent collective biases displayed by the different groups as they often directed the blame for delays to other groups. This could discourage a search for the root causes of delays and their solution.

Table 2-1: Summary of Past Research Work of Delay Causes Measurements

	Baldwin et al In USA-1971	Arditi et al -Turki 1985	Sullivan et al- UK 1986	Okpala and Aneikwu 1988 - Nigeria	Dlakwa and Culpin 1990- Nigeria	Waheed- 1994 Egypt	Assaf- 1995 Saudi Arabia	Al-Khalil and Al-Galfy 1999- Saudi Arabia	Ogunlana et al 1996 - Thailand	Kumaraswamy and Chan 1998- Hong Kong
project owner	N/A	public	N/A	N/A	public	public & Private	public	Public	Private	N/A
Project type	N/A	Building & Civil	Big Civil Projects	N/A	N/A	Building & Civil	Building	Water and Sewage Projects	High rise	Civil and Building Projects
Value in $/ project	N/A	N/A	>5,000,000	N/A	N/A	Average 2,950,000	>2750000	N/A	5550000-640000000	N/A
Method of data gathering	Mailed questionnaire	Mailed questionnaire	Interview questionnaire	Interview then mailed questionnaire	Mailed questionnaire	Interview questionnaire	Interview questionnaire	Mailed questionnaire	Interview questionnaire	Mailed questionnaire
Participants	contractors& architects& engineers	public clients, consultants and contractors	contractors clients and consultant	engineers, consultant, clients, architects and quantity serviors	owners, consultants and contractors	owners and contractors	contractors & A/E and owners	contractors, consultants and owner	contractors, consultants, owners and construction	clients, consultants and contractors
No of used delay causes	17	23	16	20	17	16	56	60	25	83
No of delay causes group categorizes	1	1	1	1	1	1	9	6	6	8
what asked for participants	Importance in 4 levels	define the most 5 importance causes	deefine the frequency	Importance in 4 levels	Importance in 5 levels	Importance in 4 levels	Importance in 4 levels	Frequency in 4 levels & severity in 4 levels	define the existed delay cause from the list	assesss the rate of significance in 5 levels
Technique used to delay cause rank	Severity Index	Avrage score for each delay cause	Average frequency	severity index	Mean value for each delay cause	Severity Index	Importance Index	Severity Index, Frequency Index and Importnace Index	percentage from total sample size (Sample is 12 projects)	relative importance index
Technique used to get rank agreement for groups	Rank Agreement Factor	NO	NO	Rank Agreement Factor (RAF)	NO	NO	rank correlation coefficient	coefficient of concordance	NO	rank Agreement Factor

Table 2-2 : Direct Delay Causes List

GROUP	DIRECT DELAY
Preconstruction related delays	Owner's failure to co-ordinate with government authorities in pre-construction stage
	Unrealistic contract tender price
	Delay in design work
	Improper technical study by the contractor during the bidding stage
	Delay in mobilisation from contractor
	Delay of shop drawing approval
	Original contract duration is too short
	Preparation and approval of planning and network schedule before or short after project
	Problems due to Project Delivery System
	Delay to furnish and deliver the site to the contractor by the owner
Material related delays	Unavailability of required material
	Delay in material delivery
	Damage material in store
Labour related delays	Unavailability of manpower (skilled, semi-skilled and unskilled)
	Low skill of manpower
	Low labour productivity
Equipment related delays	Unavailability of required equipment
	Failure of equipment
	Unskilled equipment operator
	Equipment productivity
Contractor related delays	Shortage of technical professionals in the contractor's organisation
	Ineffective planning and scheduling of the project by the contractor
	Improper construction method implemented by the contractor
	Difficulties in financing the project by the contractor
	Problems between the contractor and suppliers, subcontractors
	Accidents during construction period
	Unsuitable leadership of contractor's construction manger
	inefficient contractor site management
	Delay in taking action
	Contractor's poor co-ordination with the parties involved in the project

GROUP	DIRECT DELAY
Designer related delays	Design changes and modifications by consultant
	Ambiguities, mistakes and inconsistencies in design specifications and drawings
	Design complexity
	Delay in taking actions regarding material, shop drawings approval and providing design information
Client related delays	Delay in contractors progress payments
	Owner financial problems
	Design changes by owner
	Owner's poor communication with the construction parties and government authorities
	Deficiencies in owner's organisation
	Interference by the owner in the construction operations
	Slow decision making by the owner
	Excessive bureaucracy in the owner's administration
Project related delays	Site possession
	Difficulties in obtaining work permits from public authorities
	Mistakes and discrepancy of contract clauses
	Inefficient delay penalty
	Weather delay conditions
	Unrealistic contract price or time
	Effects of subsurface site conditions materially differing from contract documents
	Project Delivery System
External related delays	High inflation
	Strikes
	Changes in government regulations and laws

b) From the previous studies, it has been shown that the causes of delays vary from one country to another and are very sensitive to each country's economy. Research conducted in developed countries (Sullivan et al, 1986 in the UK , Baldwin et al, 1971 in the USA and Kumaraswamy and Chan 1998 in Hong Kong) revealed that the major causes of delays are different in ranking of importance but they can be generalised as:

- Weather conditions
- Shortage of plant and labour
- Problems generated from subcontractors
- Design related causes
- Changes to site and underground conditions

However, in developing countries, the major causes of delays varied from one country to another. In Egypt (Waheed, 1994) the shortage of management techniques was the main cause of delays, while obtaining material was the main one in Turkey (Arditi et al, 1985) and the financial deficiencies are the major causes of delays in Saudi Arabia (Assaf et al, 1996) and Nigeria (Dlakwa and Culpin, 1990).

The common major causes of delays in developing countries can be generalised as:

- Shortage of construction materials
- Financial obstacles for both the owner and contractor
- The excessive office works especially in public projects
- Shortage of qualified workers and managerial staff
- Change orders
- Shortage of managerial skills for both the contractor and the owner
- Design related causes

The difference in importance or influence of delay causes between developed countries and the developing countries is mainly due to the construction industry environment. In developed countries the industry infrastructure is available in terms of construction material factories, training institutions, technical institutions and public funds. In developing countries there is still a shortage of this infrastructure. Most of construction materials and equipment are still imported from out of the country. The shortage of funding, especially from the public sector is noticeable in most of the developing countries.

c) None of the research distinguished between the delay consequences and delay generators. For example, material shortage can follow as a consequence of an improper supply chain strategy and late delivery of material amongst other causes.

d) None of the research attempted to model delays and how they occur. The past research work was dedicated only to measure and rank the delay causes. These causes are events that already direct delays. These events delay the completion time of the project and they may rise to make claims and disputes. There are many delays that are not recognized because they did not affecting the whole project. The knowledge of probable delay causes can be valuable for the contractor to put into consideration the probable direct delay and make contingency for them in any bid for future work.

So, the efficient way to deal with delays in construction projects is to model the delay occurrence, predict the probable delays, and search for where the delays will come then attempt to reduce their effect in the project. By this way preventive and remedial actions can be taken. This research will be in this stream.

2-6 Summary

Delay is a dominant feature in all construction projects and so many studies have been conducted internationally to determine and assess the importance of the delay causes. Twelve studies have been conducted around the world to define the delay causes and rank the level of importance of these delay causes. In this chapter, these studies are individual analysed and the results of each study are presented. All the conducted researches used a method of questionnaire to collect the data from construction personnel participants. There are many comments are recorded from these researches such as: all studies' participants are from different work groups such as owners, designers and contractors and these groups are attempting to blame others for delay causes, the rank of delay cause is highly sensitive to the project location and general economical situation and there is no distinguish between the delay causes and their generators. These researches dedicated to define direct delays. The list of direct delays is gathered in Table 2-2. Unfortunately these direct delays are events that actually occurred during the project life so the importance of this knowledge is limited in improving and enhance the project time performance. All these research work are from the reactive or descriptive type of research. To enhance the management tasks in mitigating the effect of project delays, a search for the root delay causes will be more efficient in defining the future direct delays. This research work is an attempt to search for the root delay causes and model the project delays to predict the future delays before the project start. By this approach, a management means to mitigate delays will be more efficient. The proposed approach to model delays and to predict the future delays in the construction project is presented in chapter 3.

Chapter 3

Proposed Approach to Model Delay in Construction Projects

3-1 Introduction

As mentioned in chapter 1- section 1-2, there is a need to model the delays in construction projects and as mentioned in chapter 2, there is no research work has been conducted in defining the root delay causes and predicts the probable delays in future project life. This chapter presents the framework of a proposed delay prediction model. This model is a predicative model that can be used to define the critical and the future delay causes. The model assumes that the delay is generated earlier than being real and propagated until delay the whole project. The proposed model is titled as Delay Hierarchy Propagation Model (DHPM). The constraints and principles of the proposed model are presented and the research methodology that was followed in order to achieve the research objectives then presented.

3-2 DHPM (Delay Hierarchy Propagation Model) Constraints

The Delay Hierarchy Propagation Model (DHPM) is proposed to model the delay propagation in the construction projects. This model will be based on three constraints. These constraints are resulted from analysing some of aspects in the construction projects. These constraints are discussed below.

3-2-1 Constraint 1: Root Delay Causes

The delays that are recorded in the construction project are direct delays. Direct delays are defined as the real or actual delays that occur and are documented in any construction project. Direct delays can be used as the basis for claims or dispute between project parties. It is proposed that these direct delays are the outcomes of some earlier events that later become real or direct delays. These earlier events have been given the term "root delay causes". These root delay causes thus can become direct delays. Root delay causes need therefore to be identified and managed before they become direct delays. It is more efficient to manage root delay causes instead of managing direct delays after once this has happened. Most of these root delay causes come into being earlier, before the direct delay occurs or even before the project starts. This assumption coincides with some of the recent studies that recommend concentration on the pre-construction stage as a tool for mitigation of the construction chronological problems (Ehrenreich, 1994, and Pocock, et al, 1997).

3-2-2 Constraint 2: Delay Propagation in Construction Project

Figure 3-1 explains the assumption of project delay propagation. The project delay is the result of a chain of successive steps. The delay is generated firstly from a deficiency of one or more of the root delay causes. If any effort is done to reduce the effects of the root delay causes, a valuable reduction or avoidance of direct delays will result. If there is no effort to manage the root delay causes, a direct delay will occur during the project construction stage. This direct delay will affect one or more of the current and/or future project activities to be delayed. The efforts done to mitigate the effect of the direct delay in project activities may result in reducing project delay. If no effort is made to mitigate the impact of direct delays on affected activities, time extension of original activities duration may resulted. The time extension is then tested and if the activity lies on the current project program critical path, the project will be exposed to delay. If the activity is not in the critical path, a comparison between the activity time extension with its float or slack will be made. If the time extension is more than the activity float, a definite project delay will be occurred.

3-2-3 Constraint 3 : Resource Shortage is the Underpinning Source for Project Delay

Project delay results from the time extension of project activities as presented before. This extension of activity time is the direct effect of any resource shortage. The construction project delay problem can be viewed as a result of four interrelated different categories as shown in Figure (3-2). These categories are:

- Category (1): External factors, Non Controlled Category.
- Category (2) :Management, Controlled Category
- Category (3) :Resource Category
- Category (4): Task or activity Category

Each of these categories can influence the activity duration as following:

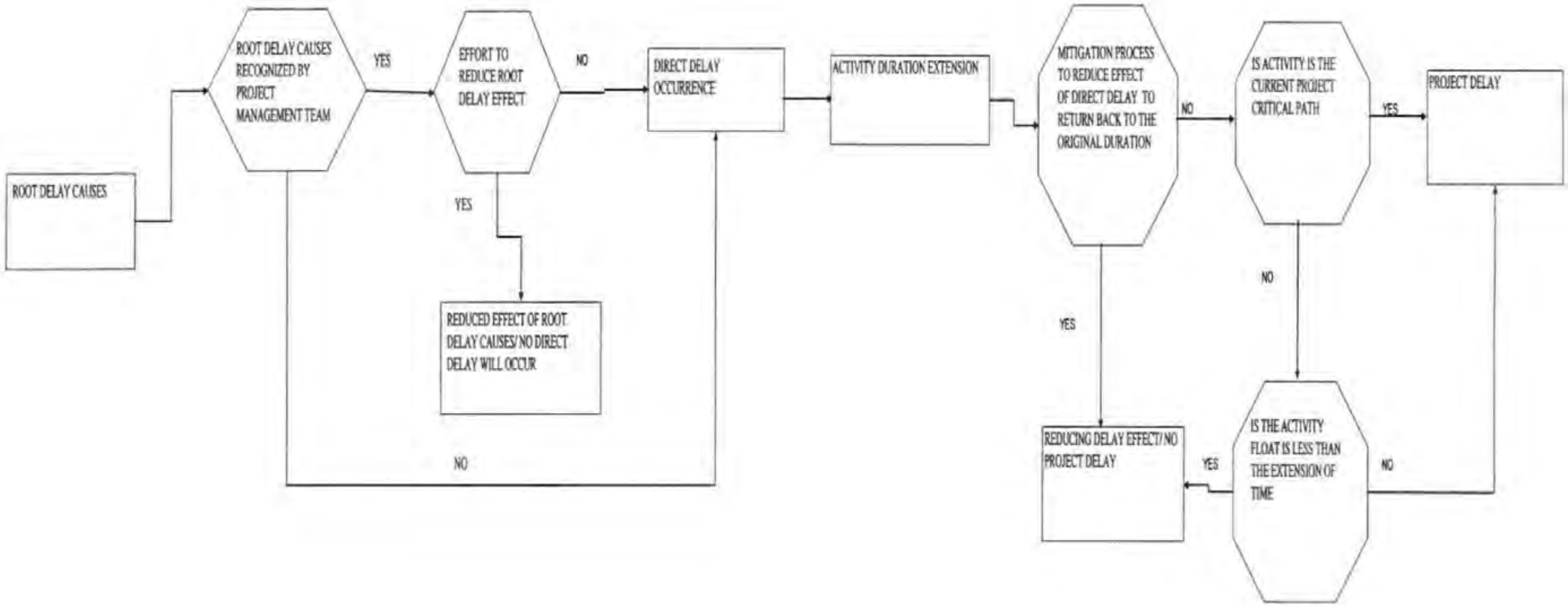


Figure (3-1): Delay Propagation in Construction Project

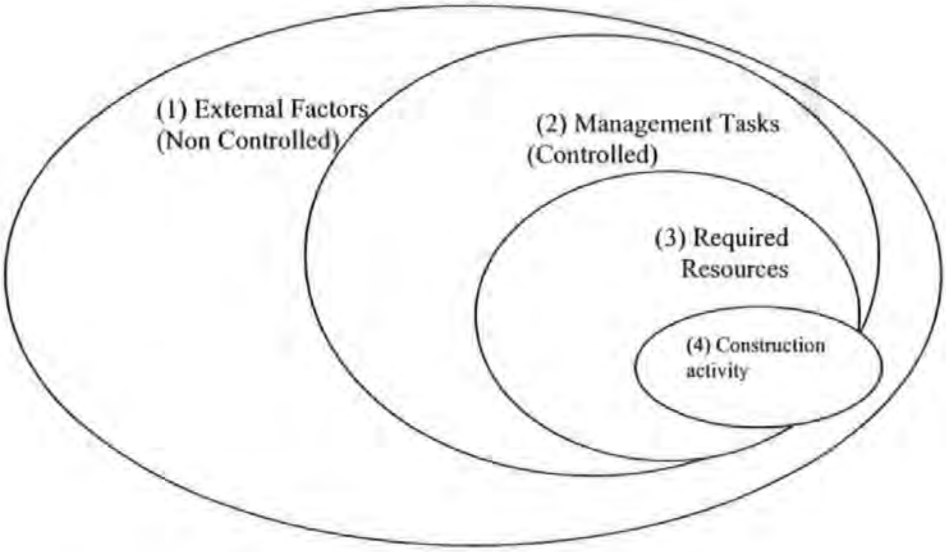


Figure (3-2) Level of Impact on Construction Process

- *Category (1),* external factors (Non Controlled) category: this category contains most of the non-controlled factors that influence the direct delay that occurs. This category contains the factors that are out of project management staff control. It contains the changing economical conditions and governmental regulations. This category can affect the management category, *category (2),* and can affect directly the execution of the construction activity, *category (4),* as the overlapped area in the Figure (3-2). Most of the factors in this category are covered in the contract documents and they are outside of the proposed delay model.
- *Category (2)*, management (controlled) category: this category contains the managerial and financial aspects that are required to facilitate the availability of resources which are in *Category (3). Category (2)* contains the managerial and financial tasks that required to operate the project as communication, planning, controlling, co-ordination and supplying information. Any shortcoming in this category will affect the performance of *Category (3)*. In other words, this category has a direct control and effect on the performance of category (3) elements.
- *Category (3)*, resource category: this category contains the resources that are required to carry out activity. This category contains materials, labour, plant, information of design and safety and work space (place, climate, light). This category has a direct effect on the construction activity performance *Category (4).* In other words any shortage or reduction of resources supply to the activity will definitely increase the activity duration, or delay the activity completion.

- *Category (4)*, the construction activity category: this represents the process of using the supplied resources from *Category (3)*, to a finish product. The finish product of this process is a completed activity. Delay in activity completion beyond a certain predefined date will delay the whole project.

Based upon this constraint, *Category (2)* can be considered as perhaps the most important category required managing project delays because it contains the delay causes. It contains the root delay causes which affect the availability and performance of the required resources in *Category (3)*. The shortage of resource in *Category (3)* will impact the performance of activity, *Category (4)*. Hence any deficiencies in root delay causes will affect the resource shortage and the resource shortage will then lead to activity delay. Based on this assumption 3, any deficiencies on the root delay causes will impact one or more of the resources to be shorten, and this shortage of resource supply will definitely affect the time performance of project activities and hence expose the project to delay.

From the above constraints, it is concluded that:

1- Project delay occurrence is generated from some of root delay causes that come into being earlier, before the direct delay occurs in construction project.
2- The most efficient effort to mitigate the effect of direct delay is to enhance the prediction and management of root delay causes.
3- Control of resource supply is the efficient way to prevent or reduce activity delays.
4- Activity delay is the result of resource shortage or reduced resource supply rate
5- Project delay is a result of project activities delays

Based on the above constraints, the Delay Hierarchical Propagation Model (DHPM) is proposed.

3-3 Delay Hierarchy Propagation Model (DHPM) Framework Design

As shown in Figure 3-3, The Delay Hierarchy Propagation Model (DHPM) consists of two interrelated sub models; model A: Resource Shortage Possibility (RSP) Model, and Model B: Predicting Project Delay (PPD) Model.

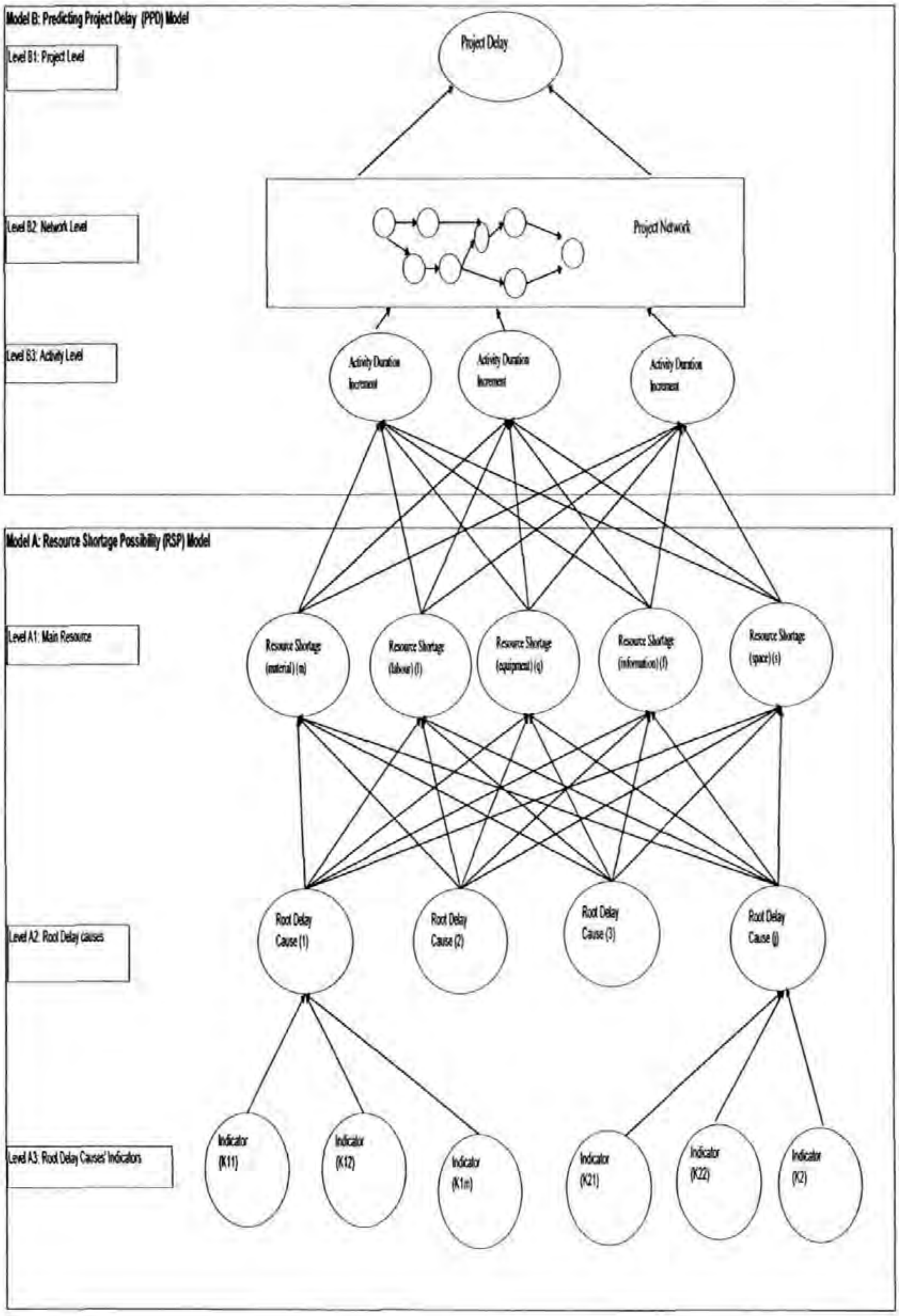


Figure (3-3) Delay Hierarchy Propagation Model (DHPM)

The objective of the Model A: RSP model is to estimate the possibility of resource shortage (shortage of material, labour, equipment, information and space). The objective of the Model B: PPD model is to predict the probable project finish time and to define the critical sources of project delay. The output of Model A will be one of the inputs of Model B.

Model A consists of three hierarchical levels:

- level A3: the root delay causes indicators. These indicators are used to measure and assess the root delay causes.
- level A2: the root delay causes
- level A1: the main resources.

Model B also consists of three levels;

- level B3 : individual project activities
- level B2 : the project network
- level B1 : the project

3-4 DHPM Model Description

In Model A: RSP model, the direct delay starts from any deficiency of one or more of the root delay causes in level A2 either before or during the construction life of the project. This deficiency will affect the possibility of the construction resources in level A1 to be shortened. To measure any of the root delay causes, a number of root delay causes' indicators is used and these indicators are found in level A3.

Model B: PPD: This model starts by evaluating the effect the of resource shortage, at level A1 resulting from Model A, on individual activity time performance, Level B3. This effect will increase the activity duration by a probable time increase. This probable increment may or may not affect the project to be delayed. Activity sequencing and type of activities relationship will affect the propagation of this increase. The effect will be assessed in the networking structure- Level B2.

Level B1 then calculates the probability of project completion time by determining the probable delays due to the combination of activity duration increments and the networking structure.

Model A: RSP verification is presented in chapter 5. Model A application is presented in chapter 6. The details of Model B: PPD and its verification are presented in chapter 7.

3-5 Research Methodology

To achieve the research objectives those have been mentioned in section 1-3, and as shown in figure 3-4, the research stages are the following:

Literature review

This literature review has two objectives; to search for the past research work regarding the construction project delays and to determine the direct delays. Literature review is presented in chapter 2.

Design the DHPM

The proposed Delay Hierarchy Propagation model is designed based on assumptions. The model design and assumptions are presented in chapter 3.

Root delay causes

Cause-Effect technique is used to determine the root delay causes by analysing each one of the direct delay. Cause-Effect application is shown in section 4-3.

Determination of the root delay cause' indicators.

Root delay causes' indicators are the indicators that are used to evaluate the root delay causes. Root delay causes' indicators will be resulted from the past research work regarding key performance indicators (KPI), project parties pre-qualification selection and other relevant works. Section 4-4 shows how the root delay cause' indicators are derived.

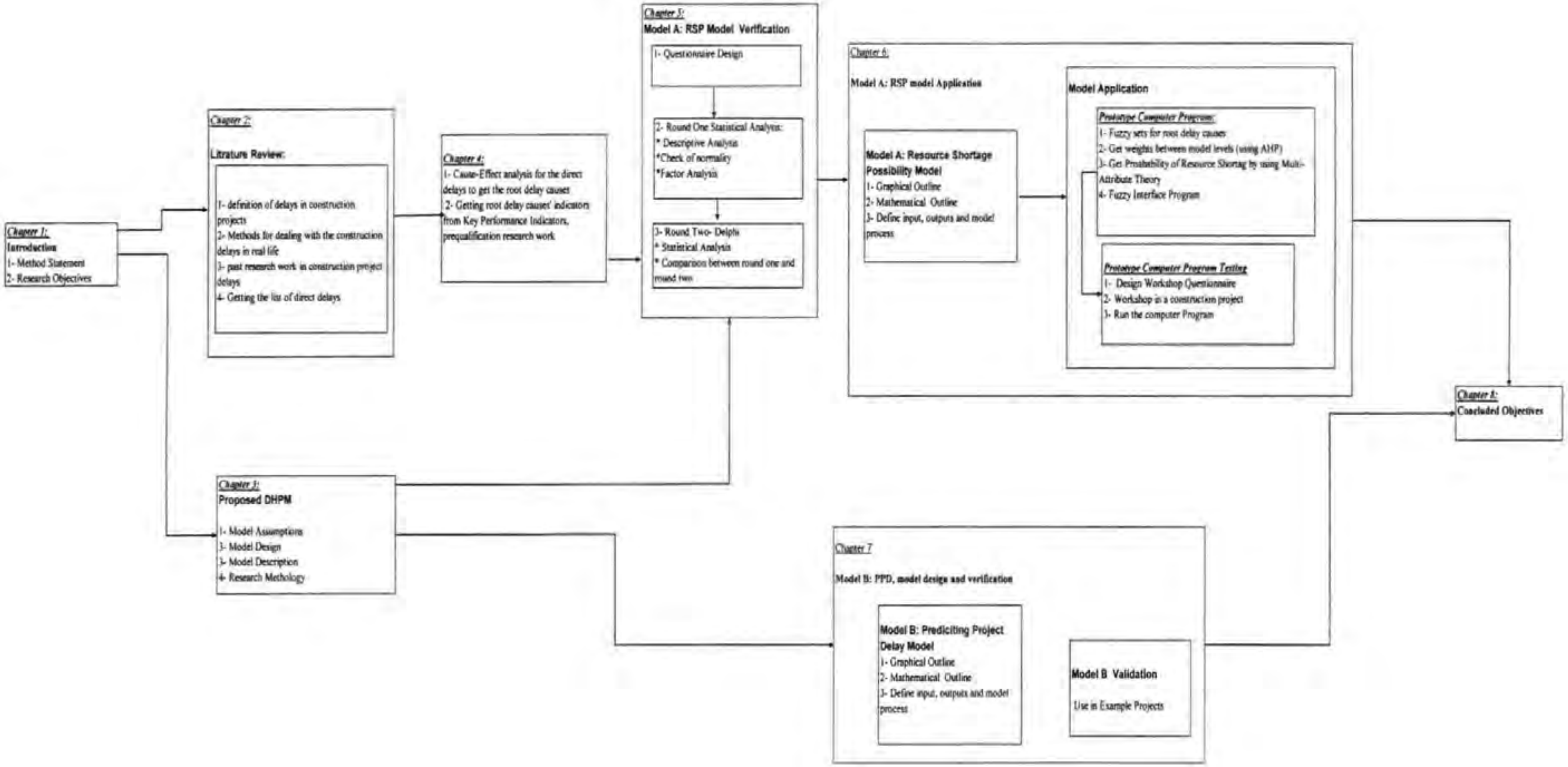


Figure (3-4) Research Methodology Flow Chart

Model A: (RSP) is verified using Delphi method.

An interview questionnaire is designed to verify Model A basis. The questionnaire will be mainly from closed-question types. Two rounds of The Delphi interview questionnaire were conducted with some of construction personnel. The collected data then statistically analysed to verify the model basis. The interview questionnaire design, statistical analysis and the Delphi analysis are presented in chapter 5. The RSP model is modified due to verification results.

Model A: (RSP) Model Application.

The modified RSP model is applied in two main steps: design a prototype computer program and testing this prototype computer program. The prototype computer program is used to calculate the possibility of resource shortage.

The prototype computer program uses Multi-attribute theory, fuzzy logic and Analytical Hierarchical Process (AHP) theory. The program inputs are the root delay causes' indicators which are entered as fuzzy sets. The relative weights between the three model levels shown in Figure 3-3, are calculated using the Analytical Hierarchical Process (AHP) theory and the value of resource shortage possibility is calculated using multi-attribute theory.

The prototype computer program is tested in one of the construction projects. A workshop questionnaire is designed to collect the inputs of root delay causes' indicators from project parties. Then run the computer program to calculate the possibility of resource shortage.

RSP model mathematics, design of the prototype computer program and its testing are shown in chapter 6.

Model B: PPD model Design and Application

The proposed PPD model is formatted mathematically using the probabilistic scheduling. One of the inputs for the PPD model is the possibility of resource shortage that is the output of the RSP model. Model B is tested in a numerical example to calculate the probability of project delay and to determine the most critical sources of delay.

Model B: PPD design and application is presented in chapter 7.

Chapter 4

Root Delay Causes and Root Delay Causes' Indicators

4-1 Introduction

As described in Chapter 2, previous research to construction delay were regarding the frequency and severity of the direct delays in the construction industry, and there has been no research carried out to understand what the main root causes that lead to direct delays. Hypothetically as described in Chapter 3, a project delay results from earlier events which can be called as ***root delay causes***. The proposed DHPM model shown in section 3-3 and 3-4, searches for these root delay causes so that they can be measured or assessed before the project starts in order to predict the tendency of the project to delay.

The cause-effect technique is used to derive the root delay causes. The cause-effect technique is a technique used by both researchers and industry personnel to derive the root causes of a problem.

4-2 Cause-effect Diagram

The cause-effect diagram was developed by Kaoru Ishikawa in 1943, who pioneered quality management processes in the Kawasaki shipyards (Gitlow, 2001). The cause and effect diagram is used to explore all the potential or real causes (or inputs) that result in a single effect (or output). Causes are arranged according to their level of importance or detail, resulting in a depiction of relationships and of events. This can help the search for root causes, identify areas where there may be problems, and compare the relative importance of different causes.

The cause-effect diagram is also known as fishbone diagram because it was drawn to resemble the skeleton of a fish, with the main causal categories drawn as "bones" attached to the spine of the fish, and these bones can be analysed to get root causes as shown Figure (4-1).

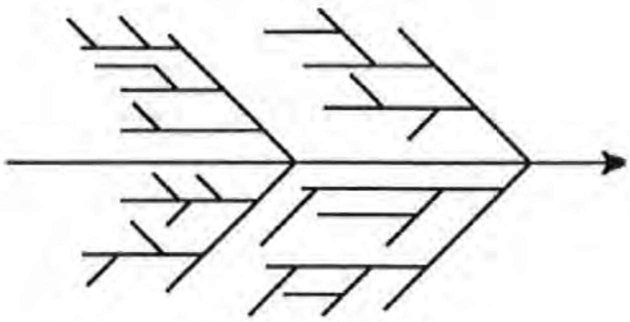


Figure (4-1) Cause and Effect (Fish-bone) Diagram

Cause and effect uses the process of "Why-Why" to get the root causes of a problem. A series of why questions are asked. Starting by asking why the main problem (output) occurs which results in a set of causes (outputs) set out in the main bones. Each one of these causes is then analysed by asking why each one of these causes is occurring. This process is repeated to get the root delay causes for the problem being analysed.

Each one of the direct delay that were collected from previous research listed in Table 2-2 will be analysed to extract its root delay causes by the cause-effect technique. This is carried out by asking the "why-why" tool to each of these direct delays. The root delay causes can be either internal or external to the project site.

4-3 Extracting Root Delay Causes from Direct Delays

The direct delays are categorised into 9 main groups based on the time of delay occurrence or the responsibility for delays as shown in Table 2-2. These groups are:

1) Preconstruction related direct delays
2) Material related direct delays
3) Labour related direct delays
4) Equipment related direct delays
5) Contractor related direct delays
6) Designer related direct delays
7) Owner related direct delays
8) Project related direct delays
9) External related direct delays

Externally related direct delays are causes that are out of the control of any of the project parties. As illustrated early in section 2-3 external related causes are thus excluded from the proposed DHPM.

The cause-effect technique will be applied for each group of direct delays.

4-3-1 Root Delay Causes for Preconstruction Related Direct Delays

The pre-construction direct delays occurring before project as shown in Table 2-2 are:

- Owner's failure to co-ordinate with government authorities in pre-construction stage
- Unrealistic contract tender price
- Delay in design work
- Improper technical study by the contractor during the bidding stage
- Delay in mobilisation from contractor
- Delay of shop drawing approval
- Original contract duration is too short
- Preparation and approval of planning and network schedule before or short after project start
- Problems due to project delivery system
- Delay to furnish and deliver the site to the contractor by the owner

These direct delays are analysed by the cause-effect technique to get the root delay causes.

Figure (4-2) shows the cause and effect diagram for the pre-construction related direct delays.

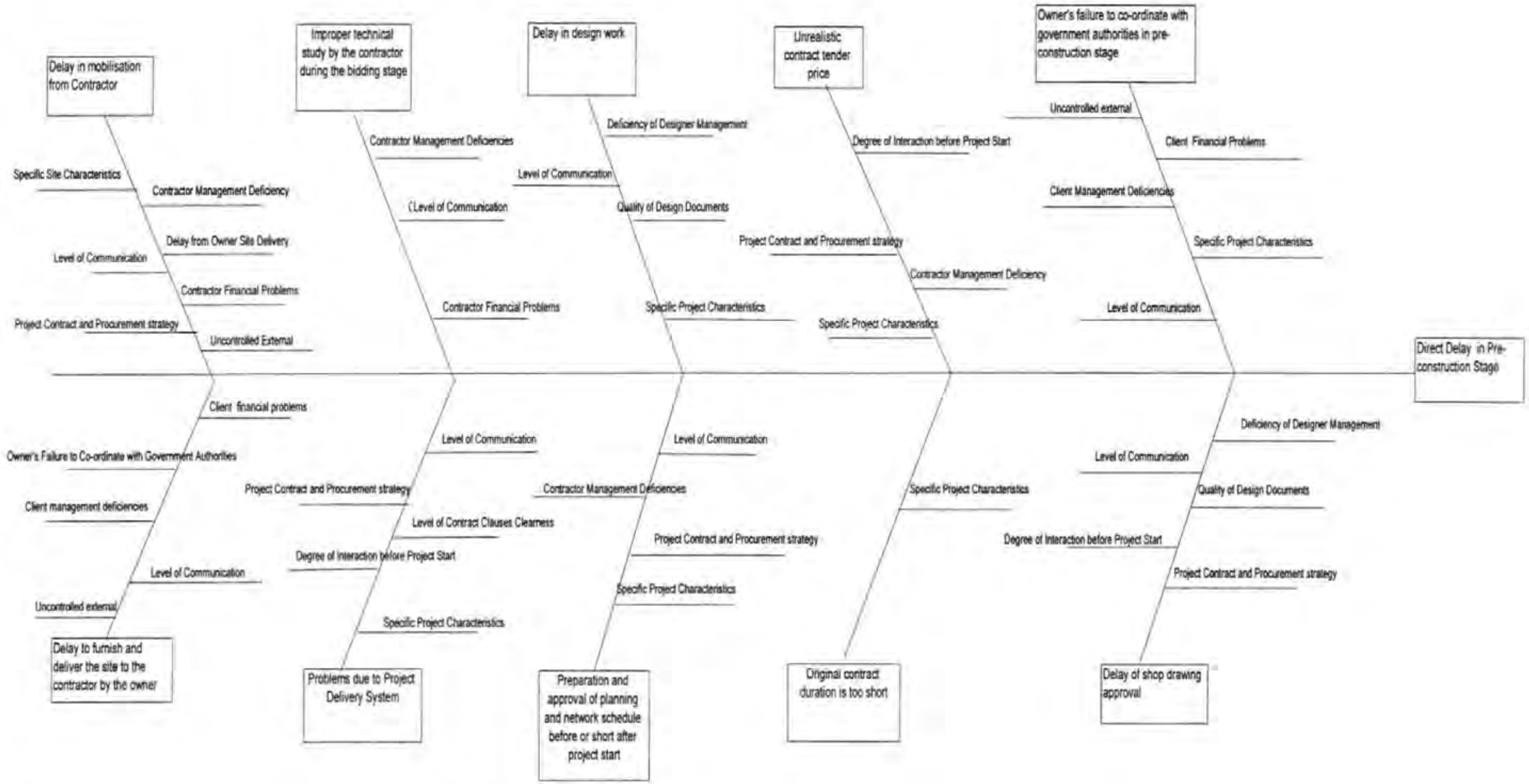


Figure (4-2): Cause and Effect Diagram for Preconstruction Direct Delays

For example "delay in mobilisation from contractor" which, is one of the preconstruction direct delays, is laid in one branch of the cause and effect diagram for this type of direct delay group. This direct delay is analysed to get the probable causes for this delay by using "why-why" questions. Delay in mobilisation from contractor can thus be caused from any one of the following causes:

- Specific site characteristics, this may due to level of site accessibility, because of difficulty to access due to excessive permission needed or because site is in a hazardous place.
- Contractor financial problems, the contractor might not have the required finance to move his equipment and temporary construction equipment to site.
- Delay in access to site from owner, the contractor has not received possession of site from the owner.
- Contractor project management deficiencies, the contractor might delay mobilisation because of errors in time planning, preparation, or delay in getting permission to site mobilisation.
- Level of Communication problems between contractor, owner and authorities organizations.
- Unfamiliarity of contractor for the procurement and contractor strategy.
- Uncontrolled external causes.

By analysing all the branches in Figure (4-2) in the same way, the total number of different root delay causes for all direct delays of preconstruction direct delays is obtained.

The root delay causes for direct delays in the preconstruction stage as derived from Figure (4-2) are:

1) Specific site characteristics
2) Specific project characteristics
3) Contractor management deficiencies
4) Level of communication between project parties
5) Contractor financial problems
6) Owner management deficiencies
7) Owner financial problems
8) Project procurement and project strategy

9) Degree of interaction between project parties in pre-construction stage
10) Efficiency of designer management
11) Level of quality of design work documents
12) Uncontrolled external factors

Non-controlled external causes are ignored since the project parties have no control over these causes.

4-3-2 Root Delay Causes for Material Related Direct Delays

Material related direct delays listed in Table 2-2 are:

- Material unavailability
- Delay in material delivery
- Damaged material in store

Before extracting the root delay causes of these direct delays, the problem of material supplying in construction industry will be discussed in general.

The material that will be used in the project should be clearly defined and specified before the project start. Material supply is one of the contractors' responsibilities and it is approved by other project parties. The information flow and communication level between project parties can therefore have an effect on material unavailability (Virhoef and Koskela, 1999).

The problem of material unavailability is mainly a management problem due to inadequate planning from the contractor (Sulivan and Harris 1986). The need for an effective materials planning system is obvious when one considers the large number of delays in materials delivery experienced by contractors (Abdul-Rahman and Alidrisyi, 1994).

The problem of material damage also affects the availability of materials on the site. In cases when the materials are not available at the right time, the contractor may purchase extra materials quantities, as available, to face the situation of material shortage, or if the material delivery rate is more than the consumption rate, then material storage will be needed. Material damage can then be a result of bad storage and bad material management.

To extract the root delay causes of the set of direct delays related to material, each of the direct delays will be analysed in the same way as presented in section 4-3-1.

Figure (4-3) shows the cause-effect analysis for material related direct delays. From that analysis, the possible root delay causes to material shortage are:

1) Contractor management deficiencies
2) Contractor financial problems
3) Communication problems with suppliers, owner and consultant.
4) Specific site conditions
5) Designer management deficiencies
6) Uncontrolled external factors

4-3-3 Root Delay Causes for Labour Related Direct Delays

The direct delays related to labour as found in previous researches are:

- Unavailability of manpower (skilled, semi-skilled and unskilled)
- Low skill of manpower
- Low labour productivity

Figure 4-4 shows the cause-effect analysis for labour related direct delays.

By analysing the "labour unavailability" this delay may result from poor contractor efficiency of labour management. This is a problem mainly resulting from poor manpower planning from the contractor side. In most cases, the contractor just having signed the contract, it has to submit according to many forms of contract a plan for its labour and its supervision staff (Clough et al, 2000). The contractor's policy in labour supply and control affects the labour availability.

The labour supply system in certain regions relies on subcontractors who are responsible for supplying the required number of workers to main contractor. This gives the main contractor in less control over the number of workers on site (Shen, 1997). Management of labour subcontractors is mainly a management problem from the contractor side.

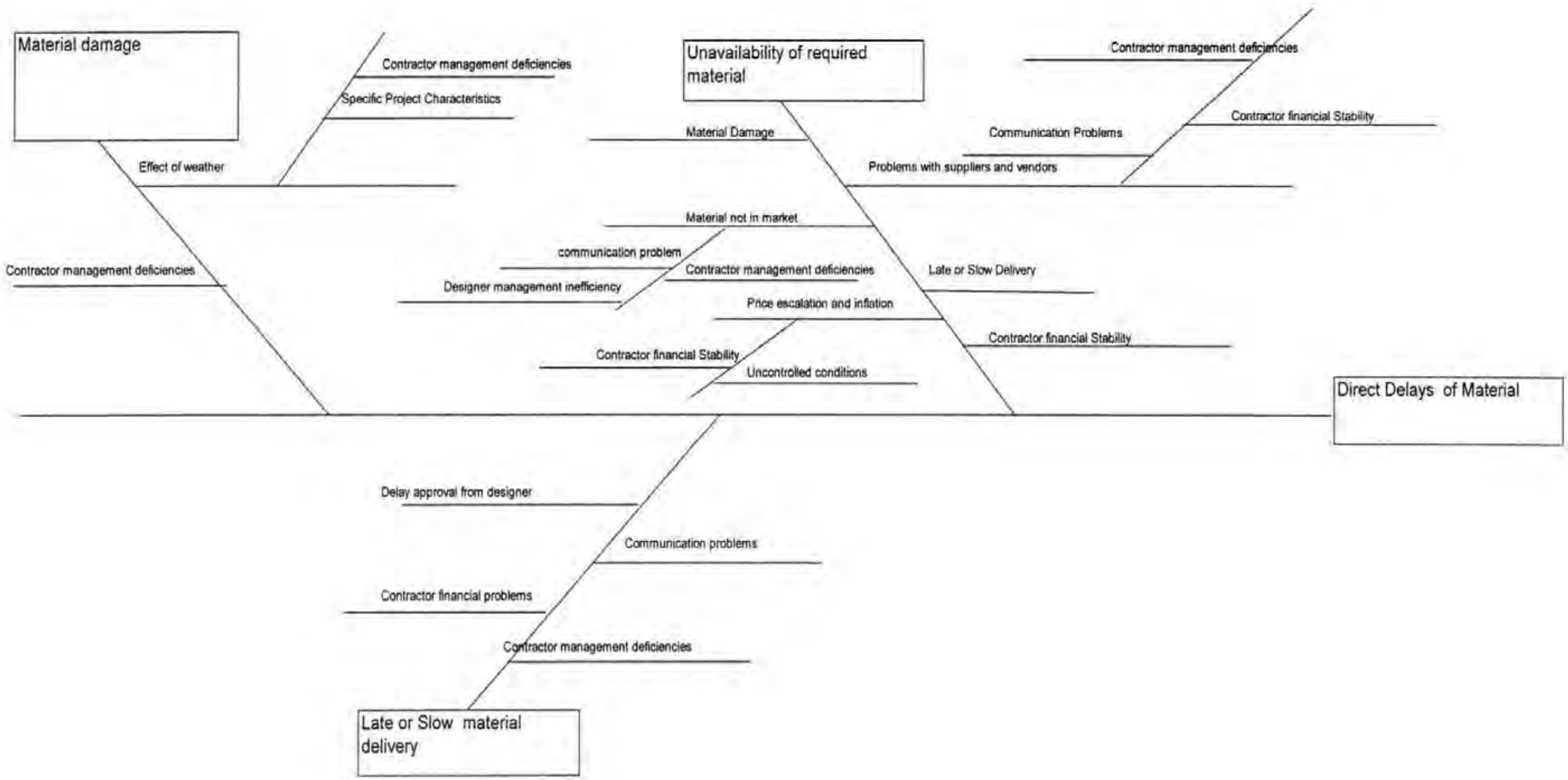


Figure (4-3): Cause and Effect Diagram for Material Direct Delays

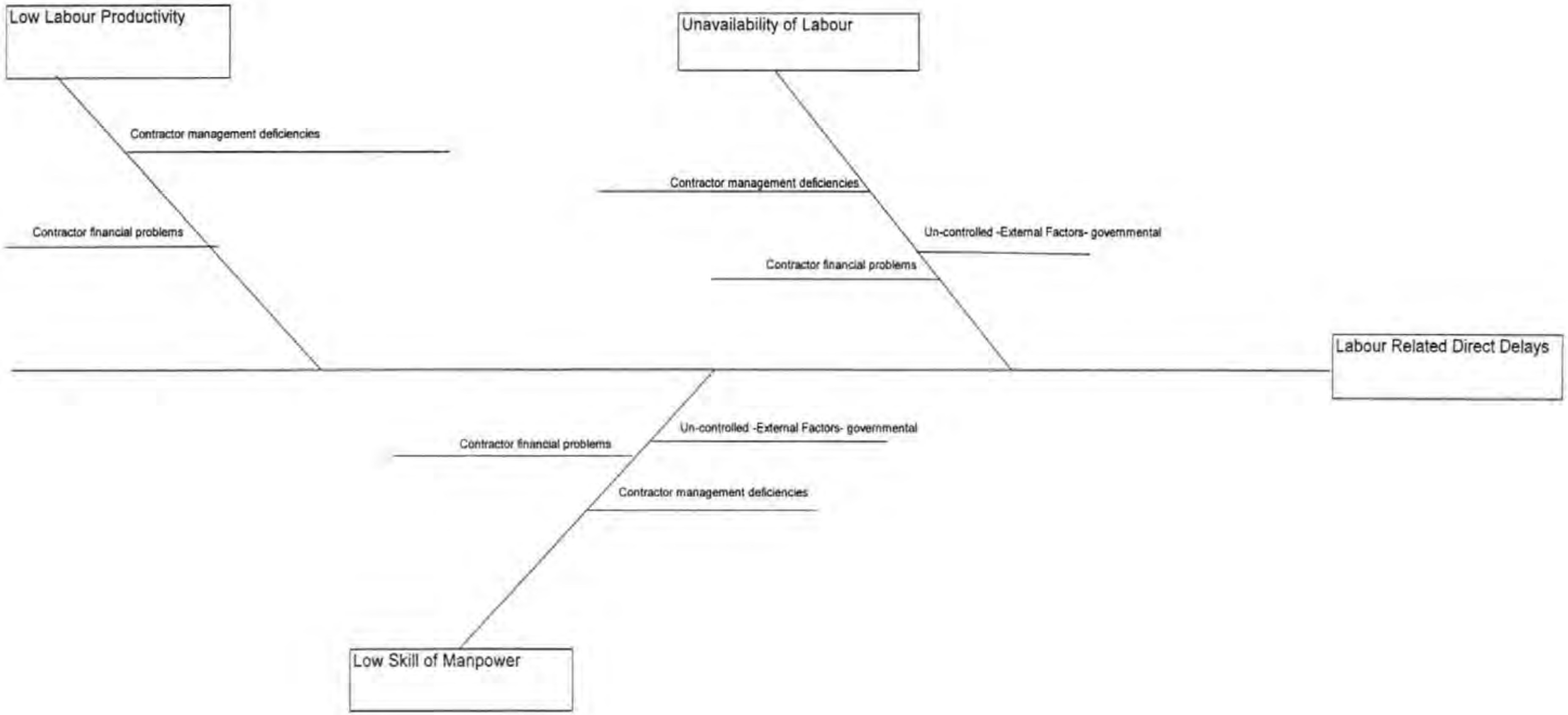


Figure (4-4): Cause and Effect Diagram for Labour Direct Delays

In general, the contractor's management capabilities in planning, organisation and orientation affect the labour availability in site.

Contractor's financial stability is required to fund labour wages in the required time and to put into practice the motivation and reward schemes that enable labourers to be available when required.

There are also many external causes related to governmental regulations that can affect the labourers' availability in site.

By analysing all labour related direct delays by the same way that illustrated before, the root delay causes for labour related direct delay can be summarised as;

1) Contractor financial problems
2) Contractor management deficiencies
3) Uncontrolled external factors

4-3-4 Root Delay Causes for Equipment Related Direct Delays

The equipment related direct delays that are found from previous studies are:

- Unavailability of required equipment
- Failure of equipment
- Unskilled equipment operator
- Low equipment productivity

These types of delays can be more sever in civil projects than in building projects. This is because civil projects involve more earthmoving operations that depend on the equipment availability and productivity (Sullivan and Harris, 1986).

On a project site, the contractor is responsible for making planning for equipment, organizing the available equipment and the control of equipment productivity. Site supervisors can achieve favourable production rates and get the most from their equipment only when they apply positive ways to manage them (Clough et al, 2000).

To get the root delay causes for equipment related direct delays, an example of equipment unavailability will be analysed by the "why-why" tool. Equipment unavailability can result from the inefficiency of the contractor's management to plan the requirements of equipment, orient the equipment when it is required, and make the required maintenance system that ensures the equipment is ready when it is required.

Or it can result from the contractor's financial problems that did not enable the contractor to fund the equipment purchasing or leasing when it was required. Equipment unavailability may also result from many unexpected or uncontrolled causes. Applying the same technique for the rest of branches, the root delay causes for equipment related direct delays as shown in Figure (4-5) are:

1. Contractor management deficiencies
2. Contractor financial problems
3. Uncontrolled external factors

4-3-5 Root Delay Causes for Contractor Related Direct Delays

The contractor related direct delays that are found in past research work as shown in Table 2-2 are:

- Shortage of technical professionals in the contractor's organisation
- Ineffective planning and scheduling of the project by the contractor
- Improper construction method implemented by the contractor
- Difficulties in financing the project by the contractor
- Problems between the contractor and suppliers, subcontractors
- Accidents during construction period
- Unsuitable leadership of contractor's construction manger
- Inefficient contractor site management
- Delay in taking action
- Contractor's poor co-ordination with the parties involved in the project

To apply the cause-effect technique contractor direct delays, the root delay causes for ineffective planning and scheduling of the project by the contractor will be studied as an example.

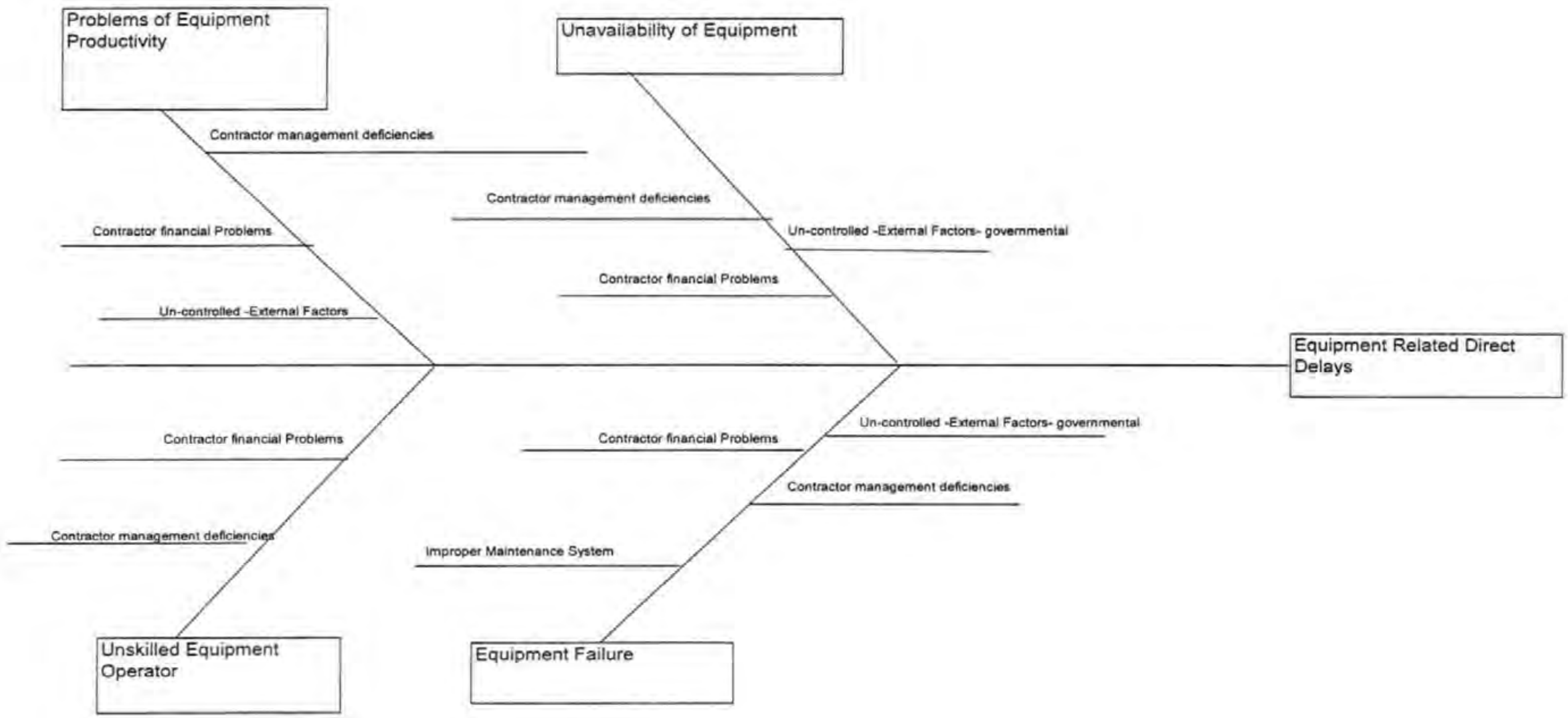


Figure (4-5) Cause-Effect Diagram for Equipment Related Direct Delays

The contractor's plan should contain the logical sequence of project tasks, estimated duration's for tasks, the financial and manpower plan requirements (Clough et al, 2000). Any delay or failure of the contractor to prepare or submit this plan in the proper way and in time will expose the project to lose the control tool to manage project time performance. Using inadequate planning techniques can affect the time performance of the project (Ognulana et al,1996). The AUDIT Commission's (1997) survey that measured the performance of completed projects in1994/1995 in the UK indicated that not-using databases and proper techniques in planning. The basis for poor planning.

Problems of planning and scheduling can be caused by any one of the followings:

- Contractor management deficiencies either it has not the sufficient experience or has unqualified technical staff.
- Contractor's financial problems that prevent contractor from using the proper staff and/or techniques to properly plan in the proper time.
- Unfamiliarity with the procurement strategy and contracts that the project is using.
- Level of project complexity and required technology that the contractor is not familiar with or does not have.
- Specific project characteristics such as time pressures i.e. there is not enough time to use the proper planning techniques.

All the other direct delays for contractor related group will be analysed by the same way. Figure (4-6) shows the cause and effect diagram for contractor related direct delays. The following is the list of root delay causes for contractor related direct delays:

1) Level of contractor management deficiencies
2) Contractor financial problems
3) Level of communication
4) Lack of trust between project parties
5) Owner management deficiencies

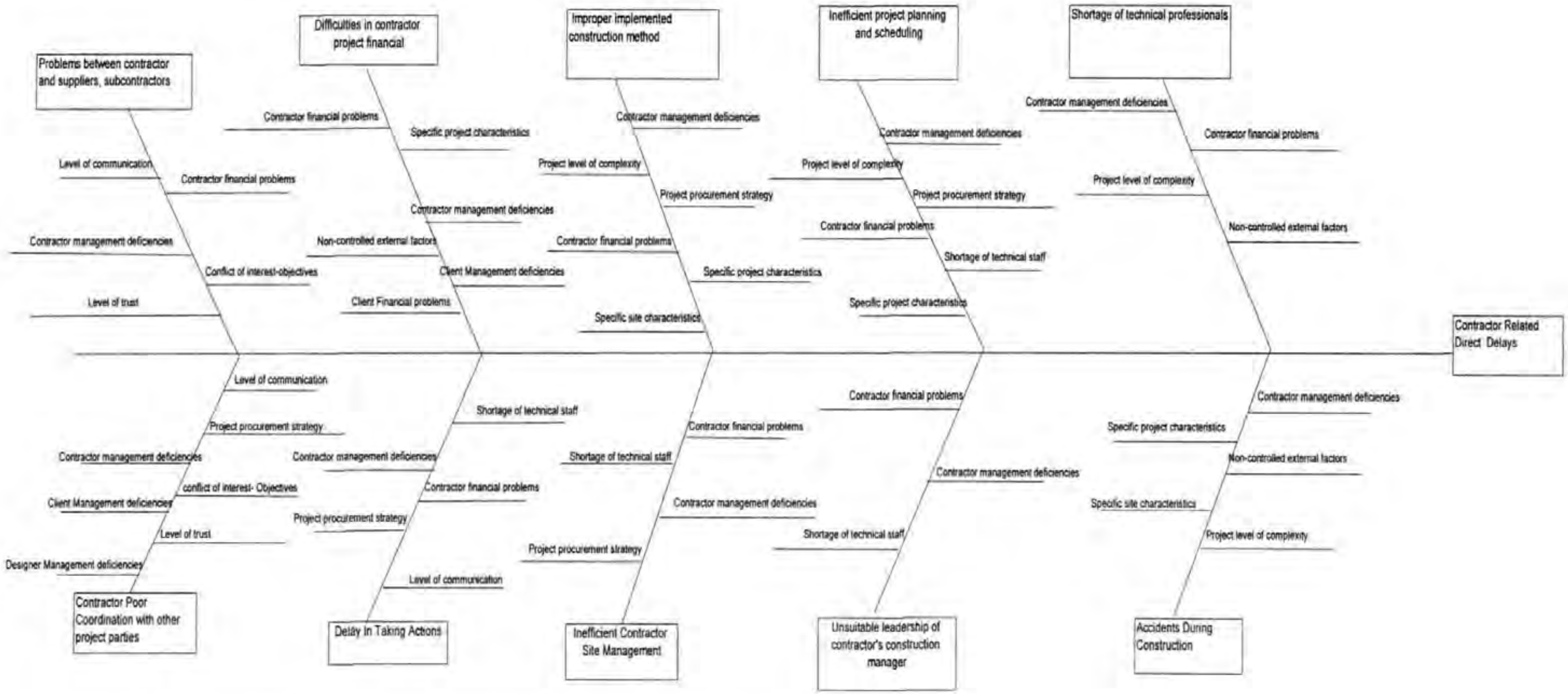


Figure (4-6) Cause-Effect Diagram for Contractor Related Direct Delays

6) Designer management deficiencies
7) Conflict of interest – Changes of objectives between project parties
8) Specific project characteristics
9) Project level of complexity
10) Familiarity with project procurement strategy
11) Uncontrolled external factors

4-3-6 Root Delay Causes for Designer Related Direct Delays

Designer or consultant related direct delays found in previous studies as shown in Table 2-2 are:

- Design changes and modifications by the consultant
- Ambiguities, mistakes and inconsistencies in design specifications and drawings
- Design complexity
- Delay in taking actions regarding material, shop drawings approval or delays in providing design information.

Each of these direct delays will be analysed using "why-why" tools to get the root delay causes of designer related delays as shown in Figure (4-7).

For example, the analysis of "design change orders or modification by designer" will be analysed. Change orders can be required by a notice or instruction from the designer to the contractor to carry out changes. These changes can be before project start or after the commencement of the project. The severity of the change varies from changing of the project concept to just change some items in the project contents.
Change orders that are generated from designer part include (Challahan et al, 1992):

- Design alteration (major changes)
- Design modification (minor changes)
- Addition works
- Work omission

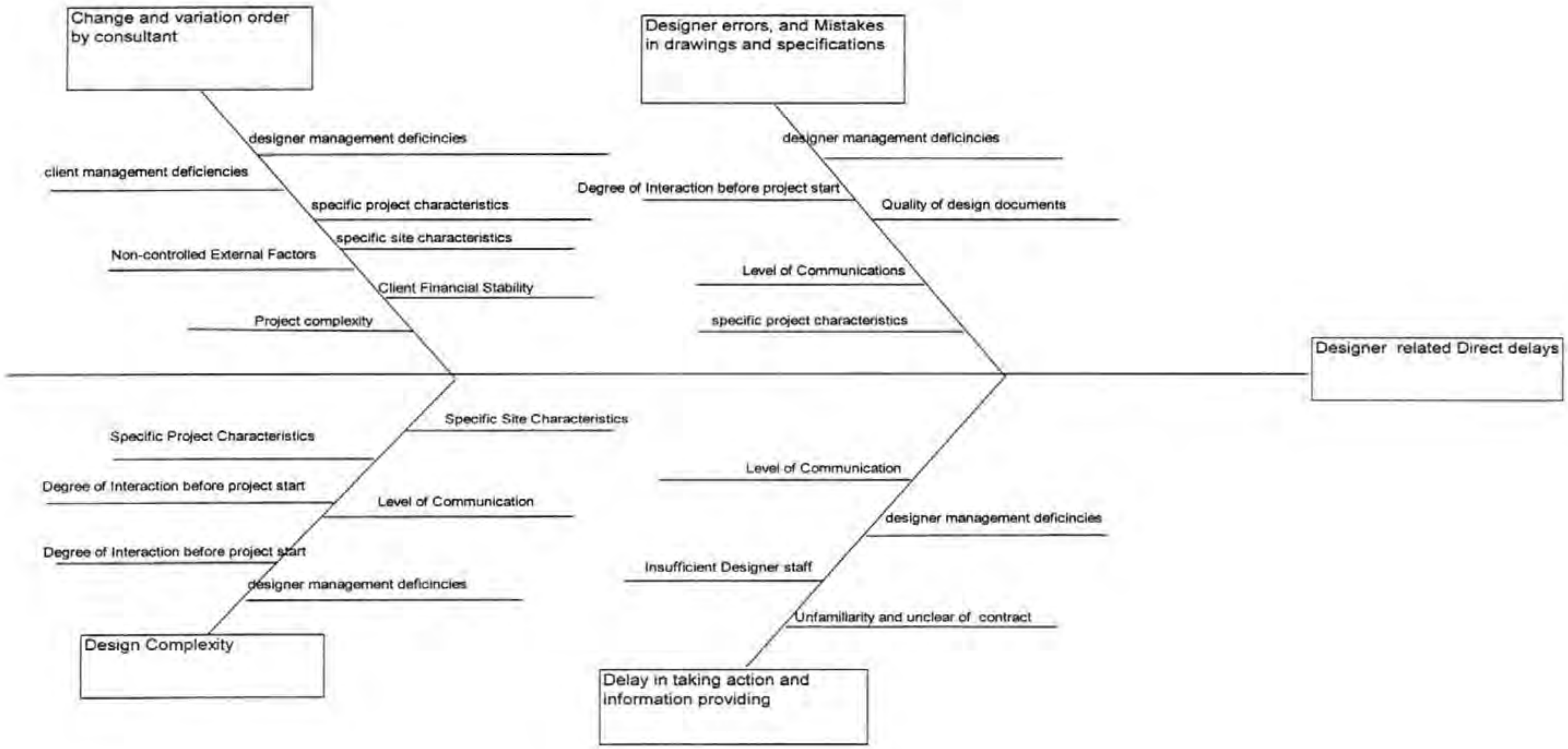


Figure (4-7): Cause-Effect Diagram for Designer Related Direct Delays

- ♦ Specification changing
- ♦ Change of timing or method statement or activities sequential

The effects of changes on the construction programme as summarised by (Scott, 1993) are:

- ♦ Complete stoppage of all parts of the project following postponement of the work
- ♦ Extending activity durations due to increased work content.
- ♦ Additional activities added to the programme because of extra work.

The root causes for change orders may be one of the following causes as shown in Figure (4-7):

- Owner management deficiencies, which can carry out a change order without evaluate its effect on the project time or cost.
- Owner financial problems: these may force the owner to change the material type and/or design.
- Designer management deficiencies in terms of inexperience, insufficient of staff, errors generated or overloading the architects and engineers (Shen, 1997)
- Specific project characteristics: short design time offered by the owner (Shen, 1997 and Latham, 1994)
- Inefficiency of designer management: level of design complexity (Sullivin and Harris, 1986).
- Specific Site conditions: changes that can not be avoided, such as redesign in response to unforeseen ground conditions or defects in existing buildings.
- Non-controlled external factors

The analysing for the rest of direct delays related to contractor is achieved in the same way and results in the set of their root delay causes. The root delay causes for designer related causes as shown in Figure (4-7) are:

1) Designer management deficiencies
2) Owner management deficiencies
3) Owner financial problems

4) Quality level of design documents
5) Specific project characteristics
6) Specific site characteristics
7) Level of project complexity
8) degree of interaction between project parties before project start
9) Level of Communication between project parties
10) Uncontrolled external factors

4-3-7 Root Delay Causes for Owner Related Direct Delays

The project owner has a great influence on the project's time performance (Kometa et al, 1996). The owner related direct delays that were found in previous studies as shown in Table 2-2 are:

- Delay in contractors progress payments
- Owner financial problems
- Design changes by owner
- Owner's poor communication with the construction parties and government authorities
- Deficiencies in owner's organisation
- Interference by the owner in the construction operations
- Slow decision making by the owner
- Excessive bureaucracy in the owner's administration

To obtain the root delay causes for owner related direct delays, the "why-why" tool will be applied as before. For example, the root delay causes for "slow decision making by owner" as shown in Figure (4-8) are:

- Owner management deficiencies: owner management has to analyse and study and take action in the proper time. In case of insufficient professionals, inexperience and non support to finish the project a delay of taking action will be resulted.
- Owner financial problems: the owner has to fund the project. The delay in revision of bills before approval to fund and the availability of funds will affect the decision regarding funding.
- Level of communication will affect the speed of taking decision by the owner.

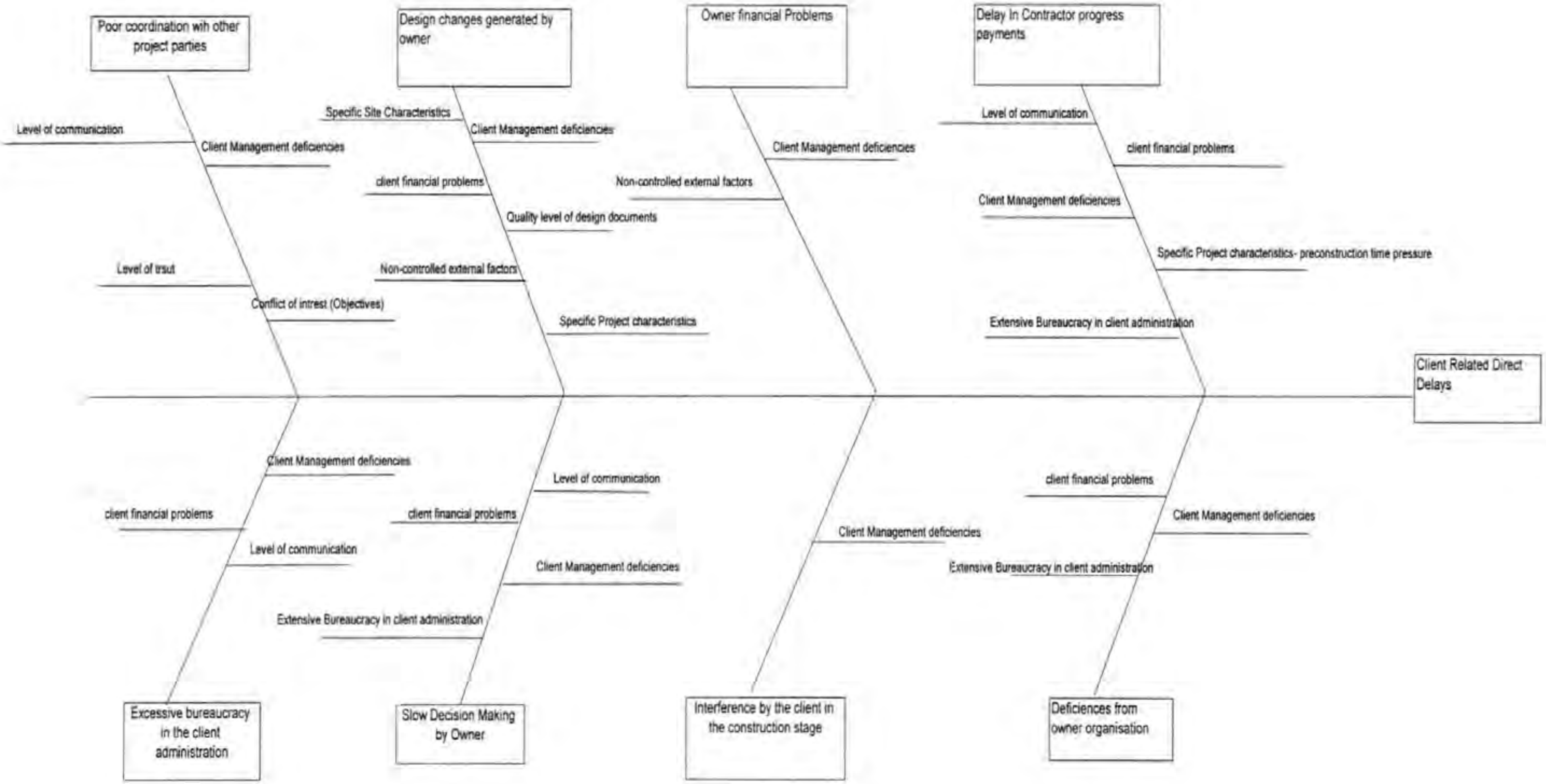


Figure (4-8): Cause-Effect Diagram for Owner Related Direct Delays

- Extensive bureaucracy in owner admission, this is a owner management deficiency feature

The rest of direct delays related to owner will be studied by the same way and the root delay causes for owner related direct delays can be derived which are:

1) Owner financial problems
2) Owner management deficiencies
3) Lack of trust
4) Conflict of interest (objectives)
5) Level of communication
6) Specific project characteristics
7) Specific site characteristics
8) Uncontrolled external factors

4-3-8 Root Delay Causes for Project Related Direct Delays

Project related direct delays that found in the previous studies as shown in Table 2-2 are:

- Site possession
- Difficulties in obtaining work permits from public authorities
- Mistakes and discrepancy of contract clauses
- Inefficient delay penalty
- Weather delay conditions
- Unrealistic contract price or time
- Effects of subsurface site conditions materially differing from contract documents
- Project Delivery System

To get the root delay causes of these delays, "why-why" tool will be used. For example, the root delay causes of "site possession" delay are:

- Owner management deficiencies: the owner has to provide access of the site to contractor. Any management deficiency of owner part, will delay the submit and site access to the contractor

- Contractor management deficiencies: the contractor has to finish permits of works to give the site access. Inefficiency of contractor management will affect the accessibility to site
- Level of required permits: this can affect the level of site accessibility
- Specific site characteristics, such as level of hazard, level of contamination, site of antic places.
- Non-controlled external factors.

Applying the same analysis for the direct delays related to project, the root delay causes for project related direct delays can be derived as shown in Figure (4-9). The root delay causes for project related factors are:

1) Specific project characteristics
2) Specific site characteristics
3) Owner management deficiencies
4) Contractor management deficiencies
5) Designer management deficiencies
6) Project delivery system
7) Uncontrolled external factors

4-3-9 List of Root Delay Causes

The cause-effect technique has been used to obtain the root delay causes for all the direct delays obtained from past research work. These root delay causes can be categorised into three main categories:

(1) Root delay causes due to the project's main players: designer(s), contractor(s) and owner.

(2) Root delay causes from the inter-relationship work environment: communication, trust and agreement of project objectives.

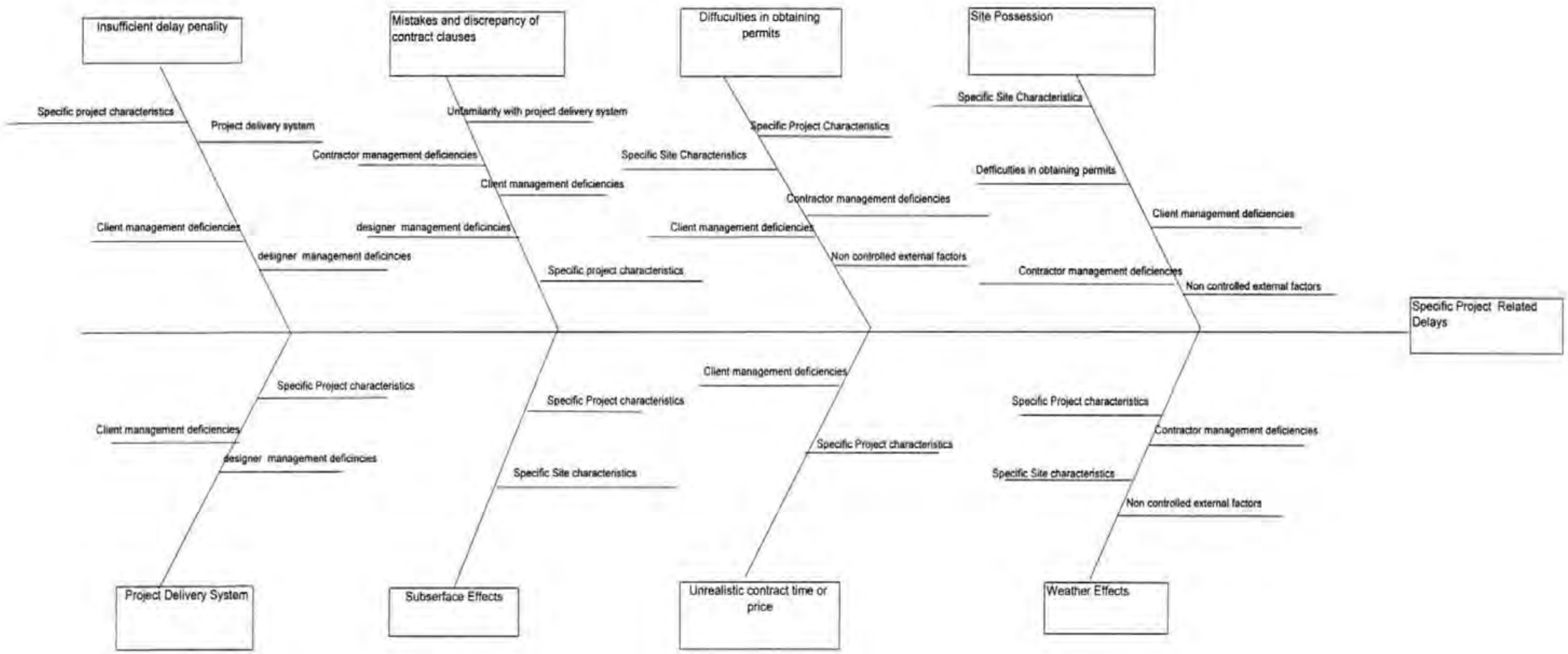


Figure (4-9) Cause-Effect Diagram for Project Related Direct Delays

(3) Root delay causes related to the specific project: design documents, site characteristics, project characteristics, project procurement strategy, interaction before project start and the level of project complexity.

As can be noticed from the above presentation many of these root delay causes influence more than one direct delays.

The following list of root delay causes will be used as the entities in level A-2 in the proposed DHPM as shown in Figure 3-3. The root delay causes can be listed as:

1) Designer's management deficiencies:

Describes the level of consultant and designer management efficiency in design and/or construction supervision work.

2) Quality of design work documents

Measures the level of accuracy and matching of design work documents such as drawings, specifications, calculations....etc

3) Contractor's management deficiencies

Defines the level of contractor(s) technical and managerial capabilities to execute and finish project in project contractual time.

4) Contractor's financial problems

This measures the ability of contractor(s) to fund the project and not to stop the project due to contractor financial problems.

5) Owner's management deficiencies

This is the efficiency level of owner and/or owner representative(s) to provide the required information and support to finish project as scheduled.

6) Owner's financial problems

This measures the ability of owner(s) to fund the project and provide contractor(s) payments when required.

7) Efficiency level of communication between project parts

This measures the level of communication efficiency between project parties during construction phase.

8) Level of interactions between project parties in pre-construction phase

Measures level of interaction between project parties before project start to union project objectives and discuss project risks.

9) Level of trust between project parties:

Measures the level of trust between project parties to complete project as contracted.

10) Level of project complexity and required technology:

This measures level of project complexity and required technology.

11) Level of objectives harmony between project parties

This measures level of matching between owner and other project parties goals.

12) *Specific site characteristics*

This measures the level of specific site characteristics in terms of location, weather, underground, environmental conditions

13) Specific project characteristics

This measures the level of specific project characteristics in terms of time, cost and quality

14) Project contract and procurement strategy

This measures the level of familiarity of the contract used and of the project procurement techniques

The list of root delay causes extracted using cause-effect technique is verified by an interview questionnaire with construction industry personnel; questionnaire design and result are found in Chapter 5.

There is a need to find measures to assess each one of these root delay causes. These measures are called root delay causes' indicators which are found in the proposed DHPM in level A3 as shown in Figure 3-3. After defining the root delay causes, the following section will define the root delay causes' indicators. This part of the research will use the previous research regarding key performance indicators, project parties prequalification to obtain the root delay causes' indicators.

4-4 Root Delay Cause' Indicators

Root delay causes' indicators are the indicators that will be used to assess or measure each of the root delay causes. Each of the root delay causes can have many indicators. These indicators are collected from previous research work regarding key performance indicators (KPI), prequalification for contractor and consultant selection and from project success factors research. The related indicators for each root delay causes will be obtained in two steps; (i) general discussion related to the particular root delay cause then (ii) identify the root delay causes' indicators. The fourteen root delay causes that are listed before in section 4-3-9 will be analysed to obtain their root delay causes' indicators. For example to measure the level of designer management deficiency as one of the root delay causes, the scale of designer management efficiency should be defined first. An analysis is carried out to obtain the indicators that can be used to measure the designer management efficiency.

4-4-1 Designer's management efficiency indicators

Designer management deficiencies as a root delay cause will appeare due to low level of designer's management efficiency. Designer is defined as the part that provides the design work for the project, offering technical advice when required and provides the technical supervision services; sometimes they are referred to as a consultant. Latham (1994) suggested that owners should select consultants to undertake creative professional services based on quality and cost. The term 'design' has a wide definition under the regulations; it includes drawings, details and specifications (Baxendal and Jones, 2000). In the traditional design-bid-build procurement approach, the owner usually selects and employs the architects and assigns them to design the building or facility (Yean, 2003).

To get the designer's management efficiency indicators, the previous research work for designer selection will be searched.

Ling et al (1997) identified that there are four main factors that contractors should consider when selecting a consultant in a design-build contract; task performance, contextual performance, fees and relationship factor. Task performance is the proficiency and skill in job-specific tasks (Van Scotter and Motowidlo, 1996). In the construction industry task performance means that the designer possesses the proficiency and skill in design tasks. Contextual performance arises because people usually work in organisations and therefore need to communicate and coordinate with each others (Borman and motowidlo 1993). The contextual performance states that 'controllability', 'initiative', 'commitment', and 'social skills' are used to evaluate contextual performance. (Ling et al 2000).

Torbett et al (2001) stated that the most common indictors used to measure design performance are:

- *Design review and quality indicators*
- *Time based indictors*
- *Owner feed back*
- *Out-sourced design percentage*

The out-sourcing percentage should be less than 10% of the total design work.

Chung et al (2002) gathered the criteria that are used by many of organizations to evaluate consultant to be selected. They summarized them into four groups:

- Background of construction firm
- Past experience
- Capacity to accomplish the work
- Project approach

Long et al (2004) stated that the problems associated from consultant are:

- Inadequate experience
- Lack of standardization in design
- Lack of responsibility
- Impractical design
- Inadequate project management assistance
- Slow response lack of involvement through project life

There is another indicator that has a major influence in design work quality and that is the capability of the design work leader. The design work in traditional procurement is carried out by a group of specialists including architects, structural engineers, quantity surveyors, service engineers and other technical experts. This design groups is managed by a design team leader. The competence of the design work team leader is very important to ensure efficiency of the design work. A competent team leader will improve the communication and mutual understanding when accomplishing the design tasks. The leadership style of the team leader will affect the satisfaction of the design team members (Maxey et al, 2003)

To choose the indicators of designer management efficiency, the financial indicators were excluded from list of indicators since finance is used only for selection and in general they are not indicators of the designer management efficiency. Owner feedback is reflected by general designer reputation. The indicators that can be used to evaluate designer management efficiency are:

- *Designer experience in current work: to measure its familiarities and knowledge background regarding the proposed project*
- *Quality of design revision policy: to measure its ability to management the product when it is in process and to eliminate the most problems of matching, mistakes, omissions, ..etc*
- *Task performance: to measure the technical and proficiency capabilities of the staff.*
- *Percentage of outsourcing work: to measure the control effort during product process*
- *Quality of design group leadership:*
- *Designer general reputation*

Many of these indicators and the later indicators for the root delay causes are of the subjective type. A linguistic term is used to represent each one of these indicators.

4-4-2 Quality of design work documents indicators

Design work documents includes the construction drawings, specifications, tender documents and other specialties reports.

CIIA report (1995) defined the design work evaluation criteria as:

- Accuracy of the design documents
- Usability of the design documents
- Cost of the design efforts
- Constructability of the design
- Economy of the design
- Performance against schedule
- Ease of start-Up

So, the indicators that can be used to evaluate level of design documents after excluding the financial related indicators are:

- *Accuracy level of design documents*
- *Usability of the design documents*
- *Design constructability*

4-4-3 Contractor's management deficiency indicators

Extensive research work has been carried out to evaluate the contractor's management capability prior the project award in order to make sure that the contractor has sufficient management and technical capabilities to carry out work as per owner objectives and design documents.

In the study of Fong and Choli (2000) to rank the owner criteria for contractor selection, the criteria were ranked as: contractor financial stability then contractor past performance. Herbert and Biggart,(1993) stated that contractor management capabilities can be evaluated using criteria related to the project management structure, human resources and quality management. Ng (1992) stated four criteria for contractor management evaluation: management and organization of contractor work, resource management, coordination-control- response and documentation quality.

Hatush and Skitmore (1997) divided the contractor's capabilities into technical and management abilities. Technical ability means that the contractor has sufficient technical knowledge to use technical methods to finish the project. Management ability means that the contractor has sufficient managerial tasks to manage through planning, orientation and communication with other project players. They stated that the contractor's technical ability can be assessed by its experience, plant and equipment possession and by the contractor's personnel. Contractor's management abilities can be measured by past quality performance, the experience of technical personnel and by management knowledge. Kumaraswamy (1996) used past experience, technology and personnel as the main groups for assessing contractor personnel management abilities.

Each one of these groups was divided into subgroups; experience being measured in terms of general works and specialist work in similar work categories and region. Personnel are measured by managerial, supervisory and operational in experience, qualification and experience. Technology is measured by plant and equipment possession, process of reporting, recording and retrieval, organization structures and style and human skills and experience. Lam et al (2000) added the response to brief, approach to cost effectiveness and methodology to work program to the selection criteria of contractor.

Mahdi et al (2002) stated that experience in similar projects and similar geographical area and past experience records in scheduling finishes, safety and relationship with others as being the most important criteria to evaluate contractor management capabilities.

Lam et al (2001) added contractor general reputation, the past records of relationships with others and past records for safety as the criteria to evaluate contractor management capabilities.

Similar criteria to assess contractor management and technical abilities were used by Sonmez et al (2001) and Fong and Choli, (2000).

Analysing of the past research outputs suggests the indicators that can be used to evaluate the contractor's management and technical capabilities are:

- *Experience in general :(Measured by the years of work, value of work done)*
- *Contractor possess the required experience in similar type of projects (measured by no of jobs in similar projects)*
- *Contractor's past records in finishing project ahead or in schedule- to measure its ability to planning and control work program.*
- *Plant and equipment possession and maintenance strategy*
- *Level of contractor staff experience and management capabilities*
- *Contractor's document control strategy*
- *Project team organization structure*
- *Head office organization structure*

- *History of past records of relationship with other project parties.*
- *Level of contractor staff overloading*

4-4-4 Contractor's financial stability indicators

The contractor's financial problems are measured by the level of the contractor's financial stability. This root delay cause measures the ability of contractor(s) to fund the project and not to stop or slow down the project progress due to the contractor's financial problems. The contractor is responsible for finance the work whenever required.

Research work regarding contractor pre-qualification addresses the contractor financial stability and soundness are the most important criteria used to contractor selection (Hatush and Skitmore, 1997; Fong and Choli, 2000).

Russel (1990) used the following financial ration to evaluate contractor financial soundness and stability as a criteria for contractor selection in the pre-qualification process:

- current assets
- fixed assets
- current liabilities
- long-term liabilities
- stockholder's equity

These criteria can be evaluated from the contractor's financial statements. The quality of the financial statement and type of accounting method used to describe revenues earned can also identify the contractor's financial stability (Smith, 1991).

Hatush and Skitmore (1997) used four criteria for evaluating the contractor 's financial soundness; financial stability, credit rating, bank arrangement and financial status. These criteria are similar to those Russel (1990) used and can be derived from financial statement analysis.

Kumaraswamy (1996) categorised the contractor's financial ability into two measures: the contractor's financial stability and its general financial capacity. The contractor's financial stability measures the ability of the contractor not to go into bankruptcy or get into major financial problems. The contractor's financial stability is measured by net worth, gearing and assets and a liabilities profile. These criteria are similar to used by Russel (1990) and Hatush and Skitmore (1997).

Mahdi (2002) in his work to rank contractor selection used the following indicators to evaluate the contractor financial stability:

- contractor's credit level or payment record to its creditors such as suppliers and subcontractors
- Number of projects in hand
- quality of banking arrangement
- adequacy of banking statements
- liquidity ratio
- operations ratio
- leverage ratio

Analysis of this previous research work derives the following criteria that can be used to evaluate the contractor financial stability:

- *Number of projects in hand*
- *Value of work in hand*
- *Working capital*
- *Quality of bank arrangement*
- *Liquidity ratio*

4-4-5 Owner management efficiency indicators

The owner's management deficiency is measured by owner's management efficiency. A study of the research into owner's performance in the construction industry concluded that owner performance influences successful project execution which in turn affects the performance of all participants (Kometa, et al 1996).

The construction owner may be an individual or an organisation who commissions a building project (Bryant et al 1969). Naoum and Mustapha (1994) grouped owners into three categories namely, on-going, on-off and one-off owners. Morledge et al (1987) considered owners as primary or secondary developers. Chinyio et al (1998) classified owners into:

- Government
- Housing authority
- Other public sector owners
- Large developers
- Large industrial, commercial and retailing organizations
- Medium and small industrial, commercial and retailing organizations
- Other private sector owners

The way the owner intends to manage the project will not only affect the project execution but also the performance of the all other project parties. Quality of owner management is influenced by (Kometa et al, 1996) :

- Project management experience of owner
- Qualifications of owner personnel
- Project auditing and quality assurance practices of owner organization.

Walker (1998) investigated the client representative's (CR) effectiveness and its effect on project success. The client representative (CR) is a person or an agency hired by the owner to manage the construction project on the owner's behalf (Walker, 1995).

The highly effective indicators that affect the CR performance were:

- Owner's willingness to accept effective and positive ideas
- Level of CR team internal communication effectiveness
- Owner's time minimisation objective
- Owner's ability to mould shared project goals and aspirations
- Overall owner contribution to project team harmony

From the above presentation, the following indicators will be used to evaluate owner management efficiency.

- *Owner management experience in similar projects*
- *Project organization structure from owner party*
- *Owner's willingness to accept effective and positive ideas*
- *Level of owner team internal communication effectiveness*
- *Owner support to finish project as scheduled*

4-4-6 Owner financial stability indicators

The owner's financial problems are measured by the level of owner's financial stability. There is little previous research that has been done to evaluate the owner's financial stability. In a study to evaluate owner involvement in project performance from consultant firm to evaluate the financial stability of owners stated that this can easily be done through credit rating or through a company's annual report of owner which contains the profitability and sources of finance (Kometa, et al 1996).

The risk of late payments, which are very common in the industry, has driven many construction firms to the edge of bankruptcy. Late payments from owner leads to cash flow problems to contractors or consultants. The type owner, public, private or one-off firm will impact the risk level that the contractor can be exposed to in terms of late payments during construction stage. In general the owner market reputation especially if the owner is from private type, will be very carefully studied from both contractor and designer side.

The indicators that can be used to evaluate owner financial stability are:

- *Type of owner, public, private, one-off firm*
- *Credit rating*
- *Number of financial sources*
- *Market reputation*

4-4-7 Efficiency level of communication between project parts indicators

Poor communication has been a problem in the construction industry. Part of the trouble comes from the way the industry is organised, the project team is made up of people from many different firms and their contributions vary and a lot of information has to pass among them. This requires a well-organised network of communication. Even when this network exists, communication still breaks down because people fail to keep their messages simple, they pass too much information or too little, or the information they give is inaccurate or misleading (Ernst, 1990).

Communication can be defined as the means of conducting and sharing information. Sender thoughts are converted into message, encoded and transmitted to the required person who receives the message, decodes and ideally understands to take action by using the piece of information, then feedback or store this information as shown in Figure (4-10).

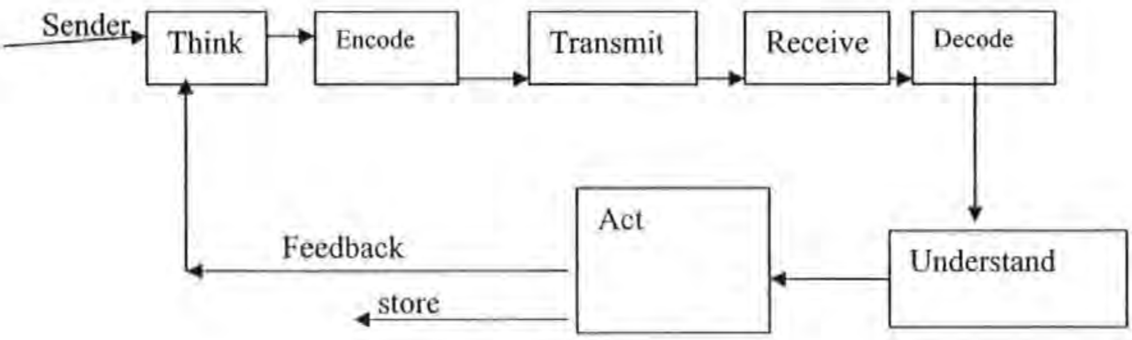


Figure (4-10) Communication Process-Source, (Fryer, 1989).

Communication in the construction industry comes in four main forms: formal, informal, verbal and non-verbal. Communication may be spoken or written. Spoken communication is direct, face to face conversation and telephones. Meetings and site instructions are examples for this method of communication. Written communications range from a note to a technical report. These documents should be planned and managed. A good report should be clear, accurate, concise and timely. Another categorisation for communication is either one or two way communication. Examples of one way communication include bar charts, network diagrams, activity listing, status reports and time documents. Two way communication examples include project team planning sessions, project team status, updating meetings, and post-project implementation review meetings (Frayer, 1989).

The Project Management Institute (PMI) publication Project Management Body of Knowledge (PMBOK 1994) lists communication as one of the eight subjects to master for the certificate as a Project Management Professional (PMP). The success or failure of any program can depend, to a large degree, upon how well information is managed. One of the most challenging aspects of project management communications is making sure every one involved in a project has ready access to the latest information (Belles, 1994).

Communication problems can arise due different languages that are used in construction project due to the different nationalities of working personnel. The result of increasing immigration and many nationalities working in the construction sector in many places creates a problem of language communication and mismanagement due to changes of language and cultural aspects (Loosemore and Lee, 2002)

Tommelien et al (1999) listed the communication success barriers as:

- Lack of trust between project parties
- Overloading: too much information in the message or the message participant is very busy to understand all the message it receives.
- Distance: number of people from the sender to the receiver
- Lack of clarity
- Poor expression-problem on message encoding: poor vocabulary, language changing, words and unclear message
- Poor choice of methods: the method of communication should suit the purpose of message

From the above discussion of the communications indicators and success factors, these criteria may be used to measure communication efficiency between project parties:

- *Clearness of communication methods, documentation for all project parties*
- *Communication channels number*
- *Regular communication are timely relevant*

- *Extensive communication paper work*
- *Time to get information*
- *Number of meetings per week during construction phase*
- *Language, and wording*

4-4-8 Level of interactions between project parties in pre-construction phase indicators

The Latham (1994) report focused on the fragmented nature of the construction industry in the UK as a major contributor to the poor communication between all parties working on a construction project.
The construction project is composed of many organisations all of them have their main objectives. The owner's main objectives from any project are to finish the project at the predefined date and in its budget with an acceptable level of quality. The contractor's main objectives related to the benefits and profits it can gain from the owner. This diversity of goals and conflict or interest can lead to an adversarial posture with each other. This essentially is a "no win" situation since one party's gain is another party's loss (Larson and Dexlen, 1997). Owners, designers and contractors and suppliers have their own objectives and measuring techniques for project success.

The problems that can be occurred following little interaction between designer and owner during design phase are:

- there is little guidance and support from the owner
- designers have difficulties in understanding owner needs and conveying these needs into design products

The nature of construction environment needs good and extensive effort to coordinate between all project parties. This coordination should be efficient and start a long time before project start. Communication enhancement and information transferring have good impact on improve the work environment from conceptual stage to design stage (Austin and Mccaffrey, 2002).

Pocock et al (1997) stated that construction project performance is enhanced due to the increase of degree of interaction score. The Degree of Interaction (DOI) is the extent of interaction among designers, builders, and project team members during a project planning, conceptual design, detailed design, procurement, construction and start up phase.

Interaction between designer and contractor in the early stages of a project has a significant impact on project cost and project schedule performance.

From the above presentation these indicators can be used to evaluate the level of interaction between project parties:

- *Amount of sharing information between all project parties*
- *Number of meetings before project start*
- *Level of participation of project parties in pre-construction phase*
- *Percentage of pre-construction time to construction phase*
- *Relationship and integration during design work*

4-4-9 Level of Trust between project parties indicators

The philosophy of sharing goals and objectives between project parties is now dominant. Phenomena of "win to win" and partnering project delivery systems are strongly recommended. Many of applications in construction projects revealed the importance of using new management styles to improve the project efficiency (Brown and Riley, 1998). One of the requirements for these applications is how to build the trust between the project parties. The presence or absence of trust within project teams has been highlighted in both the Latham (1994) and Egan (1998) Reports as a major factor leading to the success or failure of construction projects. The National Audit Office highlighted the importance of trust between project parties in their report "AUDITOR -Modernising Construction" (2001).
The industry has a reputation for being adversarial and disfavoured the trust environment. This was in sharp contrast to the traditional construction industry where conflict and adversity are the norm (Brown et al, 1999). Poor relationships between the owner, main contractor and sub-contractors leads to problems that

affect time, cost and quality, as well as damaging long-term relationships between the parties involved.

The personnel who are working in different temporary organizations and working on different projects are often employed on a temporary basis, as a result they can lack the motivation to participate in long-term relationships. They are oriented toward completing their tasks quickly and efficiency in order to move to the next project (Riley, et al 2000).

Trust is about reducing risk and uncertainty through better communications. When individuals work in trusting teams they have the ability to be flexible and respond to changes of information.

Trust can be defined as a decision to become vulnerable to or dependent on another in return for the possibility of shared positive outcomes. Trust has been described as a unique tool for developing competitive advantage for organizations. It is a goal that can only be achieved through the capabilities that are embedded in the skill and knowledge of its members. Trust is therefore seen as a vital component of any business relationship.

Shaw (1997) identified trust as an organizational factor that can, and must be consciously integrated into companies, has placed emphasis on these three mutually dependent antecedents:

- Achieving results
- Achieving integrity
- Demonstrating concern

Trust forms part of relationships people build it by working together on projects. If these relationships are successful i.e. trusting, then it is seen as being valuable and it is important to preserve and develop them. Due to the project nature of construction, where people form temporary project-based teams, this is not always possible.

It is considered that if inter-organisational relationships were to emphasize using consistent positive behavior strategies which were monitored and openly communicated both vertically and horizontally throughout the organisations, then this would be the start of building solid foundations for the development and maintenance of trust in any relationship.

The trust model adapted by Shaw (1997) gathered these factors to achieve and scale of the trust:

- Competence
- Honesty
- Fairness
- Helpful
- Commitment
- Responsibility
- Reliability dependability
- Benevolence

In their report, Swan et al (2002) concentrated on the following fields to enhance trust in construction industry:

- Honest communications
- Reliance
- Outcomes
- Building trust

From the above discussion of the need for trust in construction projects, these indicators can be used to assess the level of trust between project parties:

- *Level of competence, fairness, helpful and honesty between project parties*
- *Speed of response*
- *Trust level from past interrelation work*

4-4-10 Level of project complexity and required technology indicators

Construction projects become more complex and need advanced technological methods. Traditional project management methods are showing that new methods of analysis and management are needed to maintain project objectives. Project complexity may be generated from the project location characteristics, level of technology, construction method and project organization environment.

Complexity is one such critical project dimensions especially for certain types of projects. (Bennett, 1991)

Jones (1993) explains how an increase in project complexity leads to an increase in internal conflict within the project, so management methods and style must adapt to deal with such conflict.

Complex projects need exceptional management effort more than that used in ordinary projects (Morris and Hough, 1987). That is because:

- Level of project complexity determines planning and control techniques.
- Level of complexity is an important criteria in the selection of an appropriate project organization form
- Level of project complexity influences the selection of suitable procurement arrangement.

Project complexity is defined by Baccacrini, (1996) as "consisting of many interrelated parts" which perform the required operation in terms of differentiation and interdependency. Differentiation means the number of varied elements e.g. tasks, specialists, components or subsystems. Interdependency is the degree of interrelatedness between these elements. Complex project needs complex organization or complex technology. A complex organizational structure is one containing differentiated parts so that the greater the differentiation the more complex the organization (Hall, 1979). Organization complexity is measured vertically as the number of levels in the organization and/or horizontally as the required number of specialists and professionals. Inter-dependences and interaction between the project organizational elements is another attribute of organizational complexity in projects.

Williams (1999) added a new dimension to complex projects in addition to that put by Baccarini, 1996. He stated that the structure complexity used by Baccarini, (1996), which can be measured by the number of project elements and the level of elements interdependency, are not the only indicators of project complexity evaluation. He stated that the uncertainty in goal definition and uncertainty of intended construction methods are also measures project complexity. If construction methods are uncertain, the fundamental project management will not be known. Uncertainty in construction methods may contain the newness of the technology; technological uncertainty (Turner and Cochran, 1993).

Gidado, (1996), in his study to determine the effect of project complexity in total project time, discussed the definitions of complex and complexity in production process, then stated that " project complexity" is defined as the measure of the difficulty of implementation a planned production in relation to any one or a number of quantifiable managerial objectives". Gidado, (1996) added that the complex project has some of the following characteristics:

- It has a large number of different systems and large number of interfaces between elements.
- Involves construction work on a confined site with access difficulty.
- Difficulty in specifying clearly how to achieve the desired goal or how long it would take.
- Requires a lot of details about how it should be executed.

The required technology is another measures for project complexity. The level of technology required to execute construction tasks are one of the major dimensions of project complexity. Technology is defined as the transformation process to convert inputs to output (Kast and Rosenweig, 1979). The transformation process involves the utilisation of material means, techniques, knowledge and skills. Technology can be divided into three faces: operations (equipping and sequencing of activities); characteristics of materials and characteristics of knowledge.

Technology complexity of a task can be referred to:

- Number and diversity of inputs and outputs.
- Number of separate tasks or operations to finish the project
- Number of specialist involved in the project.

From the above discussion of the project complexity measures, project complexity and required technology may be measured by the following indicators:

- *Differentiation: Number of organizations working in the construction project*

- *Number of project sub-systems and interfaces between project elements*
- *Level of familiarity for construction method*
- *Required number of specialists and experts*
- *Type and numbers of special equipment required*
- *Level of rigidity of activities sequencing.*
- *Size of project*

4-4-11 Level of objectives harmony between project parties indicators

The key owner's goals for any project are finishing the project on or before schedule, on or less than budget and on an acceptable quality level. While the main contractor's goal of any project is to gain the maximum profit it can achieve. A conflict of interest may occur during the construction project life and hence lead to delay parts or the whole project. The conflict of interest between project players is very common.

Owners vary in their willingness to employ only those contractors who are able to meet target times. Some contracts include a bonus clause to encourage the contractor to speed up the construction process and to avoid any delays.

Quality in construction is defined as 'the totality of features required by a product or service to satisfy the given needs', and is usually prescribed in project specification documents. Quality is regarded as a main criterion in contractor selection (Latham, 1994).

The CIIA (1995) report clearly identified goal orientation as an important factor contributing to project success. Morris and Hough (1987) also provided many examples of project success and failure with reference to the owner ensuring that the project team was aware of the owner priorities of various objectives. They recommended that alignment meetings should be arranged to ensure that the owner/user needs and priorities of objectives are understood by the project team. Owners obviously have goals, but they should ensure that these are specified clearly and prioritized so that the project team can align their priorities as closely as possible to these ends. This is a pivotal function of owner or its representatives to ensure that owner's needs are clear in the minds of the project team and that goal alignment is 'customer focused'

Because of the dynamic nature of construction project and it is always being exposed to unforeseen conditions and changes, these can be an increase of construction costs and owner dissatisfaction of the project progress. These risk factors should be considered and clarified to project players before the project starts. Owners are advised to ensure that all bidders understand the risks allocated to them, and that they have made appropriate provision in their bids. It may be better to select a contractor who best understands the risks involved and will accept responsibility when a loss occurs.

Another dimension is uncertainty in the goals. The essential difficulty with such projects is that the requirements are not frozen, and uncertainty or changes in some requirements will mean that interfacing elements also need to change and then rework, feedback loops and increase project complexity. Many of these project faced delays and disruption (Williams, 1999).

From the above discussion for the importance and the measures for objective harmony between project parties, the indicators that can be used to evaluate level of objective harmony between project parties are:

- *Matching level between owner objectives and other parties objectives*
- *Clearness level of owner objectives in pre-construction phase*
- *Uncertainty of goal definition, goals are not frozen*

4-4-12 Specific site characteristics indicators

Specific site characteristics are the site conditions that are related to site location that may affect the project progress and project completion time. It measures the level of specific site characteristics in terms of location, weather, underground, environmental conditions.

Many studies have analysed the effect of site risk elements and its effect on time performance and delay occurrence. Bing et al (2005) stated that from the risk factors that should be taken into consideration in public and private partnering projects are the factors related to site accessibility. Baloi and Price (2003) put the site accessibility, geological conditions, weather conditions and unexpected site conditions as some of the risk construction related factors. Wang et al (2004) stated that one of the country's level of risk factors is delay or refusal of project approval and permits by local government. Another risk factor related to project level is the site safety from hazardous effects and accidents initiators. De Lemos et al (2004) studied the delay of permits from governmental party as one of the risk factors of bridge project. Ghosh and Jintanapakanont (2004) used the physical conditions of geological subsurface and ground water as one of the risk elements of rail project in Thailand.

From the above discussion, the indicators that can be used to assess the specific site conditions are:

- *Level of site accessibility*, which measures the level of easiness to access to the project site
- *Level of site hazards*: this measures the level of site hazards due to contaminated soil and environmental harm. For example, the oil and petrochemical project have a hazardous effect.
- *Transportation problems*: this measures the availability and efficiency of the means to transport resources to be available in time in the project site.
- *Permits and licenses for equipment and labour*: this measures the level of ease of getting licenses to permit equipment and labour to get in the site. Many places require licenses and special permits to enter the site.
- *Level of site congestion*: this measures the level of crowding of works in the project site.
- *Level of risks anticipated due to underground conditions*: It measures the level of anticipated risks that can be predicted from past history of the site's geographical region. This level contains uncertainty of underground soil conditions, water table and other geotechnical problems.
- *Weather and climatic effects*: It measures the level of effect of the weather and climatic changes in the project delay. Sites of high humidity, low temperature, high temperature are more risky than others.
- *Level of approvals from authorities*: the authorities approval is required for entering public services and to control the overall project site. The level of ease

and cooperation of the public authority affects the project performance and may affect delays.

- *Social effects*: It measures the effect of level of social issues in project performance

4-4-13 Specific project characteristics indicators

Specific project characteristics are the characteristics related to the particular project time, budget and required quality.

These indicators are:

- *Percentage of long lead time material items*: It measures the probability of delay because of the increased number of long lead time material items. The long lead time material items includes the materials are coming from overseas. This will be affected by type of customer, method of transportation, place of fabrication and environment. Long lead time material items need more effort in planning and material management. Local materials are usually easier to obtain.
- *Design time to project time*: it measures the efficiency of project design effort
- *Project profit margin*: it measures the motivation of the contractor and other parties to finish the project in time.
- *Project requiring new technology*
- *Contract time pressure:* it measures the criticality level of the project. If the project has time pressure, it will demand all project parties to finish the project as soon as possible. Any shortage of resources or any problem that arise in project execution, will surely affect the project's completion time.

4-4-14 Project contract and procurement strategy indicators

The used indicators are

- *Project parties' familiarity with contract type and procurement strategy*: it measures the level of familiarity of project parties to the contract type and contract procurement strategy.
- *Level of contract clauses clarity and completeness*: this clarity and completeness level will affect the problems of contract understanding, claims,

request for information and other contractual issues that affect the project's time performance.

- *Clauses regarding time performance- penalty in delay and reward in early finish*

4-5 Summary:

In this chapter the root delay causes were extracted from the direct delays by using the cause-effect technique. The root delay causes are the main generator for the delay as proposed in the DHPM. Fourteen root delay causes were derived. The indicators that are required to measure the root delay causes are obtained. These root delay causes' indicators are gathered from the past work of key performance indicators (KPI), project parties prequalification, risk analysis and other research work. Many of these indicators are subjective or non numeric measures. Model A: RSP model ideas included the root delay causes and the effects of root delay causes to resource shortage will be verified by an interview questionnaire with selective number of construction industry personnel. Model A: RSP model verification is presented in Chapter 5.

Chapter 5

Verification of Model A: RSP Model Principles

5-1 Introduction

This chapter objective is to verify the principles of the first part of the Delay Hierarchical Propagation Model (DHPM), the resource shortage possibility (RSP) model. The root delay causes, root delay causes' indicators and the effects of root delay causes in resource shortage as the three levels in the hierarchy model shown in Figure 3-3. The root delay causes were obtained by the cause-effect technique in section 4-3 and the root delay causes' indicators are collected in section 4-4.

An interview questionnaire was used to discuss the model basis with construction industry personnel. Thirty interviews were held with a sample of selective number of participants. This chapter presents the construction questionnaire design, components and application. This questionnaire's objective was to get information from the industry personnel regarding their judgement about the root delay causes and their indicators. The questionnaire questions are of closed type of questions. A statistical analysis was carried out based on descriptive statistical analysis, checks of data normality and factor analysis. The Delphi method of second round of questionnaire was conducted to enhance the initial data collected interviews. The Delphi application and results are presented in section 5-11 and 5-12.

5-2 Interview Questionnaire

In this section the background of the interview questionnaire and questionnaire design are defined and then from these the used construction delay questionnaire is designed.

5-2-1 Questionnaire Definition:

A questionnaire is a tool for collecting information to describe and compare knowledge and attitude (Cook, 1981).

5-2-2 Questionnaire method

From the literature in business and marketing research, there are three main methods of questionnaires (Frazer and Lawley, 2001):

i) *Mail-posted questionnaire.* A commonly used method for gathering data using questionnaires. Advantages of mail-posted questionnaire are that large populations can be surveyed at a cheap cost and it is possible for the respondent to fill in the questionnaire at a convenient time. There are two disadvantages of this method (i) most of mailed questionnaires return rates do not exceed 50%, normally from 10-30% and (ii) the non-respondent population is not taken into account in the analysis (Blair et al, 1980).

ii) *Face-to-face interview questionnaire.* More accurate than the posted-mail questionnaire. The interviewer can be more flexible and extract more information from respondent than postal method, but it is more costly. Face-to-face interview is the most prevalent one in use in western countries. (Hanneke, 2000)

iii) *Telephone questionnaire.*

5-2-3 Type of Interview Questionnaires

There are three different types of interview situations which require three different types of questionnaire. (Bellenger and Greenberg, 1976) They are structured, semi-structured and non-structured.

i) *Structured.* In structured interviews, the questionnaires set out precisely the wording of the questions and the order in which they are asked. Most of the questions have predefined answers and there is little latitude for a respondent to stray beyond them. Structured interview questionnaires are the foundation of large quantitative surveys. In a structured interview, interviewers follow a predetermined sequence of questions. Structure in the interview format ensures consistency across candidates to facilitate reliable and fair judgments

ii) *Semi-structured.* This type of interview uses questionnaires with a matrix of questions with predefined answers as well as those where the respondent is free to say whatever it likes. The semi-structured questionnaire is more flexible than the structured one.

iii) *Non-structured.* In this type of informal interview, the researcher uses checklist of questions rather than formal questionnaires on which answers are written down. This type of interview enables many types of questions techniques and probes in more discussion. This type of interview is often recorded on tape.

5-2-4 Format of Questionnaire Questions

In general there are two types of questions that are used in most of questionnaires. They are; open and closed questions. The closed question restricts the answer to a small set of response to produce precise answers. The open-ended question has merit of not imposing restrictions. Closed question type it is easer to answer and code (Hague, 1993).

5-3 Construction Project Delay Interview Questionnaire

The construction project delay interview questionnaire used is presented in terms of design and components.

5-3-1 Interview questionnaire design

From the above interview questionnaire background information, the interview questionnaire will be designed by:

i) *Questionnaire method:*

From the three questionnaire methods presented in section5-2-2, the interview questionnaire type is chosen in the construction delay questionnaire because:

a) The questionnaire is about 18 pages long and it is recommended that the length of mailed questionnaire should not be more than 12 pages, including the cover page (Honey and Alan, 2000).

b) To enhance the level of accuracy of data gathering. Some of the questionnaire parts are not easy to understand by industry personnel so using the face-to-face interview questionnaire will clarify any of these uncommon parts.

c) The face-to-face interview gives the researcher more control during the questionnaire session.

ii) *Type of interview questionnaire*

The construction project delay questionnaire used the semi-structured interview to collect data from industry personnel. Most of questions have predefined answers and the respondents were asked to pick the answer that most reflected the respondents views.

iii) *Format of questionnaire questions*

All the questions used in the construction project questionnaire are closed questions. Each question has a determined or limited range of answers.

iv) Questionnaire question-order

To avoid the effect of 'response options and response order' which occurs when the question is read to the respondent followed by the options is read for it, the respondent is almost always affected by the last choice it listen (Kronsnick and Alwin, 1987), a questionnaire copy was given to the participant and a copy with the author. The participant is then free to select and pick the answer from the listed answer.

The interview used the norm-sequence interview (Van der Zouwen and Dijkstra 1995). In this form of interview, the interviewer asks a question, and sometimes presents the answer categories, by reading the questionnaire. The question is answered by the respondent, and the interviewer receives the answer.

5-3-2 Questionnaire components

The questionnaire was in 18 pages long as shown in Appendix B. The questionnaire consists of:

a) *Introduction Page*: The introduction page describes the purpose and components of the questionnaire.

b) *Research Background*: This page presents the research's theoretical basis and the meanings of the words used in the questionnaire. In this part, a brief description of the proposed delay model basis and components was given. Definitions of the main entities of the model such as root delay causes, root delay causes' indicators are also mentioned in this part. The interview is held in site and took about 1.5 hours with the participant. This research background was used to open a discussion with the participant and eliminate any barriers that may be found in these types of interviews.

c) *Part 1: Participant's general information*: In this part, the participant is asked to define them and their work experience background. The participant is asked to answer these five questions:

- *Question 1*: asks for the employer that the participant is working for. The participant may work for a owner, contractor and consultant firms. The participant who works as owner's representative in a construction management company, which works for project control on behalf of a owner, in a owner company such as real state or in public agency working in construction sector will be considered from the owner part. The contractor part contains any participant that works for a main or subcontractor in construction industry. A consultant is working for a consultant or design firm. The consultant provides the professional consulting services in design or supervision.
- *Question 2*: asks the participant to define his level of management. The level of management is one of three; top, middle and site management. The participant, who has the authority to take decision affecting the company performance, will be from the top management level. Top management level has authority in contracting, appointing, orienting, and organizing for more than one project. The participant who belongs to the middle management level that has the authority to manage one construction project. Project managers are sample of this group. The participant belongs to the site management level has the authority to manage and control part or a sector of a project. The civil site engineer is examples of this group. The purpose of this question is to get the differentiation between their judgement regarding questionnaire questions based on the level of management.
- *Question 3*: participant's general experience. In this question, the participant is asked to define his level of experience in how many years of experience in construction industry. The participant may answer in one of the following three ranges:

- From 10-15
- from 15-20
- more than 20 years

- *Question 4*: asks the participant to define the type of work from which he gained his experience. The two areas are either from building or civil engineering projects.
- *Question* 5: asks the participant to define his past experience in different aspects in construction management. Seven construction management fields are presented to the participant to define his past experience;
    - Design Work
    - Site Management
    - Cost Estimation
    - Contract Analysis
    - Site Supervision
    - Quantity Survey
    - Claim Analysis

  The participant can tick more than one field. The purpose of this question is to see if the participant has experience in only one aspect of construction management aspect since it might be biased to defend their sector of any blame. In that case the respondent is excluded from answer analysis.

d) *Part 2: Root Delay Causes Evaluation:* In this part the participant is asked to evaluate the level of effect of root delay causes on project delay occurrence in general.

The participant is asked to evaluate level of effect of each one of the root delay causes to the project delay occurrence. The level of effect will be based on the frequency of root delay causes occurring in the construction project and the severity of this root delay cause in project delay occurrence. The level of effect is varied from very high effect to no effect.

This part of the questionnaire has two main objectives:

i) Rank the root delay causes to get the relative of weight of these root delay causes in project delay occurrence.

ii) Verify the root delay causes extracting technique.

e) Part 3 Evaluation the relationship between root delay causes and main resources shortage

In this part the participant is asked to evaluate the effect of each one of root delay causes on resource shortage. First the definition of each one of the main resources is introduced to the participant. The main resources are construction materials, labour, equipment, information and work space. Material is any required construction material which is required by the construction. Material may be individual, mixed or fabricated material resource required permitting activity to start and finish.

Labour refers to any required technical, skilled and unskilled labour associated to any project activities.

Equipment refers to any piece of equipment required for any project activity.

Information refers to any required design, supervision, coordination, orientation information required to any construction activity. Working drawings, supervision check list, specifications... are examples of the required information in construction projects.

Work Space refers to the required space and environment facilities required to permit the activity from start to finish.

The participant is asked to evaluate the level of effect from very high to very low.

This part is added for two reasons; (i) test the ideas of the relationships between root delay causes and resource shortage influence i.e. the relationship between the A2 level and A1 level members in the proposed DHPM in Figure 3-3; (ii) to evaluate the relative influence of each one of these root delay causes in occurrence of resource shortage occurrence.

f) Part 4: Measuring indicators for root delay causes

Measuring indicators for root delay causes: In this part, the participant is asked to evaluate the root delay causes' indicators as a measure for root delay causes. These indicators, which are collected from previous research in key performance indicators (KPI), contractor and consultant pre-request, project critical success factors, risk analysis and from the author's experience as presented in section 4-4.

Each root indicator is presented to the respondent in the association with its associated delay cause. The respondent is asked first to evaluate if the indicator is one of the root delay indicators. The respondent has two choices; Yes or No. If he answered by Yes, he is asked to evaluate the indicator relative importance as an indicator of the root delay cause. The relative importance of indicator varies from very highly effect to very low effect. A clarification may be added for some of technical terms that the participant may not familiar with.

The purpose of this part is:

(i) Verify the derived indicators and to eliminate the indicator that are not relevant for root delay causes.

(ii) Evaluate the level of importance of each indicator in root delay cause.

5-4 Participants' Sample Description

Before describing the sample that participated in this interview questionnaire, a general background regarding the sampling techniques used in questionnaire survey will be presented.

5-4-1 Sampling Techniques Background

Sampling technique refers to the way in which the desired numbers of respondents or elements are selected from the total population. The samples in general are of two major types: random and non random samples. The most popular technique is to take random samples from a defined population. The determination of the required number of samples is defined by population number, variation in population and the purpose of study. The samples that will be studied should represent the population from which it is taken. These samples are either taken from a probability normal distribution population or non-probability sample.

With a probability sample, each element in the population has a known probability of being selected from the sample. Probability samples are usually preferred over the non-probability approach (Bellenger and Greenberg, 1976).

The probability samples include different types of sampling techniques are:

i) ***Simple Random Sampling:***

In a population of size *N*, every sampling unit has the same chance of being selected. Although simple random sampling is conceptually straightforward, it has two major problems: precision and bias (David and Ronald, 1987). In a simple random sample, there is a small probability that the sample selected could consist of the most extreme members of the population because every possible sampling has an opportunity to be included. The second major problem of simple random sampling is the difficulty of obtaining a complete and accurate sample. A stratified sampling method is an alternative method adopted to reduce the degree to which the results of sampling could be distorted.

ii) ***Stratified Sampling:***

In essence, a sample survey of a stratified population can be thought of as a collection of independent surveys conducted within each stratum or group. The population frame is divided into "strata" or groups. Simple random sample is used to select the sample member within each group. A stratified sample is designed specifically to increase the precision and hence the probable accuracy of sample sizes (David and Ronald, 1987). A strategy that may be used to increase the probability of the sample population and target population being the same and which has certain advantages over either simple random or stratified sampling is the use of cluster sampling.

iii) ***Cluster Sampling***

In this sampling technique, the sample is drawn in two or more stages. At the first stage the total population to be sampled is drawn and divided into several clusters on the basis of some meaningful variable such as work type or geographical area. These clusters are mutually exclusive. Cluster sampling has the disadvantage that responses within one organisation (cluster) is likely to be more dissimilar than those responses in another organisation (cluster) (Harrison, 1989). This may reflect a significant variation between clusters. Although similarity of responses within particular strata is an advantage for stratified sampling, it is a disadvantage for cluster sampling because all clusters are not represented. In consequence, most cluster sample-based estimates of population parameters are likely to be less precise than stratified sample estimates and are frequently less precise than simple random sampling.

The essential difference between cluster sampling and stratified sampling comes down to whether or not all the subgroups are represented in the sample. If at least one element is selected from every subgroup, then the subgroups are treated as strata and methods on stratified sampling apply. If some, but not all, of the subgroups are selected into the sample, then the subgroups are treated as a cluster (Harrison, 1989).

The other type of sampling is the non-random samples which are selected based on specific criteria of the samples selection such as experts in one field. This ,off-course, can not be randomly selected. Non-random samples are commonly used in psychological and management researches. The biggest problem faced by non-random samples is that there is no means to check the level of data significance compared to random sample technique.

5-4-2 Participants Past Criteria

In this study, it is suggested that there should be some of criteria to be available in each expert who will participate in the study. These criteria are:

- The participant should have adequate experience in the construction industry in general. This is evaluated as not less than 10 years of experience in construction industry. Ten years of experience means that the participant has worked for at least three different projects with different work conditions and different projects' types of players. This is mentioned in the questionnaire, part 1 question 3.
- The participant should have good background in all aspects of the construction industry. This is assessed by the minimum of past task experience as two task experience. This will be checked by answer of question 5 in the part 1 of the questionnaire as shown in Appendix B.

As there is criteria that should be confirmed in the expert before participating in this study, the type of sampling used is non-random sampling type.

5-4-3 Interview Questionnaire Sessions

The sample of experts that participated in this study were selected from the Kuwaiti construction industry where the author is living and working in. Fifty eight construction personnel were asked to participate in this study, thirty of them agreed to participate in this study. First, a phone call was conducted with the person presenting the purpose of study. A copy of questionnaire was sent (faxed or emailed) to the participant before conducting the questionnaire interview session. The approved persons are asked to make an appointment to conduct the interview questionnaire session. Thirty interview sessions with industry personnel have been held with the approved participants. A structured questionnaire interview was held between the author and the participant. The interview questionnaire session took about 1.5 hours. The interview was held on the project site. A list of the sample construction personnel contacted is listed in Appendix C.

5-4-4 Participants Description

The sample of the thirty construction personnel who participated in this study is analysed. The analysis will be based on the answers part 1, of the questionnaire as described in section 5-3-2.

Table 5-1 shows the numbers of each employer type as resulted from the answers of question 1. The participants sample is consist of 8 personnel working for owner, 9 working for consultant and 13 participants working for contracting companies. Table 5-2 shows the years of experience for the sample participants as derived from question 2. All the sample participants had more than 10 years of experience and eight of them have more than 20 years of experience in construction industry. Table 5-3 shows the participants' level of management as derived from question 3. All of participants came from middle and top management levels. The answers for question 4, which classified the participants' type of work show that all the 30 participants came from building project types.

Table 5-1: Participants Employer Type

Employer Type	Frequency	percentage
owner	8	27 %
consultant	9	30 %
contractor	13	43 %
Total	30	100%

Table 5- 2: Participants Years of Experience

Years of Experience	Frequency	percentage
10-15 years	5	17 %
15-20 years	17	57 %
bigger than 20 years	8	26 %
Total	30	100 %

Table 5-3: Participants Level of Management

Management Level	Frequency	percentage
Site Management level	0	0.00%
Middle Management Level	18	60.00%
Top Management Level	12	40.00%
Total	30	100.00%

Table 5-4 define the participants' numbers of past construction management tasks as derived from question 5. All the participants had experience in more than one construction management task.

Table 5- 4: Past Experience Tasks in Construction Industry in General

No of past task experience	Frequency	percentage
two tasks	7	23 %
three tasks	7	23 %
more than three tasks	16	54 %
Total	30	100.00%

Based on the criteria mentioned in section 5-4-2, all the thirty participants are qualified to participate in this study.

To start the analysis of the questionnaire part 2, 3 and 4 , a method for data coding is needed.

5-5 Data coding

In order to carry out statistical analysis, the data is coded. There are three main data types to be coded; the respondents, root delay causes and the root delay causes indicators. The respondents were numbered from 1 to 30. The root delay causes are coded in two letters and the indicators are coded in two numeric digits. For example "designer management efficiency" takes a code of (DM) and the root delay causes indicators related to design management efficiency takes coded starting with DM, such as DM.01 for to the designer general experience. The full code system is presented in Appendix D

5-6 Data Statistical Analysis

5-6-1 Types of Data- Background

Data may be represented in scales or not scaled or as subjective type of data. Measurement scales are the most common of data even used in the daily life. Scales are the most important method of measurement. There are four basic types of scales: (1) nominal, (2) ordinal, (3) interval and (4) ratio. The nominal scale is the weakest of the four and the ratio scale is the strongest (Bellenger and Greenberg, 1976).

Nominal Scale: This is the simplest scale of measurement, but it does not represent quantification at all; it simply classifies. In nominal scale information, for example labourers in a construction company are given numbers to serve only for the purpose of identification; they have nothing to do with the relative properties of the workers.

Ordinal Scale: This is a purely ranking scale and is the next higher order scale from nominal. One has to distinguish between elements according to a single criterion. In this scale information such as X is greater than Y or X is less than Y as well as X equals Y or X is not equal to Y are available

Interval Scale: An interval scale, which is the 3rd higher in order of precision, has not only the properties of nominal and ordinal scales, but also adds a known interval between points on the scale. Using an interval scale one not only knows that an item is higher or lower than another, but also how much difference there is between them. A simple example is the Fahrenheit scale of temperature. The difference between 40^{0} and 80^{0} can be quantified but it is incorrect to say that 80^{0} is twice as hot as 40^{0}. The zero point of the Fahrenheit scale is defined as a reference point. The scale is a continuum with no absolute zero as a benchmark (Bellenger & Greenberg, 1976).

Ratio Scale: The strongest basic scale provides an absolute zero and a constant unit of measurement. On a ratio scale, the points are ordered and spaced at equidistant intervals. Measurements of length, weight, volume, speed and height are examples of ratio scales. For example, if the production output of equipment A is 100 m^3 and equipment B is 200 m^3, then B is greater than A (ordinal), B is 100 m^3 more than A (interval), and B is twice the volume of A (ratio). A large variety of specific scaling techniques have been conceived and applied during the last three decades which may be used for both quantitative and qualitative criteria and included (1) semantic deferential, (2) Likert and, (David and Ronald, 1987).

The semantic deferential: In the semantic deferential scale, the respondents are asked to express their feeling about whatever is being assessed by recording their responses on a scale of adjectives (such as hot-cold), which are paired polar opposites. The selection of a semantic deferential scale may introduce problems in terms of which adjective should be used. Any particular pair of adjectives may not be precisely polar opposites in some person's minds, and there will a range of several alternative adjectives from which to choose (David and Ronald, 1987).

Likert Scale: In the Likert scale, the matter of choosing opposite adjectives is avoided. Rather, it makes a statement or poses one description (or adjective) for whatever is being evaluated (David and Ronald, 1987). The Likert scale is a technique for measuring attitudes, beliefs, perceptions, and to a great extent, knowledge and consensus (Kaluzny and Veney, 1991). Respondent are asked to check one category from among several categories of answers that best represents their feeling about or beliefs in a statement. In general each statement has five response categories, which may be labelled as strongly disagree, disagree, undecided, agree, and strongly agree. This can be reduced to three categories, for example simply disagree; undecided and agree, or seven categories providing a finer differentiation along the continuum from strongly disagree to strongly agree. One apparent advantage of the Likert scale is that the respondent needs to consider only one adjective (description) for each item, and the problem of finding an exactly opposite adjective is not required (David and Ronald, 1987). The Likert scale has the advantage over many other attitude or perception measurement techniques of being fairly simple, straightforward, and for the most part, easy for people to answer (Kaluzny and Veney, 1991). The judgment of samplings that use Likert scale is based on the mean values and the standard deviation. Analysis of the results that come from averaging of Likert scales are criticised as the values that came from averaging Likert scale are not meaningful as the mean value will be a fraction while the Likert scale points are not fraction. The statistical that are more efficient to be used to judge the analysis of Likert scale is using mode or median more than the average values. Most of researches work that was conducted in psychological and management studies used the average values to judge the results of a questionnaire. Many the research works that used to determine and rank the causes of delays in construction industry used sort of mean values of Likert scale. These studies used certain types of Likert scale mean values to rank delay causes; Sullivan and Harries (1986), Assaf et al (1995), Dlakwa and Culpin (1995), Kumaraswamy and Chan (1998), Ogunlana et al (1996), Al-Khalil and Al-Ghafly (1999) and Frimpong et al (2003). There are many studies in another aspects used the mean values to jude a questionnaire results. Bushait et al (1999) used a questionnaire of 70 statements asking for quality practices in the design organizations. The respondents were asked to choose the relevant answer for each one of these statements from five ranks "always, mostly, sometimes, rarely and never". The answers were quantified by Likert scale by giving 100% for always, 75% for mostly, 50% for sometimes, 25% for rarely and 0% for never. The average prevalence of quality practice statement was determined by the following equations which is the averaging of the used Likert scale:

$$\text{Average preference} = \frac{\sum_{i=1}^{5} ai * xi}{\sum xi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5\text{-}1)$$

Based on these averages the statements were ranked.

Kaming et al (1997) used questionnaire to identify variables that can influence projects to be overrun. The respondents are asked to identify each one of the variables from four points scale form very important and to not important. The authors analysed respondents' answers of this Likert scale by converting respondents answers to values of 4 for very important and I for no important. They ranked variables based on the average of Likert scale values.

Odeh and Battaineh (2002) used a questionnaire to identify the causes of delays in Jordon construction industry. The respondents were asked to identify these causes in a 5 Likert scales. They ranked these causes by using the equation that used Assaf to rank these causes.

As the answers gained from respondents from the subjective type of data, the Likert scale will be used to represent these data. All the questions used in the questionnaire ask the participant to define a level from very high, high, average, low, very low and no effect . A numerical Likert scale of 5 points, 5 for very high, 4 for high, 3 for average, 2 for low and 1 for very low is used to convert these subjective answers to numerical values.

5-6-2 Research Statistical Analysis

The statistical analysis of the questionnaire response answers was carried out using a software for statistical analysis which is SPSS for Windows© (Version 11.5, 2004). The participants' answers are presented in Appendix E.

Statistical data analysis contains three main analyses:

1- Descriptive statistical analysis, which contains mean, mode, variance and standard deviation.

2- Test of data normality to check if the data collected forms a normal distribution or not. If the data are normally distributed the parametric analysis can be applied. If the data is not normally distributed, the non-parametric analysis will be applied.

3- Factor analysis is used to check if there any possibility of reducing the number of data variables.

5-7 Root Delay Causes

5-7-1 Descriptive statistical analysis

Statistical analysis will be used to verify the theoretical model for the root delay causes. The root delay causes were derived by using the cause-effect technique presented in chapter 4. Root delay causes are the main sources for delay generation as shown in the hierarchy model (DHPM), Figure 3-3.

Benjamin and Cornell (1970) suggested that, statistically, to accept a criterion or proposed variable, it should meet two conditions:

1. Respondents' mean value is equal to or more than the average as defined in the Likert scale.
2. Participants' response standard deviation is less than 1.

Any root delay cause satisfies the above two conditions will be accepted as a root delay cause and verify the analysis technique that is used to extract the root delay causes in section 4-3. By statistical analysis for part 2 of the interview questionnaire, if the mean value of root delay cause effect in delay occurrence resulted is over (Likert scale average) and its standard deviation less than 1.0, this will verify the proposed cause-effect technique that was used to extract the root delay causes.

The respondent's answers for each one of the root delay causes are statistically analysed. Table 5-5 shows the mean and standard deviation for the sample data regarding root delay causes effect on project delay. There are six root delay causes satisfy the conditions, and four root delay causes have mean value more than 3, with their standard deviation being more than one and three root delay causes that have mean values less than 3 and standard deviations more than 1.

The root delay causes which have mean value less than 3 are "the level of project "complexity and required technology", "trust between project parties" and "interaction between project parties in the preconstruction phase".

"Complexity and required technology" was recorded as the least effect on project delays and that is because all the respondents came from the building industry and the projects in building industry are mainly built in a traditional construction method. All the participants have more than 10 years of experience with these types of projects so they see this type of root delay cause as not a considerable effect on project delay.

"Trust between the project parties" has mean value less than 3, this may be because most of the participants have been working in the construction industry for long time and because the work market in Kuwait is small. This cause may be more important in other pats of the world depending on the diversity of the market.

Table 5-5: Sample Mean and Standard Deviation for Root Delay Causes

Code	Root Delay Cause	Mean	Std. Deviation
DM	Designer management deficiencies	3.433	1.224
DD	Quality of design work documents	3.400	1.037
CM	Contractor management deficiencies	4.300	0.750
CF	Contractor financial problems	4.233	1.006
OM	Owner management deficiencies	3.633	0.765
OF	Owner financial problems	4.167	1.117
MM	Efficiency level of communication	3.800	0.805
NT	Level of interactions in preconstruction stage	2.900	1.094
TR	Trust between project parties	2.667	1.093
CT	Level of project complexity and required technology	2.867	1.196
OB	Level of objectives harmony	3.133	1.137
SC	Site characteristics	3.533	0.973
PP	Project characteristics	3.500	1.414
PS	Project contract and procurement strategy	3.833	1.020

"The interaction between project parties in preconstruction phase" has a mean value less than 3. That is because the type of project design in building projects is mainly familiar and most of work in building project main tasks are familiar for the sample participants. The changes between projects in the method of construction and newness material are rare. The common project procurement strategy used in Kuwait is the traditional one (design-bid-build). There is limited possibility to interaction between project parties during design phase. Interaction between project parties starts in the bidding stage. The information that may affect the project to be delayed in the preconstruction stage will relate only to either quantity survey or the cost estimate.

So the question arises that "is any possibility to reduce the number of root delay causes based on the participants' answers? Factor analysis will be used to test if there is any possibility to reduce the number of variables.

5-7-2 Factor analysis for root delay causes:

Factor analysis is used to explore the possibility of an under lying structure in a set of interrelated variables without imposing any preconceived structure on the outcome (Child, 1990). Factor analysis is a statistical technique widely used in psychology and social science. In some branches of psychology, it is necessary to use it in questionnaire analysis. Factor analysis is defined generally as a method for simplifying a complex set of data (Kline, 1994).

Factor analysis is a statistical approach that can be used to analyze interrelationships among a large number of variables and to explain these variables in terms of their common underlying dimensions (factors). The statistical approach involves finding a way of condensing the information contained in a number of original variables into a smaller set of dimensions (factors) with a minimum loss of information

Factor analysis could be used for any of the following purposes (Benjamin and Cornell 1970):

- To reduce a large number of variables to a smaller number of variables for modelling purposes, where the large number of variables precludes modelling all the measures individually.
- To select a subset of variables from a larger set, based on which original variables have the highest correlations with the principal component factors
- To verify a scale or index by demonstrating that its constituent items load on the same factor, and to drop proposed scale items which cross-load on more than one factor
- To establish that multiple tests measure the same factor, thereby giving justification for administering fewer tests
- To identify clusters of cases and/or outliers

Factor analysis takes the input of number of variables' data, equivalent those that move together are considered a single thing, which it labels a factor. Factor is the common correlation thing between variables. The main objective of factor analysis is to determine the most important factors in the study. Factor analysis depends on the correlations between data variables. If the correlation between many variables is high it means that they can be substituted by considerable significance by one of them or by a factor that represents the correlation between them. If correlation is false for some reason, this inference will be mistaken.

Benjamin and Cornell (1970) suggested the factor analysis value of extraction less than 0.5 should be excluded from the list of variables. Factor analysis can be applied to any set of variables, but most often between 10 and 100. The factor analysis based on correlation analysis and extraction of principal components amounts to a *variance maximizing (varimax)* rotation

To check if the root delay causes can be reduced causes. A factor analysis using SPSS 11.5 software is used to test the sample. Table 5-6 describes the results.

All the initial values should be 1.00 for correlation, extraction are estimates of the variance in each variable accounted for by the components. The extraction in this Table 5-6 is more than 0.5, which indicates that the extracted components represent the variables well. The possibility to reduce variables is not supported.

5-7-3 Check the independency of root delay causes variables

Table 5-7 represents the correlation coefficient between root delay causes as resulted from SPSS 11.5 software. As can be noticed from Table 5-7, all the coefficients are not high (to be taken into consideration as a close correlation, they should not be less than 0.75). This means that all the root delay causes are independent and the assumption that all the root delay causes are independent variables is correct can be interpreted the factor analysis result.

As the sample size is not high,30 respondents, a check of the respondents sample's answers if they are in a normal shape or not. This check is important as it will define the statistical procedure for significance testing that will be applied to this data.

Table 5-6: Extraction Values for factor analysis of root delay causes

Root delay factor code	**Root Delay Cause**	Initial	Extraction
DM	Designer management deficiencies	1.00	0.907
DD	Quality of design work documents	1.00	0.651
CM	Contractor management deficiencies	1.00	0.787
CF	Contractor financial problems	1.00	0.671
OM	Owner management deficiencies	1.00	0.708
OF	Owner financial problems	1.00	0.731
MM	Efficiency level of communication	1.00	0.756
NT	Level of interactions in preconstruction stage	1.00	0.971
TR	Trust between project parties	1.00	0.855
CT	Level of project complexity and required technology	1.00	0.971
OB	Level of objectives harmony	1.00	0.749
SC	Site characteristics	1.00	0.809
PP	Project characteristics	1.00	0.819
PS	Project contract and procurement strategy	1.00	0.633

Table 5-7: Root Delay Causes Correlation Coefficients

	DM	DD	CM	CF	OM	OF	MM	NT	TR	CT	OB	SC	PP	PS
DM	1.000	0.717	0.180	-0.231	0.152	0.597	0.588	0.500	0.661	0.468	0.524	-0.100	-0.100	-0.046
DD	0.717	1.000	0.284	0.073	0.061	0.744	0.347	0.462	0.639	0.573	0.392	0.123	0.123	0.098
CM	0.180	0.284	1.000	0.315	0.559	0.309	0.446	0.584	0.421	0.431	0.235	0.198	0.198	0.609
CF	-0.231	0.073	0.315	1.000	0.249	0.118	-0.068	0.241	0.167	-0.145	-0.119	-0.167	-0.167	0.308
OM	0.152	0.061	0.559	0.249	1.000	0.195	0.213	0.697	0.509	0.020	0.375	0.225	0.225	0.582
OF	0.597	0.744	0.309	0.118	0.195	1.000	0.345	0.466	0.668	0.482	0.607	-0.053	-0.053	-0.005
MM	0.588	0.347	0.446	-0.068	0.213	0.345	1.000	0.525	0.313	0.473	0.219	0.009	0.009	0.378
NT	0.500	0.462	0.584	0.241	0.697	0.466	0.525	1.000	0.721	0.385	0.566	0.149	0.149	0.541
TR	0.661	0.639	0.421	0.167	0.509	0.668	0.313	0.721	1.000	0.413	0.786	-0.022	-0.022	0.165
CT	0.468	0.573	0.431	-0.145	0.020	0.482	0.473	0.385	0.413	1.000	0.521	0.034	0.034	0.179
OB	0.524	0.392	0.235	-0.119	0.375	0.607	0.219	0.566	0.786	0.521	1.000	0.027	0.027	0.050
SC	-0.100	0.123	0.198	-0.167	0.225	-0.053	0.009	0.149	-0.022	0.034	0.027	1.000	1.000	0.475
PP	-0.100	0.123	0.198	-0.167	0.225	-0.053	0.009	0.149	-0.022	0.034	0.027	1.000	1.000	0.475
PS	-0.046	0.098	0.609	0.308	0.582	-0.005	0.378	0.541	0.165	0.179	0.050	0.475	0.475	1.000

5-7-4 Check of sample results normality

In general, the data sample may come from a probabilistic population and take a random distribution, or from a non-random population and take a normal distribution or it can take a non normal distribution. The statistical analysis for the normal distribution samples is called parametric statistical analysis and for non-normal distribution samples it is called non parametric statistical analysis.

Before deciding which type of data analysis will be used, parametric or non parametric statistical analysis, a normality test for the data results will be checked. The Kolomograv test will be used to check the normality of the respondents' answers regarding root delay causes. The Kolomograv test is valid for any distribution (Hollander and Wolf, 1977). Kolmogorov test is used mainly for hypothesis check, if a hypothesis H_0 for a sample has normal distribution and has mean and standard deviation, Kolmogorov test can be applied (Sprent and Smeeton, 2001).

Table 5-8 describes the values of asymmetry significance value on two tailed Kolomgrav test using SPSS 11.5. If this value is greater than 0.05, it means that the distribution is from a normal hypothesis is accepted. Unfortunately most of the samples variables data have significance values less than 0.05, it means that the sample values are not from normal distribution.

Table 5-8: Check of Root Delay Causes Normality, Kolomogorov Test

	DM	DD	CM	CF	OM	OF	MM	NT	TR	CT	OB	SC	PP	PS
	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Mean	3.47	3.40	4.30	4.23	3.63	4.17	3.80	2.90	2.67	2.87	3.13	3.53	3.53	3.83
Std. Deviation	1.22	1.04	0.75	1.01	0.76	1.12	0.81	1.09	1.09	1.20	1.14	0.97	0.97	1.02
Absolute dif.	0.24	0.25	0.26	0.28	0.35	0.27	0.30	0.26	0.29	0.24	0.28	0.28	0.28	0.33
Positive dif.	0.13	0.18	0.22	0.22	0.25	0.23	0.24	0.26	0.25	0.19	0.28	0.18	0.18	0.24
Negative dif.	-0.24	-0.25	-0.26	-0.28	-0.35	-0.27	-0.30	-0.24	-0.29	-0.24	-0.25	-0.28	-0.28	-0.33
Kolmogorov-Smirnov Z	1.29	1.37	1.41	1.52	1.92	1.49	1.63	1.44	1.57	1.34	1.53	1.56	1.56	1.82
Asymp. Sig. (2-tailed)	0.07	0.05	0.04	0.02	0.00	0.02	0.01	0.03	0.01	0.06	0.02	0.02	0.02	0.00

5-8 Root Delay Causes and Resource Shortage

In this section, a descriptive statistical analysis will be conducted to evaluate the level of importance of each one of the root delay causes to permit the resources shortage. As described in chapter 3, the delay hierarchy model supposes that each one of the root delay causes has an effect on the resource shortage. Any deficiency of the root delay causes will by itself or with other of the root delay causes will affect a resource to be shorten. In questionnaire, part 3, the participant is asked to define the level of importance of each one of the root delay causes on the resource shortage occurrence. The participant answer will be in arrange between very high effect to no effect. Likert scale will be used to represent the respondents' answers in a numeric values; 5 for very high effect and 0 for no effect. The hypothesis of the relationship between root delay cause and the resource shortage will be accepted based on the conditions put by Benjamin and Cornell (1970) that used in root delay causes acceptance in 5-7.

5-8-1 Material Shortage and Root Delay Causes

Table 5-9 shows mean and standard deviation for the root delay causes and their effect to material shortage occurrence.

Table 5-9: Root Delay Causes Effect on Material Shortage

Code	Root Delay Cause	Mean	Std. Deviation
DM	Designer management deficiencies	2.567	1.251
DD	Quality of design work documents	2.867	1.252
CM	Contractor management deficiencies	3.900	1.423
CF	Contractor financial problems	4.233	1.006
CM	Owner management deficiencies	2.833	1.085
CF	Owner financial problems	3.933	1.048
MM	Efficiency level of communication	3.400	1.070
NT	Level of interactions in preconstruction stage	2.933	1.172
TR	Trust between project parties	2.833	1.341
CT	Level of project complexity and required technology	3.333	1.061
OB	Level of objectives harmony	2.833	1.341
SC	Site characteristics	3.500	0.938
PP	Project characteristics	3.567	0.858
PS	Project contract and procurement strategy	3.767	1.040

Based on the mean values, it can be noticed that the contractor's financial problems and owner's financial problems are the causes of most important effect on material shortage occurrence. This not surprising as the material shortage is very sensitive to the availability of finance.

Many of the root delay causes had not ascertained the conditions to be accepted. As it can be seen, the standard deviation is high and almost all root delay causes has more than 1.0 standard deviation. That might be because the diversity of respondents' prospective for the reasons for material shortage.

5-8-2 Labour Shortage and Root Delay Causes

Table 5-10 shows mean and standard deviation for the root delay causes and their effect to labour shortage occurrence.

Table 5-10: Root Delay Causes Effect on Labour Shortage

Code	**Root delay causes**	**Mean**	**Std. Deviation**
DM	Designer management' deficiencies	1.867	1.074
DD	Quality of design work documents	1.800	0.887
CM	Contractor management' deficiencies	3.767	1.223
CF	Contractor financial; problems	4.433	0.568
OM	Owner management' deficiencies	2.400	1.248
OF	Owner financial' problems	3.433	1.135
MM	Efficiency level of communication	2.767	0.971
NT	Level of interactions in preconstruction stage	1.700	0.915
TR	Trust between project parties	2.100	1.094
CT	Level of project complexity and required technology	2.733	1.143
OB	Level of objectives harmony	2.367	1.245
SC	Site characteristics	2.967	0.964
PP	Project characteristics	2.933	0.907
PS	Project contract and procurement strategy	2.933	1.337

The most important root delay causes that affect the labour shortage are the contractor financial problems and Contractor management deficiencies. The contractor is mainly responsible for planning, arrangement and orientation of construction labour. Many of management arrangements should be applied before using labours in construction projects. Choosing the type of labour, number of labourers and site labour management are very crucial for labour shortage in construction project.

The ability to finance labourers hiring and giving labourers their wages in the correct time is very important for labour supply rate.

Owner financial problems have significant effect on labour shortage as the project is mainly financed by the owner and any inefficiency of owner financial will be reflected in contractor financial stability and hence affect the labour supply rate to site.

In Table 5-10, there are many of root delay causes having mean a value less than 3, and the standard deviation more than 1.0.

5-8-3 Equipment Shortage and Root Delay Causes

Table 5-11 shows mean and standard deviation for the root delay causes and their effect to equipment shortage occurrence.

Contractor management deficiencies and contractor financial problems are the most highly ranked sources of equipment shortage. This might be because the contractor has to make many management arrangements for equipment choice and facilitate in site. Choosing the right type and number of equipment is one of the contractor responsibilities. Maintenance programs for the construction equipment are management tasks the contractor has to do to make sure that the piece of equipment is correct to work when it is required.

Contractor financial ability is very important to equipment facilities in construction sites. Any defect in contractor financial stability will affect the availability of equipment in site.

Owner financial problem has considerable effect on equipment shortage as the owner is the main financial supplier for the project, any defect on owner ability to finance the project will be reflected in resource shortage.

The complexity level of project has a considerable effect on equipment shortage. If the project is complex or need a new equipment types, the possibility of equipment shortage will be recognized.

Table 5-11: Root Delay Causes Effect on Equipment Shortage

Code	Root Delay Causes	Mean	Std. Deviation
DM	Designer management' deficiencies	2.267	1.172
DD	Quality of design work documents	2.467	1.137
CM	Contractor management' deficiencies	4.367	0.718
CF	Contractor financial; problems	4.167	0.874
OM	Owner management' deficiencies	2.400	1.192
OF	Owner financial' problems	3.333	1.155
MM	Efficiency level of communication	2.767	1.104
NT	Level of interactions in preconstruction stage	2.767	1.431
TR	Trust between project parties	2.600	1.354
CT	Level of project complexity and required technology	3.367	1.159
OB	Level of objectives harmony	2.167	0.913
SC	Site characteristics	3.200	1.324
PP	Project characteristics	3.267	1.311
PS	Project contract and procurement strategy	3.100	1.398

As it can be noticed from Table 5-11 there are many of root delay causes whose mean values are less than 3 and the standard deviation are greater than 1.0.

5-8-4 Information Shortage and Root Delay Causes

Table 5-12 shows mean and standard deviation and rank for the root delay causes and their effect to information shortage occurrence.

A designer management' deficiency is the highest ranked source of information shortage. The designer is responsible for providing any information when it is required. Inefficiency of designer management will affect the information to be provided when it is needed. Quality of design document is the second highest ranked source of information shortage. Design drawings and specifications provide the design information required to construct any piece of project. The communication channels and level of ease of data getting will affect the information shortage.

Table 5-12: Root Delay Causes Effect on Information Shortage

Code	Root Delay Causes	Mean	Std. Deviation
DM	Designer management' deficiencies	4.500	0.731
DD	Quality of design work documents	3.900	0.923
CM	Contractor management' deficiencies	3.667	1.842
CF	Contractor financial; problems	2.867	1.252
OM	Owner management' deficiencies	3.633	1.098
OF	Owner financial' problems	2.500	1.432
MM	Efficiency level of communication	3.667	1.184
NT	Level of interactions in preconstruction stage	3.533	1.279
TR	Trust between project parties	3.300	1.512
CT	Level of project complexity and required technology	3.767	0.898
OB	Level of objectives harmony	3.000	1.390
SC	Site characteristics	3.033	1.450
PP	Project characteristics	3.067	1.285
PS	Project contract and procurement strategy	3.133	1.357

As it can be noticed from Table 5-12 that most the root delay causes have a mean value more than 3, Likert scale average.

5-8-5 Space Shortage and Root Delay Causes

Table 5-13 shows mean and standard deviation for the root delay causes and their effect to information shortage occurrence. The space defines the required area, space and environmental that is required to allow all the other resources to be converted to finish product of a project activity.

Specific site characteristics are the most important causes of work space shortage. Accessibility level of site and level of site congestion will affect the space shortage. Contractor financial and management capabilities have a considerable effect on space shortage as the contractor is responsible for prepare the site to work before work start. Any inefficiency of contractor management will affect the availability of work space.

Table 5-13: Root Delay Causes Effect on Space Shortage

Code	Root Delay Causes	Mean	Std. Deviation
DM	Designer management deficiencies	2.467	1.456
DD	Quality of design work documents	2.100	1.213
CM	Contractor management deficiencies	3.767	1.251
CF	Contractor financial problems	3.300	1.343
OM	Owner management deficiencies	2.467	1.137
OF	Owner financial problems	2.433	1.382
MM	Efficiency level of communication	3.033	1.159
NT	Level of interactions in preconstruction stage	3.000	1.438
TR	Trust between project parties	2.100	1.269
CT	Level of project complexity and required technology	2.733	1.660
OB	Level of objectives harmony	2.400	1.329
SC	Site characteristics	3.900	1.269
PP	Project characteristics	3.567	1.165
PS	Project contract and procurement strategy	2.900	1.470

The next section will explain the descriptive analysis for questionnaire answers for part 4 which regarding the root delay causes' indicators.

5-9 Root Delay Causes' Indicators

The descriptive statistics that used to analyze the root delay causes' indicators will contain; mean values, standard deviation and frequencies. The purpose of this statistical analysis is to verify these indicators and evaluate if the indicator can be a representative measure for its related root delay cause. Each participant is asked to define if this indicator is a measure for the one of the root delay cause. If yes, it also asked to define the indicator level of importance in root delay cause assessment. This level is varied from very high to very low. Likert scale is used to convert the participants' answers to values from 5 to very high and 0 for not as an indicator.

The root delay causes' indicators are founded in level A3 in the proposed hierarchical delay model as shown in Figure 3-3.

The whole list of root delay causes' indicators came from chapter 4, section 4-4.

5-9-1 Designer management efficiency indicators

The searched that can be used to evaluate designer management efficiency are:

- *DM.01 Designer experience in current work*
- *DM.02 Quality of design revision policy*
- *DM.03. Task performancee*
- *DM.04 Percentage of outsourcing work*
- *DM.05 Quality of design group leadership*
- *DM.06. Designer general reputation*

These indicators collected from past research work regarding consultant selection and consultant performance in chapter 4.

Table 5-14 shows the frequency, mean value and standard deviation for each one of the designer management efficiency indicators. Based on the mean values, designer experience (DM.01) and possession of task performance (DM.03) are the most important indicators to evaluate designer management efficiency. While, percentage of outsourcing (DM.04) and designer general reputation (DM.06) have the least mean values and have high values of standard deviation.

Table 5-14: Designer Management Efficiency Indicators

		DM.01	DM.02	DM.03	DM.04	DM.05	DM.06
Frequency	No effect	0	1	1	7	1	7
	very low	0	0	0	2	0	0
	low	1	0	1	8	0	6
	average	0	7	4	5	6	9
	high	14	17	14	5	18	7
	very high	15	5	10	3	5	1
	Total	30	30	30	30	30	30
Mean Values		4.433	3.800	4.000	2.267	3.833	2.400
Standard Deviation		0.679	0.961	1.083	1.660	0.950	1.545

5-9-2 Quality of design work documents indicators

The indicators that are searched to evaluate design document quality are:

- *DD.01 Accuracy level of design documents*
- *DD.02 Usability of the design documents*
- *DD.03 Design constructability*

Table 5-15 shows frequencies, mean values and standard deviation for design document quality indicators. Accuracy level of design document (DD.01) is the most important indicator for evaluating design document quality.

Table 5-15: Design Documents Quality Indicators

		DD.01	DD.02	DD.03
frequency	No effect	4	9	0
	very low	1	0	1
	low	0	0	3
	average	0	0	9
	high	17	7	13
	very high	8	14	4
	Total	30	30	30
Mean Values		3.633	2.567	3.533
Standard deviations		0.297	0.321	0.178

5-9-3 Contractor management efficiency indicators

The indicators used for evaluate contractor management capabilities are:

- *CM.01 Experience in general:*
- *CM.02 .Contractor possess the required experience in same type of projects*
- *CM.03 Contractor past records in finishing project ahead or in schedule*
- *CM.04 Plant and equipment possession and maintenance strategy*
- *CM.05 Level of contractor staff experience and management capabilities*
- *CM.06 Contractor has a good document control strategy*
- *CM.07 Project team organization structure*
- *CM.08 Head office organization structure*
- *CM.09 History of past records of relationship with other project parties.*
- *CM.10 level of contractor staff overloading*

Table 5-16 shows frequencies, mean values and standard deviation for contractor management capabilities indicators. Contractor staff experience (CM.05) and general contractor experience (CM.01) are the most important indicators to evaluate contractor management capabilities. Contractor past record in finishing projects ahead of schedule (CM.03) is the least value in mean.

Table 5-16: Contractor Management Efficiency Indicators

		CM.01	CM.02	CM.03	CM.04	CM.05	CM.06	CM.07	CM.08	CM.09	CM.10
frequency	No effect	0	0	12	1	1	0	1	2	8	1
	very low	0	0	1	0	0	0	0	0	0	1
	low	0	0	0	1	0	1	1	4	0	0
	average	4	5	1	9	0	8	7	6	12	9
	high	14	15	13	15	7	6	11	12	6	14
	very high	12	10	3	4	22	15	10	6	4	5
	Total	30	30	30	30	30	30	30	30	30	30
Mean Values		4.267	4.167	2.367	3.633	4.6	4.167	3.9	3.467	2.667	3.633
Standard deviations		0.691	0.699	2.076	0.999	0.968	0.95	1.125	1.332	1.768	1.098

5-9-4 Contractor financial stability indicators

The contractor financial stability indicators that were searched are:

- *CF.01 Number of projects in hand*
- *CF.02 Value of work in hand*
- *CF.03 Working capital*
- *CF.04 Quality of bank arrangement*
- *CF.05 Liquidity ratio*

Table 5-17 shows the frequencies for contractor financial stability indicators, mean values and standard deviation. Quality of contractor bank arrangements (CF.04) and liquidity ratio (CF.05) are the most important indicators for contractor financial stability evaluation.

Table 5-17: Contractor Financial Stability Indicators

		CF.01	CF.02	CF.03	CF.04	CF.05
Frequency	No effect	10	11	9	0	0
	very low	1	1	0	0	0
	low	3	0	0	0	2
	average	7	8	2	4	7
	high	5	6	10	10	9
	very high	4	4	9	16	12
	Total	30	30	30	30	30
Mean Values		2.267	2.300	3.033	4.400	4.033
Standard Deviation		1.874	1.950	2.092	0.724	0.964

5-9-5 Owner management efficiency indicators

The indicators that were searched for evaluation owner management efficiency are:

- *OM.01 Owner management experience in similar projects*
- *OM.02 Project organization structure from owner party*
- *OM.03 Owner's willingness to accept effective and positive ideas*

- *OM.04 Level of owner team internal communication effectiveness*
- *OM.05 Owner support to finish project as scheduled*

Table 5-18 shows the frequencies for owner management efficiency indicators, mean values and standard deviation. Owner experience and owner support to finish project as schedule (OM.05) are the most important indicators that can be used to evaluate owner management efficiency.

Table 5-18: Owner Management Efficiency Indicators

		OM.01	OM.02	OM.03	OM.04	OM.05
Frequency	No effect	1	1	1	1	0
	very low	0	0	0	4	0
	low	0	7	3	0	6
	average	0	8	9	5	2
	high	17	13	11	18	11
	very high	12	1	6	2	11
	Total	30	30	30	30	30
Mean Values		4.267	3.167	3.567	3.367	3.900
Standard Deviation		0.944	1.053	1.135	1.273	1.125

5-9-6 Owner financial stability indicators

The indicators that were searched to evaluate owner financial stability are:

- *OF.01 Type of owner, public, private, one-off firm*
- *OF.02 Credit rating*
- *OF.03 Number of financial sources*
- *OF.04 Market reputation*

Table 5-19 shows the frequencies for owner financial stability indicators, mean values and standard deviation. All the indicators have almost relative importance based on their mean values.

Table 5-19: Owner Financial Stability Indicators

		OF.01	OF.02	OF.03	OF.04
Frequency	No effect	3	3	4	6
	very low	1	0	0	1
	low	0	0	0	0
	average	10	11	4	3
	high	6	12	19	14
	very high	10	4	3	6
	Total	30	30	30	30
Mean Values		3.500	3.367	3.433	3.200
Standard Deviation		1.548	1.326	1.455	1.808

5-9-7 Efficiency level of communication between project parts indicators

The searched indicators for evaluation level of communication between project parties are:

- *MM.01 Clearness of communication methods, documentation for all project parties*
- *MM.02 Communication channels number*
- *MM.03 Regular communication are timely relevant*
- *MM.04 Extensive communication paper work*
- *MM.05 Time to get information*
- *MM.06 Number of meetings per week during construction phase*

Table 5-20 shows the frequencies for communication level indicators, mean values and standard deviation. Clearness of communication methods (MM.01) and time to get information (MM.05) were the most important indicators for evaluating level of communication between project parties.

Table 5-20: Efficiency Level of Communications between Project Parties Indicators

		MM.01	MM.02	MM.03	MM.04	MM.05	MM.06
Frequency	No effect	0	2	0	4	0	5
	very low	0	1	0	0	0	0
	low	0	0	3	4	1	1
	average	3	8	8	5	2	6
	high	15	19	17	14	18	14
	very high	12	0	2	3	9	4
	Total	30	30	30	30	30	30
Mean Values		4.3	3.367	3.6	3.133	4.167	3.2
Standard Deviation		0.651	1.129	0.77	1.502	0.699	1.606

5-8-8 Level of interactions between project parties in pre-construction phase indicators

The searched indicators used to evaluate preconstruction interaction between project parties are:

- *NT.01 Amount of sharing information between all project parties*
- *NT.02 Number of meetings before project start*
- *NT.03 Level of participation of project parties in pre-construction phase*
- *NT.04 Percentage of pre-construction time to construction phase*
- *NT.05 Rrelationship and integration during design work*

Table 5-21 shows the frequencies for preconstruction interaction level indicators, mean values and standard deviation. Amount of data shared before project start(NT.01) is the most important indicator for evaluating pre-construction phase interaction.

5-9-9 Level of Trust between project parties indicators

The indicators that were searched to evaluate level of trust in construction projects are:

- *TR.01 Level of competence, fairness, helpful and honesty between project parties*
- *TR.02 Speed of response*
- *TR.03 Trust level from past interrelation work*

Table 5-21: Level of interaction between Project Parties in Pre-construction phase Indicators

		NT.01	NT.02	NT.03	NT.04	NT.05
Frequency	No effect	0	3	2	17	5
	very low	0	0	0	0	0
	low	0	0	2	4	0
	average	3	9	14	5	5
	high	19	15	10	4	16
	very high	8	3	2	0	4
	Total	30	30	30	30	30
Mean Values		4.167	3.400	3.200	1.300	3.300
Standard Deviation		0.592	1.303	1.127	1.600	1.600

Table 5-22 shows the frequencies for level of trust indicators, mean values and standard deviation.

Level of competence, honesty (TR.01) and speed of response (TR.02) are the key indicators to evaluate level of trust between project parties.

Table 5-22: Level Trust between project parties Indicators

		TR.01	TR.02	TR.03
Frequency	No effect	0	1	1
	very low	0	0	1
	low	1	0	0
	average	7	6	12
	high	12	12	7
	very high	10	11	9
	Total	30	30	30
Mean Values		4.033	4.033	3.667
Standard Deviation		0.850	1.066	1.213

5-9-10 Level of project complexity and required technology indicators

The searched indicators for evaluation the project level of complexity are:

- *CT.01 Differentiation: Number of organizations working in the construction project*
- *CT.02 Number of project sub-systems and interfaces between project elements*
- *CT.03 Level of familiarity for construction method*
- *CT.04 Required number of specialists and experts*
- *CT.05 Type and numbers of special equipment required*
- *CT.06 Level of rigidity of activities sequencing.*
- *CT.07 Size of project*

Table 5-23 shows the frequencies for level of trust indicators, mean values and standard deviation. Based on the average mean, number of organisations working in the construction project (CT.01) is the highest mean value. This may because the increasing number of organisations will mean increasing of required management tasks.

Table 5-23: Level Project Complexity and Required Technology Indicators

		CT.01	CT.02	CT.03	CT.04	CT.05	CT.06	CT.07
Frequency	No effect	0	0	1	5	2	6	7
	very low	0	0	0	0	0	0	0
	low	1	2	1	0	0	1	3
	average	6	10	2	7	9	5	10
	high	10	6	19	9	11	12	8
	very high	13	12	7	9	8	6	2
	Total	30	30	30	30	30	30	30
Mean Values		4.167	3.933	3.967	3.4	3.7	3.167	2.6
Standard Deviation		0.874	1.015	0.999	1.714	1.265	1.763	1.632

5-9-11 Level of objectives harmony between project parties indicators

The searched indicators that can be used to evaluate the objective harmony between project parties are:

- *OB.01 Matching level between owner objectives and other parties objectives*
- *OB.02 Clearness level of owner objectives in pre-construction phase*
- *OB.03 Uncertainty of goal definition, goals are not frozen*

Table 5-24 shows the frequencies for level of objectives harmony indicators, mean values and standard deviation. Based on the average mean, clearness level of owner objectives in pre-construction phase (OB.02) is the most important indicator. This indicator will affect and determine all the objectives for other players from entering the project.

Table 5-24: Level Objectives Harmony between Project Parties Indicators

		OB.01	OB.02	OB.03
Frequency	No effect	5	1	12
	very low	0	0	0
	low	4	4	0
	average	13	5	5
	high	7	17	7
	very high	1	3	6
	Total	30	30	30
Mean Values		2.667	3.533	2.433
Standard Deviation		1.398	1.074	2.112

5-9-12 Specific site characteristics indicators

The searched indicators that can be used to evaluate the level of special site characteristics are:

- *SC.01 Level of site accessibility*
- *SC.02 Level of site hazardous*
- *SC.03 Transportation problems*
- *SC.04 Permits and licenses for equipment and labours*
- *SC.05 Level of site congestion*
- *SC.06 Level of risks anticipated due to underground conditions*
- *SC.07 Weather and climatic effects*
- *SC.08 Level of approvals from authorities*
- *SC.09 Social effects*

Table 5-25 shows the frequencies for specific site characteristics indicators, mean values and standard deviation. Based on mean values, level of site accessibility is the most indicator for evaluation specific site characteristics. Site accessibility is very important to access labourers, materials and equipment. Site accessibility level determines the working time. In some cases when the site in the down city or city centre or in crowded street, the authorities determines specific times for construction work.

Table 5-25: Specific Site Characteristics Indicators

		SC.01	SC.02	SC.03	SC.04	SC.05	SC.06	SC.07	SC.08	SC.09
frequency	No effect	0	1	2	2	8	5	1	6	6
	very low	0	0	0	0	0	0	0	0	1
	low	0	1	0	3	1	0	10	9	13
	average	4	10	11	10	8	6	10	5	5
	high	21	15	9	11	13	11	6	8	4
	very high	5	3	8	4	0	8	3	2	1
	Total	30	30	30	30	30	30	30	30	30
Mean Values		4.033	3.567	3.633	3.333	2.6	3.4	2.967	2.5	2.1
Standard Deviation		0.556	0.971	1.273	1.241	1.673	1.694	1.129	1.57	1.373

5-9-13 Specific project characteristics indicators

The searched indicators that can be used in evaluating the specific project characteristics are:

- *PP.01 Percentage of long lead material items*
- *PP.02 Design time to project time*
- *PP.03 Project profit margin*
- *PP.04 Project requires newness technology*
- *PP.05 Contract time pressure*

Table 5-26 shows the frequencies for specific project characteristics indicators, mean values and standard deviation. Based on the mean values, percentage of long lead items is the most important indicators for evaluating project specific characteristics.

Long lead items determine the percentage of imported materials. The imported materials need more time, cost and management tasks. The control of long lead items is almost small as long lead items are fabricated and shipped from outside the place of project. Sometimes, the critical long lead items such as big air conditions units or chillers equipments require visits to the place of fabrication for all project decision makers costing more time and money.

Table 5-26: Specific Project Characteristics Indicators

		PP.01	PP.02	PP.03	PP.04	PP.05
frequency	No effect	3	17	10	3	8
	very low	0	3	1	0	0
	low	1	1	1	8	5
	average	8	6	7	2	0
	high	15	3	9	17	12
	very high	3	0	2	0	5
	Total	30	30	30	30	30
Mean Values		3.367	1.167	2.333	3.000	2.767
Standard Deviation		1.326	1.533	1.845	1.339	1.924

5-9-14 Project contract and procurement strategy indicators

The searched indicators that can be used to evaluate the level of project control and procurement strategy are:

- *PS.01 Project parties familiarity with contract type and procurement strategy*
- *PS.02 Level of contract clauses clearness and completeness*
- *PS.03 Clauses regarding time performance- penalty in delay and reward in early finish*

Table 5-27 shows the frequencies for specific project characteristics indicators, mean values and standard deviation. Based on the mean values, all the searched indicators have close mean values.

Table 5-27: Project Contract and Procurement Strategy Indicators

		PS.01	PS.02	PS.03
frequency	No effect	4	5	3
	very low	0	0	0
	low	0	4	1
	average	12	3	2
	high	7	14	20
	very high	7	4	4
	Total	30	30	30
Mean Values		3.300	3.100	3.600
Standard Deviation		1.535	1.647	1.354

5-10 Comments for Questionnaire Answers Statistical Analysis

As it can be noticed from the mean values and standard deviation for the effect of root delay causes on resource shortage that are presented in Tables 5-9 to 5-13, the mean values for many of them are less than 3, the Likert scale average and standard deviations are more than 1.0. This means that the diversification of respondents' answers regarding the effect of root delay causes effect on resources shortage.

To get more precise information from the data, round two of the questionnaire was distributed to selected numbers of the first round participants using the Delphi method. The Delphi method is a technique used to enhance data quality gathered.

5-11 Delphi Method

The purpose of applying the Delphi method is to verify and enhance the level of significance of the collected data. The first round process of interview questionnaire may have many of shortcomings such as mis-understanding, careless from participants or fatigue because of the problem of the time consuming of questionnaire filling. The second round of questionnaire interview is used to improve the quality of the collected data and get the most certified information. The Delphi technique is one of the methods that are developed to verify collected data. The Delphi method is a systematic procedure to evoke expert opinion and to obtain the relative importance of multiple criteria (Dalkey, 1970). The Delphi technique aims to reach the most averaging from the experts by many of repetitive cycles.

5-11-1 Theoretical Background about Delphi

Delphi is the name given to a set of procedures for electing and refining the opinions of a group, usually a panel of experts or individuals by a series of intensive interrogations of each individual expert, by a series of questionnaires (referred as "round"), concerning some primary question interspersed with controlled feedback. In the Delphi method the experts' answers from round one are statistically analyzed and feedback to some of the experts. Figure 5-1 illustrates the Delphi process as described by Grubbstrom (1988).

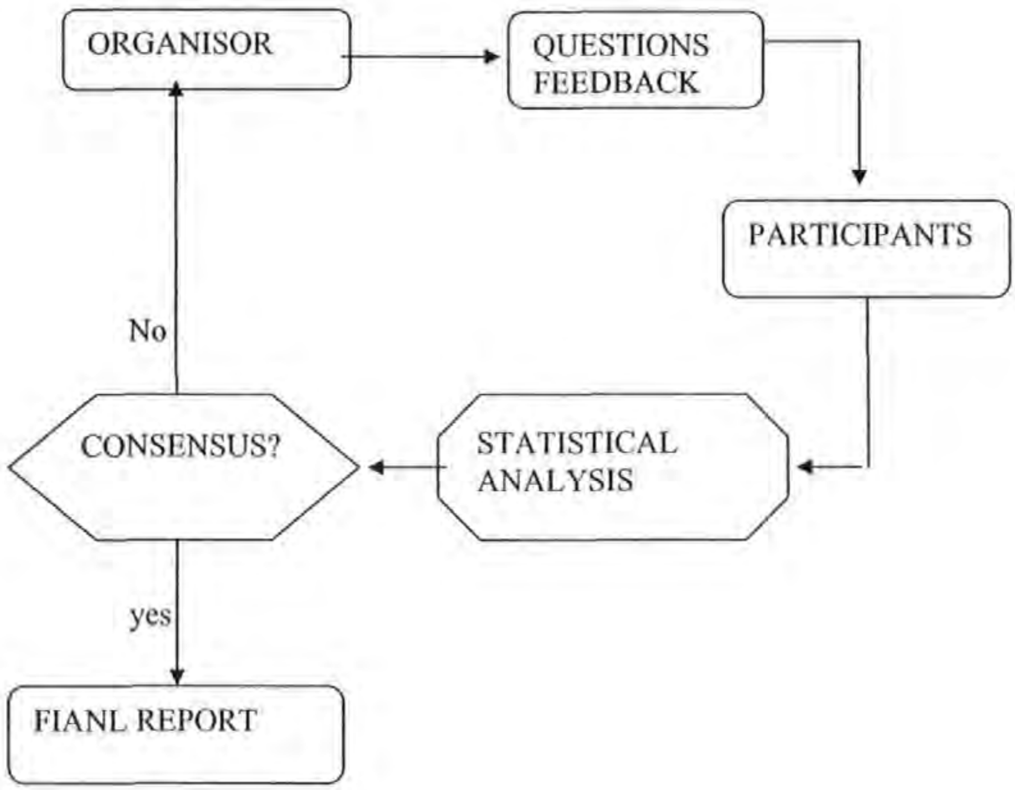


Figure (5-1) The Delphi Process (Grubbstorm, 1988).

The Delphi method leads to increased accuracy of group responses (Grubbstorm, 1988).

The Delphi method has three main characteristics:

- *Anonymity*: The group members are not known to each other and interaction of the group members is handled in a completely anonymous fashion. As a result, the expert can change or modify their answers from a previous evaluation without any embarrassment.

- *Controlled Feedback*: issuing the questionnaires in a sequence of round and giving participants a summary of the statistical analysis of the results at the end of each round, is a device to ensure objectivity. The primary effect of this controlled feedback is to prevent the group from taking on its own goals and objectives

- *Statistical Group Response*: The statistical analysis is presented to the expert.

The Delphi method can use two basic ways of questioning experts (Linstone and Turoff, 1975):

(1) Face-to-face contact between experts,

(2) Multi-round (iterative) processes without face-to-face contact and with controlled feedback.

The first method (1) includes the traditional "round-table discussion". In a traditional discussion, each expert receives permanent and uncontrolled feedback from all other experts in the form of their opinions as well as more general responses. A discussion may be structured to include several distinct rounds. The other method is to present the results of the successive rounds via post or emails. This method is used because less in cost and reduces the pressure of group discussion.

The advantages of the Delphi method are the following (Shneiderman, 1988):

(1) All decision-makers (experts) are deeply involved in the evaluation process because the Delphi method allows them to suggest what criteria or objectives should be considered in the analysis. Therefore, the Delphi method can produce more agreement on criteria or objectives selected.

(2) Because of its anonymity, the Delphi method allows the experts to express their opinions freely and to assign numerical values to what is essentially an opinion, even though an educated one. The experts are given the opportunity to express

their subjective value judgements for each criterion or objective and can be assured that their judgements will be taken into account.

5-11-2 Delphi Application in Second Round of Delay Interview Questionnaire

First, the descriptive statistical analysis for round one of interview questionnaire results is carried out. A second round of interview questionnaire was carried out by presenting the average resulted from round one to a number of selected participants who contributed in the first round questionnaire. The participant is free to change or insist its first answer. The averages that were presented to the round two participants are categorised into two groups; the whole sample average and its round one answers.

Total number of six participants contributed in second round interview questionnaire, about 20% from first round participants. The choice of the six participants was based on availability. A sample of the round two interview questionnaire is presented in Appendix F.

5-12 Delphi Result Analysis

The answers that have been gathered from second round will be treated as numeric numbers of Likert scale as have been done in the first round. A descriptive statistical analysis will be conducted to verify first round answers.

5-12-1 Root delay causes

Table 5-28 shows the mean values and standard deviation for second round questionnaire regarding the answers for effect of root delay causes on project delay occurrence. The comparison of mean values and standard deviation of round one that shown in Table 5-5 and what in Table 5-28 reveals that the average for all root delay causes have mean value more than 3 (more than the Likert scale average), and the standard deviations in the second round are less than 1.0 for all root delay causes. This means that the second round confirms that all the root delay root causes have a significant effect on project delay as suggested by Benjamin and Cornell (1970). After round two, the assumption of the root delay causes have significance effect on project delays is clearly verified.

Table 5-28: Analysis and Rank for Root Delay Causes- Round Two

code	root delay causes	Mean	Std. Dev.
DM	Designer management' deficiencies	3.833	0.408
DD	Quality of design work documents	3.667	0.516
CM	Contractor management' deficiencies	5.000	0.000
CF	Contractor financial; problems	4.667	0.516
OM	Owner management' deficiencies	4.000	0.632
OF	Owner financial' problems	4.500	0.548
MM	Efficiency level of communication	4.333	0.516
NT	Level of interactions in preconstruction stage	3.333	0.516
TR	Trust between project parties	3.333	0.516
CT	Level of project complexity and required technology	3.500	0.548
OB	Level of objectives harmony	3.500	0.548
SC	Site characteristics	3.833	0.408
PP	Project characteristics	3.833	0.408
PS	Project contract and procurement strategy	4.833	0.408

5-12-2 Material Shortage and Root Delay Causes

Table 5-29 shows the mean values and standard deviation for root delay causes effect on material shortage for round two analysis. Comparing Table 5-9 and Table 5-29 shows the changes of mean values and standard deviation shows that the standard deviation less than one. The rank of root delay causes effect on material shortage is changed, but the first ranked for the both rounds is the same which is contractor financial capabilities.

Table 5-29: Root Delay Causes Effect on Material Shortage- Round two

Code	Root Delay Cause	Mean	Std. Deviation
DM	Designer management' deficiencies	3.000	0.632
DD	Quality of design work documents	3.000	0.753
CM	Contractor management' deficiencies	4.500	0.837
CF	Contractor financial; problems	5.000	0.000
OM	Owner management' deficiencies	3.500	0.548
OF	Owner financial' problems	3.667	0.506
MM	Efficiency level of communication	3.833	0.753
NT	Level of interactions in preconstruction stage	3.167	0.753
TR	Trust between project parties	3.000	1.265
CT	Level of project complexity and required technology	3.500	0.548
OB	Level of objectives harmony	3.500	0.548
SC	Site characteristics	3.333	0.816
PP	Project characteristics	3.167	0.753
PS	Project contract and procurement strategy	4.667	0.516

5-12-3 Labour Shortage and Root Delay Causes

Table 5-30 shows the mean values and standard deviation for effect of root delay causes on labour shortage. By comparing Table 5-30 and Table 5-10 which shows the analysis for round one, it is noticed that the standard deviations have been reduced. The three top ranked causes for labour shortage are the same from the two rounds.

There are four root delay causes that did not ascertain the predefined conditions to accept a suggestion as suggested by Benjamin and Cornell (1970). These root delay causes be excluded from the influencers of labour shortage. These four root delay causes are:

- Designer management deficiencies

- Quality of design work documents
- Owner management deficiencies
- Level of interactions in preconstruction stage

Table 5-30: Root Delay Causes Effect on Labour Shortage- Round two

Code	Root Delay Cause	Mean	Std. Deviation	rank
DM	Designer management' deficiencies	2.500	0.837	10
DD	Quality of design work documents	1.833	0.408	14
CM	Contractor management' deficiencies	5.000	0.000	1
CF	Contractor financial; problems	4.333	0.516	2
OM	Owner management' deficiencies	2.167	1.169	12
OF	Owner financial' problems	3.833	0.753	3
MM	Efficiency level of communication	3.167	0.408	9
NT	Level of interactions in preconstruction stage	2.000	0.000	13
TR	Trust between project parties	2.333	0.516	11
CT	Level of project complexity and required technology	3.667	0.816	4
OB	Level of objectives harmony	3.333	1.211	7
SC	Site characteristics	3.500	0.548	6
PP	Project characteristics	3.333	0.516	8
PS	Project contract and procurement strategy	3.667	0.516	5

5-12-4 Equipment Shortage and Root Delay Causes

Table 5-31 shows the mean values and standard deviation for effect of root delay causes on equipment shortage. By comparing Table 5-31 with Table 5-11-which shows the statistical analysis and rank for round one- It is noticed that the top two ranked root delay causes for equipment shortage were the same in the two rounds of questionnaire. The most important causes for equipment shortage from the root delay causes are contractor management capabilities and contractor financial stability as in round one.

Table 5-31: Root Delay Causes Effect on Equipment Shortage- Round two

Code	Root Delay Cause	Mean	Std. Deviation
DM	Designer management' deficiencies	2.000	0.894
DD	Quality of design work documents	2.500	1.049
CM	Contractor management' deficiencies	4.667	0.516
CF	Contractor financial; problems	4.667	0.516
OM	Owner management' deficiencies	3.000	0.632
OF	Owner financial' problems	3.333	0.516
MM	Efficiency level of communication	3.667	0.516
NT	Level of interactions in preconstruction stage	3.000	0.632
TR	Trust between project parties	2.667	0.816
CT	Level of project complexity and required technology	3.833	0.983
OB	Level of objectives harmony	3.000	0.000
SC	Site characteristics	3.500	0.548
PP	Project characteristics	3.833	0.408
PS	Project contract and procurement strategy	3.833	0.753

As it can be noticed from Table 5-31 that these root delay causes will be excluded from the root delay causes of equipment shortage:

- o Designer management' deficiencies
- o Quality of design work documents
- o Trust between project parties

<u>5-12-5 Information Shortage and Root Delay Causes</u>

Table 5-32 shows the mean values and standard deviation for effect of root delay causes on information shortage. Comparing between Table5-32 and Table 5-12

Table 5-32: Root Delay Causes Effect on Information Shortage- Round two

Code	*Root Delay Cause*	*Mean*	*Std. Deviation*
DM	Designer management' deficiencies	4.667	0.516
DD	Quality of design work documents	4.333	0.516
CM	Contractor management' deficiencies	3.333	1.211
CF	Contractor financial; problems	3.167	1.169
OM	Owner management' deficiencies	4.333	0.516
OF	Owner financial' problems	2.833	1.169
MM	Efficiency level of communication	3.833	0.408
NT	Level of interactions in preconstruction stage	4.167	0.753
TR	Trust between project parties	3.667	1.506
CT	Level of project complexity and required technology	4.333	0.516
OB	Level of objectives harmony	3.000	1.095
SC	Site characteristics	3.667	0.816
PP	Project characteristics	3.167	1.169
PS	Project contract and procurement strategy	3.667	0.816

shows that the standard deviation for all were enhanced and the ranks for the top two causes are the same.

The only root delay cause that will be excluded as an influencer for information shortage is the owner financial problems.

5-12-6 Space Shortage and Root Delay Causes

Table 5-33 shows the mean values and standard deviation for effect of root delay causes on space shortage. By comparing Table 5-33 with Table 5-13, it is noticed that the standard deviation for all root delay causes is enhanced. The rank for root delay causes was changed for almost all root delay causes. This means that the second round answers were changed to be close to the mean.

As it can be noticed from Table 5-33, these root delay causes will be excluded from space shortage root delay causes:

- Design management deficiencies
- Quality of design work documents
- Contractor financial problems
- Owner financial problems
- Trust between project parties
- Level of objective harmony

Table 5-33: Root Delay Causes Effect on Space Shortage- Round two

Code	*Root Delay Cause*	Mean	Std. Deviation
DM	Designer management' deficiencies	2.833	0.983
DD	Quality of design work documents	2.500	0.548
CM	Contractor management' deficiencies	3.833	0.983
CF	Contractor financial; problems	3.667	1.033
OM	Owner management' deficiencies	3.333	0.516
OF	Owner financial' problems	2.500	0.837
MM	Efficiency level of communication	4.000	0.632
NT	Level of interactions in preconstruction stage	3.333	0.816
TR	Trust between project parties	2.667	0.516
CT	Level of project complexity and required technology	3.333	0.816
OB	Level of objectives harmony	2.667	0.816
SC	Site characteristics	4.000	0.632
PP	Project characteristics	3.667	0.516
PS	Project contract and procurement strategy	3.333	0.516

5-12-7 Root Delay Causes Indicators

Table 5-34 shows the mean values and standard deviation for answers of round two analyses for questionnaire, part 4. In general the standard deviations were enhanced meaning that the most answers are coming to the sample average and the diversity of sample answers are limited.

From Table 5-34, the indicators that have a mean value less than 3 and standard deviation more than 1.0 will be excluded from the list of indicators for the related root delay cause.

5-13 Modified DHPM

The Delphi method analysis for the answers for round two data revealed that :

1- All the root delay causes that are used in design the DHPM model are verified,

2- The root delay causes in level A2, and their relationship with the resources in Level A1 in Figure 3-3 are subjected to modification

3- The root delay causes' indicators are subject to be modified.

Figure 5-2 shows the modified DHPM model Table 5-34 shows the list of root delay causes that will be used in the modified DHPM model. Table 5-35 shows the refined root delay causes' indicators that will be used in model application.

5-14 Conclusion:

Statistical analysis for the questionnaire analysis was carried out. The descriptive analysis for root delay causes and indicators revealed that there is a large diversion around the mean values. The Delphi method was used to enhance the data gathered. In general the answers for the second round answers verified the basis of Model A: Resource Shortage Possibility (RSP) model and the relationship between level A2 and A3 subject to be modified. DHPM modification is presented in Figure 5-2. The modified RSP model in Figure 5-2 and the refined root delay cause' indicators will be used in RSP model application in chapter 6.

Table 5-34: Comparison between round two and round one answers

	Code	Root Delay Cause Indicator	Round One		Round Two	
			Mean	Std. Dev.	Mean	Std. Dev.
D M	DM.01	Designer experience in current work	4.43	0.68	4.83	0.41
	DM.02	Quality of design revision policy	3.80	0.96	4.17	0.75
	DM.03	Task performance	4.00	1.08	4.17	0.75
	DM.04	Percentage of outsourcing work	2.27	1.66	2.50	1.23
	DM.05	Quality of design group leadership	3.83	0.95	3.83	1.17
	DM.06	Designer general reputation	2.40	1.55	2.83	1.17
D D	DD.01	Accuracy level of design documents	3.63	1.63	4.33	0.52
	DD.02	Usability of the design documents	2.57	1.76	2.83	1.17
	DD.03	Design constructability	3.53	0.97	3.83	0.98
C M	CM.01	Experience in general	4.27	0.69	4.33	1.03
	CM.02	Contractor possess the required experience in same type of projects	4.17	0.70	4.00	0.63
	CM.03	Contractor past records in finishing project ahead or in schedule	2.37	2.08	3.50	1.05
	CM.04	Plant and equipment possession and maintenance strategy	3.63	1.00	2.83	0.98
	CM.05	Level of contractor staff experience and management capabilities	4.60	0.97	3.50	0.55
	CM.06	Contractor has a good document control strategy	4.17	0.95	3.00	1.41
	CM.07	Project team organization structure	3.90	1.13	3.33	1.37
	CM.08	Head office organization structure	3.47	1.33	3.50	1.05
	CM.09	History of past records of relationship with other project parties.	2.67	1.77	2.50	0.84
	CM.10	level of contractor staff overloading	3.63	1.10	4.50	0.55
C F	CF.01	Number of projects in hand	2.27	1.87	4.67	0.82
	CF.02	Value of work in hand	2.30	1.95	4.67	0.52
	CF.03	Working capital	3.03	2.09	3.50	0.55
	CF.04	Quality of bank arrangement	4.40	0.72	3.83	0.41
	CF.05	Liquidity ratio	4.03	0.96	5.00	0.00

Table 5-34 : Comparison between round two and round one' answers (Continue)

	Code	Root Delay Cause Indicator	Round One		Round Two	
			Mean	Std. Dev.	Mean	Std. Dev.
OM	OM.01	Client management experience in similar projects	4.27	0.94	4.67	0.52
	OM.02	Project organization structure from client party	3.17	1.05	3.67	0.52
	OM.03	Client's willingness to accept effective and positive ideas	3.57	1.14	3.83	0.98
	OM.04	Level of client team internal communication effectiveness	3.37	1.27	4.00	0.00
	OM.05	Client support to finish project as scheduled	3.90	1.13	4.33	0.52
OF	OF.01	Type of client, public, private, one-off firm	3.50	1.55	4.17	0.41
	OF.02	Credit rating	3.37	1.33	3.67	0.52
	OF.03	Number of financial sources	3.43	1.46	3.33	1.03
	OF.04	Market reputation	3.20	1.81	3.67	0.82
MM	MM.01	Clearness of communication methods, documentation	4.30	0.65	4.67	0.52
	MM.02	Communication channels number	3.37	1.13	3.50	0.84
	MM.03	Regular communication are timely relevant	3.60	0.77	3.83	0.41
	MM.04	Extensive communication paper work	3.13	1.50	3.67	0.52
	MM.05	Extensive communication paper work	4.17	0.70	5.00	0.00
	MM.06	Number of meetings per week during construction phase	3.20	1.61	3.67	0.52
NT	NT.01	Amount of sharing information between all project parties	4.17	0.59	4.83	0.41
	NT.02	Number of meetings before project start	3.40	1.30	3.83	0.41
	NT.03	Level of participation of project parties in pre-construction phase	3.20	1.13	3.00	1.27
	NT.04	percentage of pre-construction time to construction phase	1.30	1.60	2.00	0.63
	NT.05	relationship and integration during design work	3.30	1.60	3.50	1.38
TR	TR.01	Level of competence, fairness, helpful and honesty between project parties	4.03	0.85	4.50	0.55
	TR.02	Speed of response	4.03	1.07	4.50	0.55
	TR.03	Trust level from past interrelation work	3.67	1.21	3.83	0.98

Table 5-34: Comparison between round two and round one' answers (Continue)

	Code	Root Delay Cause Indicator	Round One		Round Two	
			Mean	Std. Dev.	Mean	Std. Dev.
CT	CT.01	Differentiation: Number of organizations working in the construction project	4.17	0.87	5.00	0.00
	CT.02	Number of project sub-systems and interfaces between project elements	3.93	1.02	4.00	0.63
	CT.03	Level of familiarity for construction method	3.97	1.00	4.17	0.75
	CT.04	Required number of specialists and experts	3.40	1.71	3.67	0.52
	CT.05	Type and numbers of special equipment required	3.70	1.26	3.67	0.82
	CT.06	Level of rigidity of activities sequencing.	3.17	1.76	3.00	1.10
	CT.07	Size of project	2.60	1.63	2.83	1.17
OB	OB.01	*1. Matching level between client objectives and other parties objectives*	2.67	1.40	2.83	0.75
	OB.02	*2. Clearness level of client objectives in pre-construction phase*	3.53	1.07	4.00	0.63
	OB.03	*3. Uncertainty of goal definition, goals are not frozen.* (7)	2.43	2.11	4.00	0.89
SC	SC.01	Level of site accessibility	4.03	0.56	4.67	0.82
	SC.02	Level of site hazardous	3.57	0.97	3.83	0.75
	SC.03	Transportation problems	3.63	1.27	3.67	1.03
	SC.04	, Permits and licenses for equipment and labours	3.33	1.24	3.67	0.52
	SC.05	Level of site congestion	2.60	1.67	3.17	1.17
	SC.06	Level of risks anticipated due to underground conditions	3.40	1.69	4.00	0.00
	SC.07	Weather and climatic effects	2.97	1.13	3.33	0.82
	SC.08	Level of approvals from authorities	2.50	1.57	3.17	0.75
	SC.09	Social effects	2.10	1.37	2.33	0.82
PP	PP.01	Percentage of long lead material items	3.37	1.33	3.83	1.17
	PP.02	Design time to project time	1.17	1.53	1.50	0.55
	PP.03	Project profit margin	2.33	1.85	3.00	1.10
	PP.04	Project requires newness technology	3.00	1.34	3.33	0.52
	PP.05	Contract time pressure	2.77	1.92	3.83	0.41
PS	PS.01	Project parties familiarity with contract type and procurement strategy	3.30	1.54	4.00	0.63
	PS.02	Level of contract clauses clearness and completeness	3.10	1.65	4.00	0.63
	PS.03	Clauses regarding time performance- penalty in delay and reward in early finish	3.60	1.35	4.17	0.41

Table 5-35 Refined Root Delay Cause' indicators

Code	Code	Root Delay Cause Indicators
DM	DM.01	Designer experience in current work
	DM.02	Quality of design revision policy
	DM.03	Task performance
	DM.04	Percentage of outsourcing work
	DM.05	Quality of design group leadership
	DM.06	Designer general reputation
DD	DD.01	Accuracy level of design documents
	DD.02	Usability of the design documents
	DD.03	Design constructability
CM	CM.01	Experience in general
	CM.02	Contractor possess the required experience in same type of projects
	CM.03	Contractor past records in finishing project ahead or in schedule
	CM.04	Plant and equipment possession and maintenance strategy
	CM.05	Level of contractor staff experience and management capabilities
	CM.06	Contractor has a good document control strategy
	CM.07	Project team organization structure
	CM.08	Head office organization structure
	CM.09	History of past records of relationship with other project parties.
	CM.10	level of contractor staff overloading
CF	CF.01	Number of projects in hand
	CF.02	Value of work in hand
	CF.03	Working capital
	CF.04	Quality of bank arrangement
	CF.05	Liquidity ratio
OM	OM.01	Client management experience in similar projects
	OM.02	Project organization structure from client party
	OM.03	Client's willingness to accept effective and positive ideas
	OM.04	Level of client team internal communication effectiveness
	OM.05	Client support to finish project as scheduled
OF	OF.01	Type of client, public, private, one-off firm
	OF.02	Credit rating
	OF.03	*Number of financial sources*
	OF.04	Market reputation
MM	MM.01	Clearness of communication methods, documentation
	MM.02	Communication channels number
	MM.03	Regular communication are timely relevant
	MM.04	Extensive communication paper work
	MM.05	Extensive communication paper work
	MM.06	Number of meetings per week during construction phase

Code	Code	Root Delay Cause Indicators
NT	NT.01	Amount of sharing information between all project parties
	NT.02	Number of meetings before project start
	NT.03	Level of participation of project parties in pre-construction phase
	NT.04	percentage of pre-construction time to construction phase
	NT.05	relationship and integration during design work
TR	TR.01	Level of competence, fairness, helpful and honesty between project parties
	TR.02	Speed of response
	TR.03	Trust level from past interrelation work
CT	CT.01	Differentiation: Number of organizations working in the construction project
	CT.02	Number of project sub-systems and interfaces between project elements
	CT.03	Level of familiarity for construction method
	CT.04	Required number of specialists and experts
	CT.05	Type and numbers of special equipment required
	CT.06	Level of rigidity of activities sequencing.
	CT.07	Size of project
OB	OB.01	*1. Matching level between client objectives and other parties objectives*
	OB.02	*2. Clearness level of client objectives in pre-construction phase*
	OB.03	*3. Uncertainty of goal definition, goals are not frozen.* (7)
SC	SC.01	Level of site accessibility
	SC.02	Level of site hazardous
	SC.03	Transportation problems
	SC.04	. Permits and licenses for equipment and
	SC.05	Level of site congestion
	SC.06	Level of risks anticipated due to underground conditions
	SC.07	Weather and climatic effects
	SC.08	Level of approvals from authorities
	SC.09	Social effects
PP	PP.01	Percentage of long lead material items
	PP.02	Design time to project time
	PP.03	Project profit margin
	PP.04	Project requires newness technology
	PP.05	Contract time pressure
PS	PS.01	Project parties familiarity with contract type and procurement strategy
	PS.02	Level of contract clauses clearness and completeness
	PS.03	Clauses regarding time performance- penalty in delay and reward in early finish

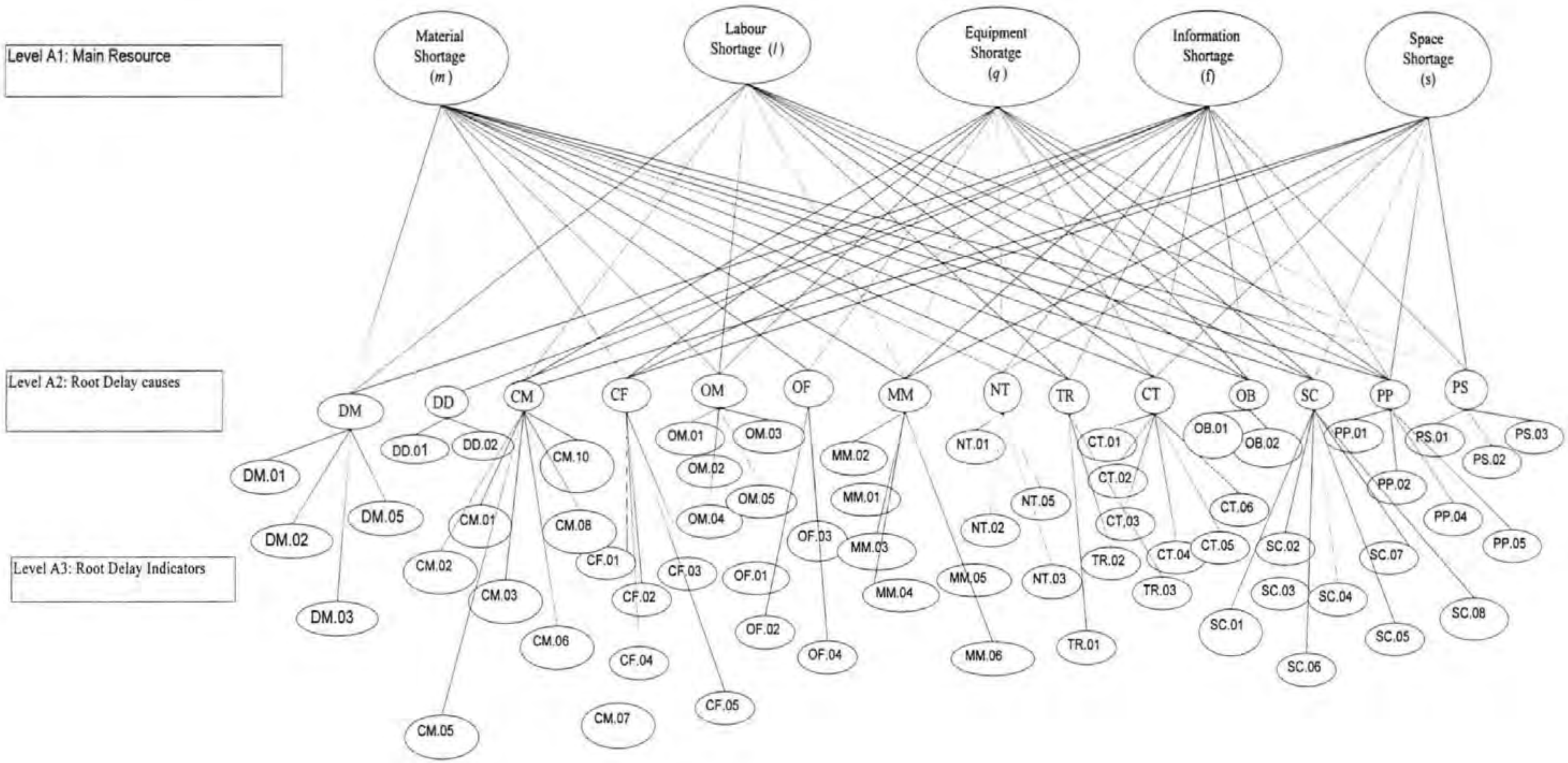


Figure 5-2 The Modified RSP model

Chapter 6

Model A: Resource Shortage Possibility (RSP Model)-Computer Program and Testing

6-1 Introduction:

The proposed Delay Hierarchical Propagation Model (DHPM) presented by Figure 3-3 and outlined in section 3-3 consists of two interrelated sub-models Model A: Resource Shortage Possibility (RSP) Model and Model B: Predicating Project Delay (PPD) model. The concepts of the RSP model were verified in chapter 5 and the modified RSP model is presented in Figure 5-2.

In this chapter the structure, formulation and application of Model A- Resource Shortage Possibility model (RSP) model is presented and discussed.

In this chapter the algorithm for the Model A will be presented, a computer prototype is derived to enable the RSP in to be used in the construction industry. This prototype computer program is tested in a real construction project.

6-2 Model A: Resource Shortage Possibility (RSP) Model Structure

Figure 6-1 shows the hierarchy structure for Model A: Resource Shortage Possibility (RSP) model. The hierarchy is a system of collected parts with ordered relationships within a whole system. There are upper and lower levels and there is a specific type of relationship between the upper and lower levels.

As shown in Figure 6-1, the RSP model consists of three interrelated levels. Level A3, root delay causes indicators, level A2, the root delay causes and level A1 contains

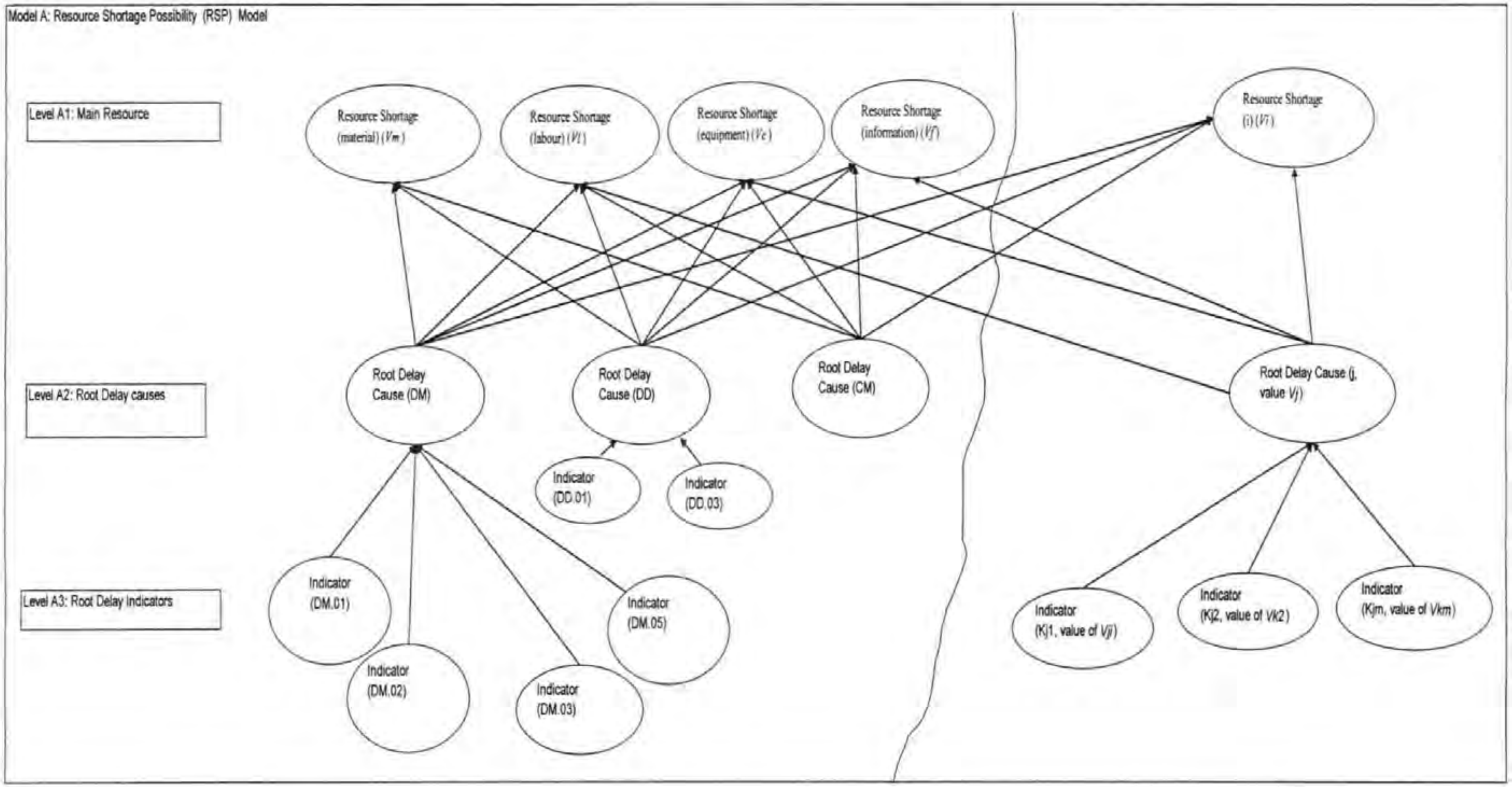


Figure (6-1) Model A: Resource Shortage Possibility Model the five main resources. The main objective is to determine the possibility of resource shortage (at level A1) based on evaluation of the lower levels values.

The model assumes that the delay is generated as a result of any deficiency on one or more of the root delay causes which are found in level A2 in the model. These root delay causes affect the availability of one or more of the main construction resources. The output of RSP model is the possibility of resource shortage. The possibility of these resource shortages are then used to assess the risk of delay to individual project activities in level B3 in Figure 3-3. To predict the risk of project to delay, an assessment for each one of the root delay causes in level A2 is required. Root delay causes' indictors are used to assess this risk to the root delay causes. The root delay causes' indicators are at the lowest level in the model- level A3.

The application of the RSP model starts by assessing the values for the root delay causes' indicators in the lower level (A3) as external inputs to the model. The value of the resource shortage possibility will be based on the value of these external inputs at level (A3) and the relative weighting between the levels of the model; this is the relative weights of variables between level (A3) to level (A2) and level (A2) to level (A1). These relative weights represent the level of impact of a level on its immediate upper level.

The model starts by evaluating root delay causes' indicators values; *(Vjk)* This value are in a non numerical values and can be valued by a linguistic value. Good, very good, bad are samples of such linguistic values.

For example, quality of the contractor's banking arrangement (CF.04) is one of the indicators used to assess the contractor's financial stability. The assessment of this variable may be high, average, low. The linguistic terms for criteria evaluation are in every day usage in many construction works. To deal with these non numerical data inputs, the fuzzy set is chosen to represent the values of root delay causes' indicators . Fuzzy set can handle these linguistic variables and it has been successfully applied in many construction applications.

The objective of RSP model is to obtain the possibility of resources shortage, which is found in level A1. The value of resource shortage possibility (*Vi*) is the result of assessing the root delay causes' indicators values which level A3 in Figure 6-1 and the relative importance between level A2 to A3, A1 to A2. The relative weights between any two variables in any two succeeding levels determine the relative importance or relative influence between the variables.

6-3 Resource Shortage Possibility Model (RSP)Model Formation

6-3-1 Model variables

As mentioned above, the output of this model is to predict the possibility of resource shortage. This possibility of resource shortage value will represent the risk level of resource shortage.

This value is an uncertain value and depends on the value of the values of the root delay causes' indicator in level A3 and the relative weights between levels.

To obtain this resource shortage possibility values (level A1), a set of variables are defined for the model variables:

1- *(Vi)* is the value of resource shortage possibility for the elements in level A1. The output of the RSP model will be the five values for possibility shortage of material, labour, equipment, information and space.

2- *(Vj)* is the value of a root delay cause. Each one of the root delay causes takes a value based on the assessment of its indicators. There are fourteen root delay causes in level A2, which are derived in section 4-3.

3- *(Vjk)* is the value of root delay cause's indicator (*k*) which measures a root delay cause (*j*). For each root delay cause, there are number of indicators. The indicators numbers for each root delay cause is (*m*).

The variables that are used in the model are from the unquantifiable/ qualitative type variables. These qualitative variable are expressed in a linguistic terms in reality, so they will be treated as linguistic variables. A linguistic variable is a variable whose values are words or sentences using either natural or artificial language. (Hsieh et al, 2004). The root delay indicators are described with linguistic variable. As illustrated before in section 4-4, all of these indicators are assessments of managerial and non quantitative criteria aspects.

6-3-2 Model mathematical

To get the value of resource shortage possibility (*Vi*) on level A1, the value of root delay causes (*Vj*) (level A2) is calculated first. The value of each root delay cause depends on the values of its indicators and the relative weight between these indicators. Multi-attribute theory provides the method to calculate a value based on lower level inputs based on preference. For level (A2) members, the value will be derived from equations (6-1) and (6-2):

$$Vj = \sum_{k=1}^{m} (Vjk) * (Wk - j) \qquad (6\text{-}1)$$

on the condition

$$\sum_{k=1}^{m} (Wk - j) = 1 \qquad (6\text{-}2)$$

Where;

- (*Wk-j*) is the relative importance of indicator (*k*) used to measure a root delay cause (*j*).This weight represents the relative importance between level A3 and A2.
- *m* is the number indicators for each root delay cause.

The value of possibility of resource shortage (*Vi*) will be calculated from equation (6-3) and (6-4)

$$Vi = \sum_{j=1}^{14} (Vj) * (Wj) * (Wj - i) \qquad (6\text{-}3)$$

on the condition

$$\sum_{j=1}^{14} (Wj - i) = 1 \qquad (6\text{-}4)$$

Where;

- (*Vj*) is the value of root delay cause that resulted from equation (6-1)
- *(Wj-i)* is the relative importance weight of root delay causes (*j*) with respect to certain type of resource shortage (*i*).

- *(Wj)* Absolute relative importance weight of root delay cause (*j*). This value represents the relative importance of root delay causes in project delays in general.
- 14 is the number of root delay causes.

Substituting equation (6-1) in to equation (6-4) the result to provide equation (6-5).

$$Vi = \sum_{j=1}^{14} (Wj) * (Wj - i) * \sum_{k=1}^{m} (Vjk) * (Wk - j) \text{.................} \quad \text{...(6-5)}$$

This equation will be used to determine the value of resource shortage possibility. This value depends on the value of root delay causes' indicators (*Vjk*) and the relative weights. These relative weights depend on aspects such as location of project, type of project and many other factors.

There are three mathematical steps required to obtain the value of resource shortage possibility in the RSP model. These steps are:

- Step1: determine the relative weights (*Wj, Wj-i and Wk-j*)
- Step 2: defining the root delay cause' indicators values
- Step 3: calculate the value of resource possibility

6-3-3 Model mathematical steps:

Step 1: Determining the relative weights (*Wj, Wj-i and Wk-j*)

There are many methods that can be used to estimate relative weights between independent variables. These weights are based on relative influence or preference judgement. These methods are either numerical based, or non numerical based. Numerical based weighting methods use a numeric scale to represent the level of importance or preference of a set of variables or criteria. A measure scale of 0-10 is commonly used to define the preference between a set of variables. Non numerical methods, are based on a rank or comparison between a set of variables or criteria (Pongpeng and Liston, 2003).

One of the numerical bases methods is the simple additive weight method (SAW), in which all the variables or criteria values are weighted by a suitable real score number measuring the importance of the variable or criterion, and then subsequently summing all variables scores. The weight for a variable or criteria will be relative to its contribution to the added number. Despite its simplicity, the SAW method is characterised drawback that no interaction among the attributes is admitted, since the preferential independence axiom is required. To overcome this drawback, methods such as Analytical Hierarchy Process (AHP) can be suggested (Saaty, 1980), and other tools such the Choquet integral have been developed (Al-Harbi, 2001).

Analytical Hierarchy Process (AHP) has been chosen to determine the relative importance because it is a useful tool in dealing with multi-criteria decision making problems, which are similar in hierarchy to the proposed DHPM structure and it has been successfully applied in many of construction industry research work (Al-Harbi, 2001, Cheung et al., 2001, Fong and Choi, 2000 and Mahdi et al, 2002). In addition to the AHP approach agrees well with the behaviour of a decision maker. The strength of this approach is that it organizes tangible and intangible factors in a systematic way, and provides a structured simple solution to the decision maker (Skibniewski and Chaol, 1990).

The AHP background is presented in section 6-4 and the application of AHP technique in determining the relative weights will be presented in detail in section 6-8.

<u>Step 2: Defining the root delay causes' indicators values</u>

Because the root delay causes indicators will be in a non quantifiable/ subjective qualitative values. *The fuzzy logic* basis will be used to represent these values. Background for fuzzy set and fuzzy logic is presented in section 6-5.

<u>Step 3: Calculating the value of resource shortage value</u>

To determine the value of resource shortage, *multi-attribute theory* will be used. Multi-attribute theory represents a family of methods that describes and models integral evaluation of different attributes. The criteria may represent different interests.

The values of resource shortage as shown in equation (6-5) is assumed as a multi-attribute function. The multi-attribute theory will be used also to get the values for possibility of resource shortage as shown in Equation (6-5). Background for multi-attribute theory is presented in section 6-7.

6-4 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a theory of measurement concerned with deriving dominant priorities from paired comparisons of homogeneous elements with respect to a common criterion or attribute (Saaty, 1994). AHP was introduced by Thomas Saaty (1980) to provide a simple multiple-criteria analytic method for evaluating alternatives solutions (Goicoechea, 1992). AHP helps in identifying priorities on the basis of the decision-maker's knowledge and experience of each problem. AHP takes into consideration judgements based on people's feelings and emotions as well as their thoughts (Saaty, 1994). The strength of AHP lies in its ability to structure a complex, multi-person, multi-criteria problem hierarchically and then to investigate each level separately, combining the results as the analysis progresses. The theory behind AHP can be briefly described as follows (Golden et al, 1989).

6-4-1 Theory of the AHP

AHP has the capacity to handle both quantitative and qualitative sets of criteria. AHP allows the user to establish criteria for decision-making in a hierarchical manner and analyses the complex decision problem by incorporating the user's knowledge-based preference (Hassell et al, 1992).

AHP theory depends on the pair-wise comparison between a set of criteria (Harker, 1989). This method is a way of converting qualitative measures into quantitative measures. All the paired comparison methods use the same principle in the sense that every expert compares each criterion with all other criteria to indicate preference. For example, if A and B are two criteria, an expert would say whether A is more important than B or the converse or of equal importance. The number of times each criterion is chosen over the other criteria is tabulated for each expert and then added together to determine the total number of times each criterion is chosen over all other criteria.

6-4-2 Mathematical foundations of the AHP

The basic mathematical concepts used in the AHP are summarised as follows:

(a) Assume the elements (criteria) C_1, C_2, ...Cn in some level in a hierarchy and denoting their normalised unknown priority weights by w_1, w_2...w_n, respectively. The value of w_i reflects the degree of importance of C_i with respect to C_i's.

(b) Construct a set of pair-wise comparison matrix (size n x n) for each level with one matrix by using scale measurement shown in Table 6-1. The pair-wise comparisons are carried out in terms of which elements dominates the other reciprocals are automatically assigned in each pair-wise comparison. These pair-wise comparisons are structured into an *n*-by-*n* reciprocal and positive matrix $A = (a_{ij})$, which is called the judgement matrix. Thus, given the matrix:

$$A = \begin{array}{c} \\ C_1 \\ C_2 \\ . \\ . \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & .... & C_n \end{array} \\ \left[\begin{array}{cccc} a_{11} & a_{12} & .... & a_{1n} \\ a_{21} & a_{22} & .... & a_{2n} \\ . & & .... & . \\ . & & .... & . \\ a_{n1} & a_{n2} & .... & a_{nn} \end{array} \right] \end{array}$$

Where $a_{ij} = 1/a_{ji}$ for all i, j = 1,2, ..,n, and a_{ij} is a value represents the relative importance of pair comparison of criteria ci to criteria Cj

Elements of matrix *A* are derived using the scale described in Table 6.1. There are $(n(n-1)/2)$ judgements required to develop an *n*-by-*n* judgement matrix, since reciprocals are automatically assigned in each pair-wise comparison. Notice that by using ratio scales, the estimated weights $w = (w_1, w_2...w_n)$ are only unique up to multiplication by a positive constant; this means that *w* is equivalent to *cw* where *c*>o.

(c) Calculate the criteria weights by calculating the eigenvalue for the judgement matrix. Saaty's method computes *w* as the principle maximum (right) eigenvalue (proper vector or characteristic vector) of the matrix *A*. Computing a vector of unknown weights or priorities $w = (w_1, w_2...w_n)$ for these objectives from the judgement matrix *A* using the following equation:

$$w_i = (\sum_{j=1}^{n} a_{ij} w_j) / \lambda_{max} \quad \text{for all } i, j, k = 1, 2, .., n. \qquad ......(6\text{-}6)$$

d) The eigenvalue method yields a measure for consistency. As shown by Saaty (1988), λ_{max} is always greater than or equal to *n* if and only if *A* is a consistent matrix, where *n* is the matrix size (Saaty, 1988). Thus, (λ_{max} - *n*) provides a measure of consistency.

Saaty (1988) defines the consistency index (CI) as:

$CI = (\lambda_{max} - n)/(n-1)$. .... (6-7)

Where λ *max* is the maximum eigenvalue and *n* is the matrix size.

Table 6-1: Scale of Relative Importance,[This table is reproduced from Saaty (1980)].

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance of both elements.	Two elements contribute equally to the property
3	Weak importance of one element over another.	Experience and judgement slightly favour one element over another.
5	Essential or strong importance of one element over another.	Experience and strongly favour one element over another.
7	Demonstrated importance of one element over another.	An element is judgement strongly favoured and its dominance is demonstrated in practice.
9	Absolute importance of one element over another.	The evidence favouring one element over Another is of the highest possible order of confirmation.
2,4,6,8	Intermediate values between two adjacent judgements	
Reciprocals	If activity i have one of the proceeding numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

This consistency index is incorporated in measuring the reliability of the results of AHP. Saaty (1988) compared the CI to the index derived from a completely arbitrary matrix whose entries are randomly chosen. Saaty has obtained the results shown in

Table 6-2, where n represents the dimension of the particular matrix and RI denotes the random index computed from the average of the CI for a large sample of random matrices.

(CR) is defined as the ratio of the CI to the RI. Thus CR is a measure by the following equation:

$$CR = CI / RI \qquad \text{.......}(6\text{-}8)$$

Experience suggests that the CR is acceptable if it does not exceed 0.10 (Shtub *et al*, 1994).

Table 6-2: Random Inconsistency Index (R. I.)-(Saaty, 1988)

Matrix Size (n)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

6-5 Fuzzy Background and Fuzzy Basis:

6-5-1 Introduction

The information used in all engineering applications is either deterministic, or indeterministic or uncertain information. Unfortunately most of engineering science is based on that the information are deterministic, which does not reflect real life. Uncertainty of information can be the result of many things; because of complexity, ignorance, chance, randomness, imprecision inadequate information, lack of knowledge, vagueness. Uncertainties can be classified into two main groups: random or probabilistic uncertainty and vagueness uncertainty. Historically, probability theory has been the primary tool used to represent uncertainty in mathematical models. Because of this, all uncertainty was assumed to follow the characteristics of random numbers. It is in the most complex system where only a few numerical data exist and where much imprecision or information may be available, fuzzy reasoning provides a way to understand the system behaviour by allowing approximate interpolating between observed inputs and output situations (Ross, 1994). Fuzzy system is less accurate than other mathematical algorithms in providing the ultimate understanding of the problem, but fuzzy system can focus on modelling the problems of imprecision or vague information. Fuzzy sets can provide a mathematical way to represent vagueness in humanistic systems (Bandemenr and Gottwald, 1995). Fuzzy sets can deal with non-random uncertainty, especially uncertainty in natural language. Fuzzy set theory is an excellent tool for modelling the kind of uncertainty associated with vagueness, with imprecision and/or with lack of information regarding a particular element of the problem in hand.

Fuzzy set theory is not intended to replace Probability theory but rather to provide solutions to problems that lack mathematical rigor inherent in probability theory. The main concepts associated with Fuzzy set theory are membership functions, linguistic variable, natural language computation, linguistic approximation, fuzzy set arithmetic operations and fuzzy weighted average (Schmucker 1984).

6-5-2 Background

Zadeh, (1965) proposed the idea that set membership is the key to decision making when faced with uncertainty. Zadeh (1965) extended the work in possibility theory in to a formal system of mathematical logic for representing and manipulating 'fuzzy' terms, called fuzzy logic. Using fuzzy logic, sets may be defined using vague, linguistic terms such as good market conditions, attractive project, or highly risky. These terms cannot be defined with a precise single value, but fuzzy set theory provides a means by which these terms may be formally defined in mathematical logic.

After Zadeh's paper on fuzzy sets (Zadeh, 1965), many theoretical developments in fuzzy logic took place all over the world. Fuzzy set theory was developed specifically to deal with uncertainty that are not statistical in nature (Klir and Yuan, 1995).

6-5-3 Fuzzy set and fuzzy logic system

Fuzzy set and fuzzy logic will be used to present the uncertainty of future events not based on random.

The fuzzy theory sets provides a suitable method of analyzing complex systems and decision processes when the pattern of indeterminacy is the result of inherent variability or vagueness rather than randomness (Zadeh, 1994). Fuzzy set theory has been used to tackle ill-defined and complex problems due to incomplete and imprecise information.

Fuzzy-logic in general can enable effectively and efficiency quantifies imprecise information, to reason and make decisions based on vague and incomplete data (Baloi and Price, 2003).

Fuzzy logic system is used to capture both quantitative and qualitative information in the form of numerical and linguistic data.

The fuzzy logic system has these features (Yan et al, 1994):

a. Input: the input is a subset of variables which are described in a linguistic words; high, good, bad..
b. The process is using if-then statement to link between the set of input and set of outputs. IF X is high, Y is low.
c. Out put which is the crisp value of averaging the processed input. This crisp value is determined by defuzzifcation of the output.

6-5-4 Difference between fuzzy set and crisp set

The crisp set or ordinary set has definite boundary to the set, for example a set of people "between" 1.5 to 2.1 meter tall is a crisp set all of its member should be in the tall range from 1.5 to 2.1 meter. So any x, arbitrary person from the universe, and X is its membership to that crisp set. The membership can be represented mathematically as:

$$X_A(x) = \begin{cases} 1, & x \in A \\ 0, & x \notin A \end{cases} \quad \text{...} \quad (6\text{-}9)$$

where, the symbol X_A gives the indication of an unambiguous membership of element x in set A, and symbols $\in$, $\notin$ denote contained-in and not-contained in the crisp set. In crisp set, the membership value is either 1 when the element belongs to the set, or 0 if it is not belongs to that set. Zadeh expended the notion of primary membership to accommodate various "degree of membership" on the real interval [0, 1], where 0 denote there is no membership and 1 denotes that there is fully membership. The infinite number of values between 0,1 can represent the degree of membership for an element x to a universe. The membership function, denoted μ takes a value from 0 to 1. The key difference between crisp and fuzzy sets is their membership function; a crisp set has unique numbers 0, 1 but fuzzy set has infinite number of membership function. The flexibility of fuzzy in dealing with the member of membership function as it can get the maximum to be as crisp in some applications. In fuzzy set, the membership is presented mathematically as

$\mu(x) \in [0,1]$ .... (6-10)

This is the value that define the degree of belongs that element (x) to a fuzzy set.

A fuzzy set is a set whose elements have varying degrees of membership (Schmucker 1984). Membership functions in fuzzy set theory plays a similar role to that of probability distribution functions in probability theory. Membership functions used to represent uncertainty.

These membership values are generally assigned based on subjective judgment with the help of experts and they can be changed according to the application.

In general, any subset $A \in$ universal may be represented by m discrete values (or continuous intervals) of x together with membership values (or continuous membership functions) μ_A ass following:

$A(x|\mu_{Ax})=[x_1|\mu(x_1), x_2|\mu(x_2), \ldots\ldots\ldots\ldots\ldots x_m|\mu(x_m)]$ .... (6-11)

Writing $(x|\mu)$ does not mean a division.

Fuzzy set definition is characterised by the values of the set (x) and their membership functions (μ). There are many of fuzzy set graphical presentation, the most and easiest one to use is the triangular shape.

For example, let x be the level of labour experience, which ranges from excellent experience to no experience. The membership degree excellent experience x=1, while function degree for no experience x=0. By dividing the range of labour experience into increment of 0.1 and the fuzzy membership function in triangular shape. The level of labour experience may be high experience, average experience and low experience. Set A is a linguistic value describing the short experience. Fuzzy set A can be represents as:

$A=[x1=1|\mu_A(x1)=0,\ x2=0.9|\mu_A(x1)=0,\ x3=0.8|\mu_A(x1)=0,\ x4=0.7|\mu_A(x1)=0,\ x5=0.6|\mu_A(x1)=0,\ x6=0.5|\mu_A(x1)=0,\ x7=0.4|\mu_A(x1)=0.2,\ x8=0.3|\mu_A(x1)=0.4,\ x9=0.2|\mu_A(x1)=0.6,\ x10=0.1|\mu_A(x1)=0.8,\ x11=0|\mu_A(x1)=1]$,which can be written as:

$A(x|\mu_x)=(1|0, 0.9|0, 0.8|0, 0.7|0, 0.6|0, 0.5|0, 0.4|0.2, 0.3|0.4, 0.2|0.6, 0.1|0.8, 0|1)$

For this fuzzy set, the values of x are 0.4,0.3,0.2,0.1,0 which have membership values 0.2, 0.4, 0.6, 0.8, 1.0 respectively. All other x have 0 membership function, co it can be written as:

$A(x|\mu_x)$=(0.5|0.0, 0.4|0.2, 0.3|0.4, 0.2|0.6, 0.1|0.8, 0|1)

These sets can be represented in triangle shapes as in Figure (6-2).

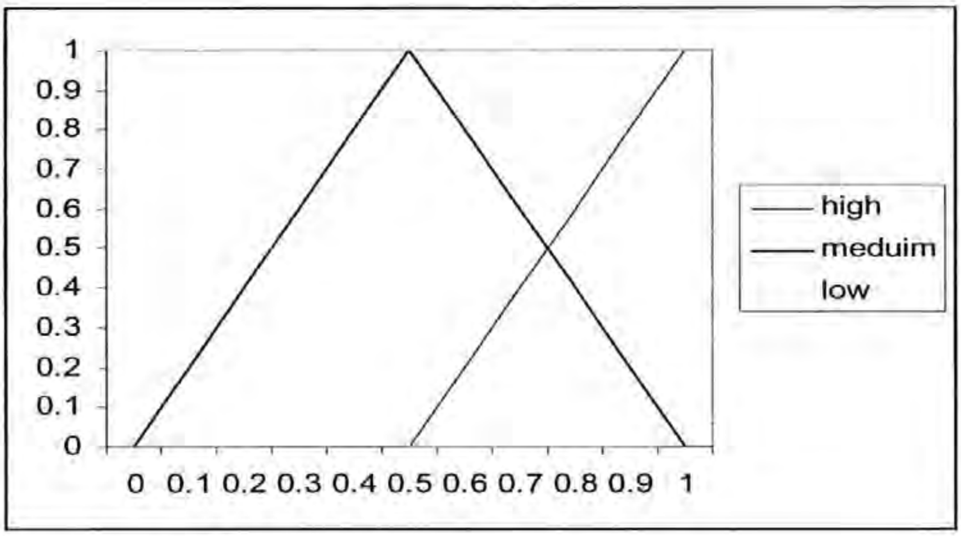


Figure (6-2) Triangular Fuzzy Membership Function

6-5-5 Application of fuzzy sets, logic and ruled bases in construction industry modelling.

Fuzzy logic has been used in many of construction management problems including risk analysis, selection of contractors and resource allocation as described below.

a) Fuzzy set, logic and ruled bases models in application in risk analysis in construction industry

There have been many attempts to apply fuzzy logic within the construction risk management domain. Kangari (1988) presents an integrated knowledge-based system for construction risk management using fuzzy sets. His system called Expert-Risk performs risk analysis before and during the construction phase. Chun and Ahn (1992) proposed the use of fuzzy set theory to quantify the imprecision and judgment at uncertainties of accident propagation by using an accident event tree. Peak et al, (1993) proposed the use of fuzzy sets for the assessment of bidding prices for construction projects. Tah et al (1993) used a linguistic approach to evaluate the contingency risk allocation that the contractor may put in the tendering stage. Ross and Donald (1996) used the basis of linguistic approach and fuzzy logic for assessing the management of hazardous waste sites. Ross and Donald (1996) used fuzzy set theory for the mathematical representation of fault trees and event trees as used in risk management problems. Wirba et al. (1996) used verbal linguistic values to represent the likelihood of a risk event occurring, the level of dependence between risks, and the severity of a risk event. Carr and Tah (2001) used fuzzy set theory and causal relationship model to represent the values of risk factors and the likelihood of risk factors to predict the combined effect on earthmoving productivity. Okoroh and Torrance (1999) used fuzzy sets for earthmoving subcontractor's risk elements in construction refurbishment projects. Blair and Ayyub (1998) used the combination of fuzzy set and probabilistic stochastic modelling to evaluate risk analysis of construction of Mobile Offshore Base (MOB). Choi et al (2004) used the fuzzy based to consider the uncertainty range of of risk factors of underground factors in construction projects.

b) Fuzzy set application in contractor selection

Wong et al (2000) combined fuzzy logic with multi-attribute and probability to project selection. Lam et al (2000) used fuzzy neural network to rank prequalification of contractor instead of crisp neural network. NG et al, (2002) derived a method to estimate fuzzy membership function that can be used in project procurement selection. Hsieh et al (2004) used the combination of fuzzy set theory and analytical hierarchy process which is called Fuzzy Analytical Hierarchy Process (FAHP) to select the planning and design professionals for public works. They stated that the use of Fuzzy Analytical Hierarchy Process (FAHP) or Fuzzy Multiple Criteria Decision Making (FMCDM) has been widely used to deal with decision making in decision making problems in many application fields.

c) Fuzzy in determining activity duration

The predication of project activity duration is largely influenced by the number of interrelated factors. These factors are based on historical data, judgments and expectations. The project activity duration is dependent upon many of subjective and human based judgments (Laufer and Cohenca 1990). Ayyub and Halder (1984) pioneered the concept of fuzzy set theory to evaluate the impact of qualitative factors on the duration of construction project activities. Boussabaine (2001) used a neurofuzzy model to predict construction project duration. Neurofuzzy combines neural network and fuzzy set logic. Lorterapong and Moselhi (1996) used fuzzy set logic to determine uncertainty in activity duration and the fuzzy relations to calculate the fuzzy forward and backward path in network calculations.

d) Other applications in the construction industry

There are many application of fuzzy set in construction problems modeling, these either use fuzzy logic alone or combined with another analytical tool. Lue et al (2001) used a combination of fuzzy set logic and genetic algorithm in a scheduling problem of time-cost trade-off. Lue et al, (1999) used the same combination in scheduling resource leveling.

Lin and Chen (2004) used linguistic terms variables and fuzzy values to take a bid/ or no bid decision making process.

Lam et al (2001) made a mathematical system using a combination of fuzzy multiple-objective decision making theory and the fuzzy reasoning technique to suggest the optimal path of corporate cash flow that results in the minimum use of resources.

Zhang and Tam (2003) used the fuzzy sets in representing the vague multiple objectives in resource allocation problems. Fuzzy decision-making was adopted to combine the multiple objectives that are represented by fuzzy sets associated with membership functions (Bellman and Zadeh, 1970). Kumar et al (2000) used the fuzzy logic and fuzzy set to calculate the required working capital for a project.

From the above presentation, it can be concluded that the fuzzy logic is well defined and it successfully used in many of construction management application. From the listed applications in construction industry, fuzzy logic never used to model the construction delay. This study attempted to use the fuzzy logic in construction delay modelling.

6-6 Multi-Attribute Theory (MAT)

Multi-criteria analysis establishes preferences between options or attitudes to an explicit set of objectives that the decision making body has identified and for which it has established measurable criteria to assess the extent to which the objectives have been established (Jennings and Walton, 1998). Keeney and Raiffa (1976) discussed the details of the utility theory and proved its applicability in the evaluation and selection of the optimum alternative.

Multiple criteria decision making (MCDM) is an analytical method to evaluate the advantages and disadvantages of alternatives based on multiple criteria. MCDM can be classified into two categories: multiple objective programming and multiple criteria evaluation (Hsieh et al, 2004). As this work is related to evaluate the value of resource shortage, the multiple criteria evaluation will be emphasised. There are many approaches used in multi-criteria decision making such as linear additive models, outranking. Multi-attribute utility theory used to estimate a single value to express the decision maker's overall valuation of an attitude (Grubbstorm, 1988).

The Model A: RPS model will use the linear multi-attribute theory to predict the resource shortage possibility value as shown in equation (6-5).

6-7 Model Resource Shortage Possibility (RSP) Model Application

To use the RSP model calculations, a prototype computer program is prepared. It uses the structure of the modified RSP model shown in Figure 5-2 and the steps of calculations described in sections 6-3-2 and 6-3-3. It uses the mathematical techniques presented in sections 6-4, 6-5 and 6-6.

This prototype computer program is tested to compute the possibility of resource shortage of a real construction project.

6-8 RSP Model Prototype Computer Program

The prototype computer program has these steps:

- Determining the absolute relative importance weight of root delay cause (*j*); (*Wj*).
- Determining the relative importance of indicator (*k*) to measure a root delay cause (*j*); (*Wk-j*)

- Determining the relative importance weight of root delay causes (*j*) in respect to certain type of resource shortage (*i*); *(Wj-i)*.
- Construct Fuzzy-Rules that can be used in the prototype
- Using a software to compile the model entities. The used software is Matlab® 6.1- Math-solution product.

6-8-1 Determining the absolute relative importance weight of root delay cause (j); (Wj)

As mentioned in section 6-3-3, the AHP is used to determine the relative weights between the RSP model levels and the absolute weight for the root delay causes. These relative importance weights are obtained from analysing industry experts' judgement for the model variables. In chapter 5, section 5-10, six participants participated in the Delphi round of interview questionnaire. The answers from these six participants are used to obtain the relative importance weights.

Table 6-3 represents the root delay causes and their code. It is the same coding system used in chapter 5 and shown in Appendix D.

To obtain the root delay causes relative importance weights (*Wj)*, experts in construction industry were asked to evaluate the level of influence of each one of the root delay causes in project delay occurrence. The level of influence describes the relative importance of root delay causes in respect to construction project delay. Table 6-4 describes a sample of a respondent answers. As described in section 6-4 AHP technique uses the pair-wise comparison between each two criteria with respect to a certain objective. For example, criteria A is absolutely important than criteria B with respect to cost. It is recommended to make direct pair-wise comparison when the number of criteria to be judged is not big (Scholl et al 2005). The usage of direct pair-wise comparison for the fourteen root delay causes will not be valuable, so the answers collected from each one of the participants are treated as pair-comparison then apply AHP basis to obtain the relative weights between the root delay causes.

Table 6-3: Extracted Root Delay Causes and Their Codes

No.	Root Delay Cause	Code
1	Designer management efficiency	DM
2	Quality of design work documents	DD
3	Contractor management capabilities	CM
4	Contractor financial stability	CF
5	Owner management efficiency	OM
6	Owner financial stability	OF
7	Efficiency level of communication between project parts	MM
8	Level of interactions between project parties in pre-construction phase	NT
9	Level of trust between project parties	TR
10	Level of project complexity and required technology	CT
11	Level of objectives harmony between project parties	OB
12	Specific site characteristics	SC
13	Specific project characteristics	PP
14	Project contract and procurement strategy	PS

Table 6-4: Sample of expert answer for root delay causes influence

Root delay cause	Code	Respondent answer
Designer management efficiency	DM	Average
Quality of design work documents	DD	High
Contractor management capabilities	CM	High
Contractor financial stability	CF	Very high
Owner management efficiency	OM	Low
Owner financial stability	OF	High
Efficiency level of communication between project parts	MM	High
Level of interactions between project parties in pre-construction phase	NT	Average
Level of trust between project parties	TR	Average
Level of project complexity and required technology	CT	Average
Level of objectives harmony between project parties	OB	Average
Specific site characteristics	SC	High
Specific project characteristics	PP	High
Project contract and procurement strategy	PS	High

For example, to obtain the relative weights for the fourteen root delay causes for the expert answer shown in Table 6-4, set of pair comparison was used. For example, if any two of the root delay causes take the same importance level in the expert answers, they will be treated as equally importance and get an intensity of importance to 1 as shown in Table 6-1. And if the respondent agreed to make one root delay is high and other is average. This means that the difference between the two root delay causes is one level of importance. Or it can be said that there is weak importance of one element over another, intensity equal to 3 as shown in Table 6-1. For example for expert answers shown in Table 6-4, the pair comparison between Designer management efficiency (DM) and Quality of design work documents (DD) shows that DD is high and DM is average. This relationship can be translated as DD is slightly importance than DM and the importance scale of DD to DM is 3.

Table 6-1 which represents the scale of relative importance developed by Saaty, 1980, has been converted to Table 6-5 to represent the pair-comparison relative importance intensity for any two pair-wise comparisons between any two of the root delay causes for the same person with respect to certain criteria, in this case it will be the delay in general.

Based on the pair comparison of the fourteen root delay causes and by using the importance intensity shown in Table 6-5, a square matrix of 14*14 can be constructed. Table 6-6 represents the matrix for expert sample answers.

Table 6-5: Used Pair-Comparison Between Level of Effect

Impact for two root delay causes	**Importance Intensity**
Same importance; e g average and average	1
One level of importance more; e g high and average	3
Two levels of importance more; e. g. average and very high	5
Three levels of importance more; e. g. low and very high	7
Four levels of importance more; e.g. very low and very high	9

Table 6-6 . Expert sample example judgment matrix

	DM	DD	CM	CF	OM	OF	MM	NT	TR	CT	OB	SC	PP	PS
DM	1.00	0.33	0.33	0.20	3.00	0.33	0.33	1.00	1.00	1.00	1.00	0.33	0.33	0.33
DD	3.00	1.00	1.00	0.33	5.00	1.00	1.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00
CM	3.00	1.00	1.00	0.33	5.00	1.00	1.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00
CF	5.00	3.00	3.00	1.00	7.00	3.00	3.00	5.00	5.00	5.00	5.00	3.00	3.00	3.00
OM	0.33	0.20	0.20	0.14	1.00	0.20	0.20	0.33	0.33	0.33	0.33	0.20	0.20	0.20
OF	3.00	1.00	1.00	0.33	5.00	1.00	1.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00
MM	3.00	1.00	1.00	0.33	5.00	1.00	1.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00
NT	1.00	0.33	0.33	0.20	3.00	0.33	0.33	1.00	1.00	1.00	1.00	0.33	0.33	0.33
TR	1.00	0.33	0.33	0.20	3.00	0.33	0.33	1.00	1.00	1.00	1.00	0.33	0.33	0.33
CT	1.00	0.33	0.33	0.20	3.00	0.33	0.33	1.00	1.00	1.00	1.00	0.33	0.33	0.33
OB	1.00	0.33	0.33	0.20	3.00	0.33	0.33	1.00	1.00	1.00	1.00	0.33	0.33	0.33
SC	3.00	1.00	1.00	0.33	5.00	1.00	1.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00
PP	3.00	1.00	1.00	0.33	5.00	1.00	1.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00
PS	3.00	1.00	1.00	0.33	5.00	1.00	1.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00

The relative importance weight will be the eigenvalues of this matrix based on the maximum eigenvalue (Saaty, 1980).The summation of weights should be 1. The relative weight for the expert example will be:

$$\begin{bmatrix} DM \\ DD \\ CM \\ CF \\ OM \\ OF \\ MM \\ NT \\ TR \\ CT \\ OB \\ SC \\ PP \\ PS \end{bmatrix} \text{=max. eigen value (14.2589),} \begin{bmatrix} 0.03206 \\ 0.08782 \\ 0.08782 \\ 0.20933 \\ 0.01567 \\ 0.08782 \\ 0.08782 \\ 0.03206 \\ 0.03206 \\ 0.03206 \\ 0.03206 \\ 0.08782 \\ 0.08782 \\ 0.08782 \end{bmatrix}$$

Consistency Index (CI) which is used to check the matrix consistency (Saaty, 1980) is calculated to this matrix. CI is calculated by applying equation 6-7.

CI= (14.2589-14)/(14-1)= 0.0199.

Then calculate the Consistency Ratio (CR) for this matrix by applying equation (6-8). CR is equal to CI/RI. In Table 6-2, RI for matrix of size 14 is 1.57. CR equals to 0.0125, less than 0.1 which means the CR value is acceptable.

This process of applying AHP and getting the relative importance between all root delay causes was repeated for the six participants. A matrix for each respondent answers will be constructed, calculate the eigenvalues for each, then evaluate the consistency ratio (CR).

The average weights for each root delay causes resulted from the six participants are presented in Table 6-7.

Table 6-7 Root delay causes relative weights (*Wj*) resulted by AHP process

CODE	**Root Delay Cause**	**Average Relative Weight (*Wj*)**
DM	Designer management efficiency	0.067
DD	Quality of design work documents	0.058
CM	Contractor management capabilities	0.111
CF	Contractor financial stability	0.121
OM	Owner management efficiency	0.063
OF	Owner financial stability	0.113
MM	Efficiency level of communication between project parts	0.075
NT	Level of interactions between project parties before project start	0.039
TR	Trust between project parties	0.031
CT	Level of project complexity and required technology	0.040
OB	Level of objectives harmony between project parties	0.052
SC	Specific project site characteristics (location, underground, weather, environmental,..)	0.067
PP	Specific project characteristics	0.076
PS	Project contract and procurement strategy	0.086

6-8-2 Determining the relative importance of indicator (k) to measure a root delay cause (j); (Wk-j)

The six participants answers regarding the importance of root delay causes' indicators were analysed to obtain the relative importance weight of indicators to measure or assess the root delay cause.

For each root delay cause, numbers of indicators were presented in order to assess or predict the level of each root delay cause. The indicators were derived in chapter 4 and tested in chapter 5. Each root delay cause has certain number of indicators, for example designer management efficiency has 4 indicators (DM.01, DM, 02, DM.03, DM.05).

The AHP process is used to determine the relative importance for each root delay indicator. AHP is applied to determine the root delay causes absolute weight as in section 6-8-1. For each respondent 14 square matrixes of different sizes will be constructed, one for each root delay cause's indicators. The eigenvalue is calculated to represent the relative importance of indicator *(k)* to measure root delay cause *(j)*. The consistency ratio (CR) was then calculated. The entire consistency ratios are less than 0.1. Table 6-8 presents the relative weights for root delay causes' indicators. These values are calculated by averaging the eigen-values from each root delay cause's indicators for each respondent.

6-8-3 Determining the relative weight of root delay cause (j) with respect to certain type of resource shortage (i); (Wj-i)

The results of the Delphi expert answers will be used to determine *(Wj-i)* relative weights. The expert is asked to evaluate the level of importance of each one of root delay causes with respect to material, labour, equipment, information and space resource shortage. The relative weight of each root delay cause to the specific resource type is calculated using AHP as before.

Five 14 x 14 matrixes were constructed for each respondent. 14 is the number of root delay causes. The eigen values and consistency ration (CR) for each were calculated.

Table 6-8: Root Delay Causes' indicators Relative Importance

Root delay Cause	Indicator	Relative weight
Designer management efficiency (DM)	DM.01	0.462
	DM.02	0.191
	DM.03	0.175
	DM.05	0.172
Quality of design work doc. (DD)	DD.01	0.500
	DD.03	0.500
Contractor management capabilities (CM)	CM.01	0.185
	CM.02	0.187
	CM.03	0.064
	CM.05	0.185
	CM.06	0.187
	CM.07	0.064
	CM.08	0.064
	CM.10	0.064
Contractor financial stability (CF)	CF.01	0.064
	CF.02	0.064
	CF.03	0.153
	CF.04	0.356
	CF.05	0.356
Client management efficiency (OM)	OM.01	0.430
	OM.02	0.142
	OM.03	0.142
	OM.04	0.144
	OM.05	0.142
Client financial stability (OF)	OF.01	0.250
	OF.02	0.250
	OF.03	0.250
	OF.04	0.250
Efficiency level of communication between project parts (MM)	MM.01	0.289
	MM.02	0.106
	MM.03	0.107
	MM.04	0.106
	MM.05	0.290
	MM.06	0.102

Root delay Cause	Indicator	Relative weight
Level of interactions between project parties before project start (NT)	NT.01	0.478
	NT.02	0.172
	NT.03	0.175
	NT.05	0.175
Trust between project parties (TR)	TR.01	0.429
	TR.02	0.429
	TR.03	0.143
Level of project complexity and required technology (CT)	CT.01	0.385
	CT.02	0.123
	CT.03	0.123
	CT.04	0.123
	CT.05	0.123
	CT.06	0.123
Level of objectives harmony between project parties	OB.02	0.725
	OB.03	0.275
Specific project site characteristics (SC)	SC.01	0.346
	SC.02	0.129
	SC.03	0.129
	SC.04	0.129
	SC.05	0.046
	SC.06	0.129
	SC.07	0.046
	SC.08	0.046
Specific project characteristics (PC)	PP.01	0.484
	PP.03	0.172
	PP.04	0.172
	PP.05	0.172
Project contract and procurement strategy (PS)	PS.01	0.333
	PS.02	0.333
	PS.03	0.333

For resources such as space, in which 6 root delay causes have no impact on space shortage as the modified RSP, Figure 5-2, a matrix of 8 * 8 is used to obtain the relative weights of space shortage root delay causes. Table 6-9 shows the (Wj-i) for material shortage for example.

Table 6-9 (*Wj-m*) for material shortage

CODE	**Root Delay Cause**	**Average Relative Weight (*Wj-m*)**
DM	Designer management efficiency	0.021
DD	Quality of design work documents	0.028
CM	Contractor management capabilities	0.114
CF	Contractor financial stability	0.097
OM	Owner management efficiency	0.045
OF	Owner financial stability	0.065
MM	Efficiency level of communication between project parts	0.079
NT	Level of interactions between project parties before project start	0.076
TR	Trust between project parties	0.043
CT	Level of project complexity and required technology	0.067
OB	Level of objectives harmony between project parties	0.032
SC	Specific project site characteristics (location, underground, weather, environmental,..)	0.085
PP	Specific project characteristics	0.065
PS	Project contract and procurement strategy	0.102

6-8-4 Construct Fuzzy-Rules that can be used in the prototype

The model depends on the multi-criteria theory to get a value of the possibility of resource shortage (Vi). The inputs are the value of root delay cause indicators and the relative weights between model levels from. The input of root delay cause indicator will be in linguistic word. Fuzzy logic theory is used to deal with these types of data.

Fuzzy rule based models are the models that use the if-then rules in fuzzy data approach.

Based on the Boolean algebraic theory (Ross, 1995)

$$if\ x \rightarrow y\ and\ y \rightarrow z\ then\ x \rightarrow z \quad \text{... (6-12)}$$

IF x, THEN y and IF y THEN z. This if statement can be used as IF x, THEN z.

In prototype model application, assuming that x is the indicator (levelA3), y is the root delay cause (level A2) and z is the possibility of resource shortage (level A1). These IF-THEN rules are built to represent the effect of each one of the root delay causes' indicators (*Vjk*) in resource shortage (*Vi*). The relative weight of this effect is determined by multiplying *(Wj), (Wk-j) and (Wj-i).*

For example:

- IF the design revision policy (DM.03) is Low, THEN the level of designer management Efficiency (DM) is Low. If designer management Efficiency (DM) is Low, THEN the possibility of material shortage (*Vm*) is HIGH.

  This statement can be represented as:

  IF the design revision policy (DM.03) is low, THEN the possibility of material shortage (*Vm*) is HIGH.

  The effect of this indicator in material shortage possibility is calculated by the weights *(Wj), (Wk-j) and (Wj-i*) as shown in equation 6-5.

IF-Then rules were used to represent the effect of all root delay cause' indicators on each one of the resources shortage.

6-8-5 Computer Fuzzy Interface Application Program

To complete a fuzzy interface if-then rule based model, MATLAB software was used to build a fuzzy rule-based model. (MATLAB® 6.1), MathWorks Co. software was used as the fuzzy interface using IF-THEN rules. The inputs for this program are the user values for the root delay cause' indicators *(Vjk)*. These values will be represented in linguistic terms. Five separate programs were designed for each one of the resource type. 200 IF-THEN rules were designed to represent the effect of the root delay causes in each one of the main resources shortage.

The output is the crisp value of the possibility of resource shortage, this value will be used as one of the inputs of Model B- (PPD) model as shown in Figure 3-3. A sample of the program is attached in Appendix G

6-9 Prototype Model Testing

The prototype computer program was tested in an application to the construction industry project, this was achieved by using a workshop. A workshop questionnaire is designed to collect data from project. These data are the root delay causes' indicator values, which are the program inputs.

The workshop was held on a construction project and included the project parties to complete and discuss the workshop questionnaire. The collected values are entered to the prototype model to get the results of the possibility of resource shortage. The details of the testing steps are presented in the following sections.

6-9-1 Workshop Questionnaire Design

A workshop questionnaire is designed to collect data regarding the root delay causes' indicators for the project under consideration.

The data that are listed in the workshop questionnaire are of the subjective type to assess each one of the root delay causes' indicators. A copy of the workshop questionnaire is shown in Appendix H.

The workshop questionnaire was bi-language to ensure better understanding by all project parties.

6-9-2 In Site Workshop

The workshop was held at a construction project in Kuwait, where the author is living and working. The project was a building project located in Kuwait. The project size is 3,000 m^2 of land in one of the biggest most crowded and commercial streets in Hawali-Kuwait. The project volume is 3.75 MKD (KD=1.85 £). The building is consisted of two basements, ground, mezzanine and 15 typical floors. The purpose of the building is business trading project. All stories in the shopping mall (the two basement, ground and mezzanine floors) and all the offices in the typical floor tower will be rented.

The owner is one of the biggest trading companies in Kuwait, the Al-Bahr Group. The contractor is Al-Bahr contracting company. Despite the contractor being in of the owner's ownership, it awarded the project using the standard bidding strategy, design-bid-built with the least cost tender. KTC-Kuwaiti Technical Consulting office was the designer. KTC supervision staff were responsible for the quality control of the technical parts in the project. The project planning programme was in CPM technique and the estimate finish date based on the scheduling is 24 months as per contract. The starting date of the project was in 01/03/03.

The workshop duration was about two hours starting by introducing the purpose of the workshop and the delay hierarchy model ideas. Five of the project parts: two from the consultant, two from the contractors and a owner representative participated in this workshop. A workshop questionnaire was distributed to the project players. They were asked to judge the value from a sort of predefined values for each one of the indicators of the root delay causes. The participants resulted are presented in Appendix I.

6-9-3 Prototype Model Testing

The values for root delay causes' indicators judged by each one of the workshop participant were used as inputs for the designed prototype computer program. Five possibility values for resource shortage resulted from each participants' answers. These values were then averaged. The possibility of the resource shortage was as following:

(Vm) Material shortage possibility is 0.35

(Vl) Labour shortage possibility is 0.25

(Vq) Equipment shortage possibility is 0.28

(Vf) Information shortage possibility is 0.32

(Vs) Space shortage possibility is 0.22

In reality the project is still in progress and the expected date to finish will be the end of this year. The reasons for these delays are coming from the material shortage, which coincide with the model output. When the project finish a comparison study with the model output will be suggested.

6-10 Summary

This chapter presents the attempt to apply the proposed model of Resource Shortage Possibility Model. The prototype program was presented. An attempt to use it in a real construction site revealed that this is viable.

The output of the model will be the crisp values of the resource shortage possibility. These values will be used as an one of the inputs required for Model B (PPD) application as will be discussed in chapter 7.

Chapter 7

Model B: Predicting Project Delay (PPD) Model

7-1 Introduction

This chapter introduces the basis for the Model B: Predicting Project Delay (PPD) model. This model is the second part of the proposed Delay Hierarchy Propagation Model (DHPM) as shown in Figure 3-3. The PPD model has two objectives: (i) to predict the probability of project completion time for a construction project exposed to uncertain resource shortage and (ii) to highlight the critical activities and resources that can be efficiently managed to mitigate the effects of probable delays.

As shown in Figure 3-3 the outputs of Model A: RSP model, will be the inputs to Model B: PPD model. The possibility of resources shortage will be the risk factor that will affect the project to delay. The output of Model B: PPD is the probable finish time of the project and identify the expected critical areas for delay.

PPD uses the theory of stochastic networking to predict the probability of the project finishing date. This model is used in the stream of planning and scheduling as one step of project management.

This chapter starts by presenting a background of planning and scheduling in construction projects, the details of PPD model are presented and an application of the model in a numerical example is then illustrated.

7-2 Planning and scheduling in construction:

Planning construction operations involves the determination of what must be done, how it is to be performed, and the sequential order in which it will be carried out.

Scheduling determines calendar dates for the start and completion of project components (Clough et al 2000).

Griffith and Watson (2004) defined planning as the process of determining, analyzing, devising and organizing the resources required for a construction project and stated that planning and scheduling are two of the most traditional of all construction management functions. The core element of planning is the establishment of a programme which reflects the planning process in relation to real time. Planning, scheduling and control of the functions, operations and resources are among the most challenging tasks faced by construction management professionals (Barrie and Paulson 1992).

Griffith and Watson (2004) stated that the key steps to conduct a network are:

1- Determine the project activities
2- Determine the logical relationship between project activities
3- Determine the duration of each activity
4- Determine the time indicators, which identify the starting, ending time for each activity and the expected finish date for the project

The planning and scheduling process in a construction project starts by defining the project activities or tasks. These activities can be identified by studying the project parties, components, drawings, specifications, quantities and contract. One of the most common techniques used to get the project activities is by using the Work Breakdown Structure (WBS) approach. WBS is a technique used to breakdown the scope of work into manageable pieces (Ahuja, 1994). WBS provides the list of activities that can represent the project elements but without order. The level of breakdown is based on the required level of activity details.

Networking of activities is used to represent the flow of activities execution. A network consists of activities and links. Each activity represents a significant and definable task in a construction project, while links are used to indicate the logical order between tasks. A path is a connection of activities in the whole network. Failure to complete the project on time occurs when one or more paths take longer time to complete than expected. There are many types of networks that are used to represent the relationship between project activities. Activities on arrow, activity on node and precedence diagrams are the most common. The project activities, and thereby the scheduling of these activities, have interrelationships arising from physical, technical and other consideration. Networking techniques have been found to be useful in the proper planning, scheduling, and control of project activities (Pillai and Tiwari 1995).

For each activity an accurate estimate for activity duration is essential. The estimate of construction activity duration is a process of establishing the quantity of the work involved and determining the time required to complete the activity by considering the labour and plant resources needed. There are, principally, two ways, in which the labour and plant rates are obtained: (i) from experience or (ii) from building pricing books (Griffith and Watson, 2004). Determining the time required to undertake an operation is a more complicated matter.

The time estimate resulting from comparing work volume to the required resources is a deterministic value, while construction operations involve many uncertain variables and require experts to evaluate the risk and evaluate the effect of the uncertainty on activity duration. Sawhney (1997) stated that scheduling of a construction project requires incorporating risk and uncertainty in the estimating of activity time and the modelling of dynamically allocated resources.

There are two main networking techniques types; deterministic or stochastic. The type of networking depends on the estimate method for activity duration.

7-3 Deterministic Networking

The Critical Path Method (CPM) is the most common scheduling technique that uses deterministic networking to project programme. CPM was developed in the 1950's to assist in scheduling maintenance shutdowns of chemical processing plants. CPM customarily uses a single time estimate for each network activity. This method has been widely applied in construction industry. This is because, even though the construction project is dynamic, each activity is deterministic in the sense that the task is similar or identical to work that has been performed many times before (Clough et al 2000).

The CPM analysis is straightforward and effective for simple, small-scale CPM networks (Lu and AbouRizk, 2000). The CPM is best known and it is most widely used as a formal scheduling technique. Tavakoli and Riachi (1990) found that 80% of the respondents in the survey of Engineering News Record (ENR) for top 400 firms in the USA use CPM to some extent. Deterministic CPM is easy to use for the purpose of project control as well as for planning and scheduling.

The critical path is identified as the longest path in the network which contains all activates where earliest and latest event times are the same. This means that if any critical path activity taking longer than its initial or original estimate, the whole project duration is increased. On the non-critical activities, i.e. those which do not lie on the critical path, a 'float' is a calculated. This float is slack time available to non-critical activities.

But despite its familiarity and ease of use, CPM has fundamental limitations when dealing with repetitive activities and modelling resource utilization.

The lack of flexibility and inefficiency in dealing with uncertainty considerations limits its effectiveness (Halpin, 1998).

CPM assumes that the activity duration is certain and the project duration is also certain. This assumption is not proven in project real life. The estimate of activity durations should be modelled as uncertain variables and project duration evaluated from probabilistic network analysis (Banasinghe 1994). In general, project duration is difficult to predict well with certainty

To deal with the activity duration as non deterministic many networking techniques have been introduced. Stochastic networking techniques use the non-deterministic activity duration as a base for scheduling.

7-4 Stochastic networking

There are many stochastic networking techniques used for to scheduling non-deterministic activity duration. The way of determining the activity duration is different from one method to another, but they all use the same technique of networking. All methods define the activities and the logical sequence as in CPM but the activities are not deterministic durations.

These stochastic networking techniques includes:

- Program Evaluate and Review Technique (PERT)
- Simulation using Monte Carlo
- Simplified Monte Carlo Simulation
- Probabilistic Network Evaluation Technique (PNET)
- PETRI Networking Schedule

7-4-1 Program Evaluate and Review Technique (PERT)

PERT can be considered an extension of CPM. The two techniques was designed for scheduling solving problems and based on networking. PERT was developed shortly after CPM by the US Navy to manage the development of a missile project (PERT 1958). The theoretical basis for the two techniques are found in many of operation research and project management textbooks. The PERT estimate is the simplest method of stochastic methods (Klingel, 1966 and Diaz and Hadipriono, 1993).

In PERT instead of using a fixed time estimate for each activity, activity times are assumed to follow the generalized Beta distribution. The time estimates represent a pessimistic time (a), an optimistic time (b), and a most likely time (m) for duration of an activity (Haga, 1998). The network calculation in PERT is based on the expected value of the activity. The excepted value for the activity duration (*te*) is calculated by the following equations;

$$te = \frac{(a + 4m + b)}{6} \quad \text{...} \quad (7\text{-}1)$$

$$s = \frac{(b - a)}{6} \quad \text{..} \quad (7\text{-}2)$$

where, te = expected duration, a = optimistic duration, m = most likely duration, b = pessimistic duration and s = standard deviation (Ahuja, 1994).

Using the estimates mean of activity times, the network is analysed in the same manner as the CPM method. The PERT method assumes that the sum of the expected times of activities on the critical path is normally distributed. This allows the calculation of the probability of completing the project within a given time period.

$$E(T) = t_1 + t_2 + t_3 + \ldots\ldots + t_n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7\text{-}3)$$

and,

$$S^2 = S_1^2 + S_2^2 + S_3^2 + \ldots\ldots + S_n^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7\text{-}4)$$

Where $E(T)$ = expected project duration; ti = expected duration of ith activity; S = standard deviation of the project; and si = standard deviation of the ith activity

The application of PERT is easy and logical, but there are some recorded drawbacks of PERT regarding dealing with resource allocation in situation of limited resources and time-cost trade-offs applications.

There are two more shortcomings regarding PERT recorded by Ahuga (1994): the first one is it limits the probability of activity duration to only one type of distribution, Beta. The other one is the estimates of the project duration is as the sum of the mean expected values of the longest path in the network with no consideration for the level of uncertainty for the rest of activities. While this assumption gives the maximum expected value for project duration it does not necessarily evaluate the maximum uncertainty because it ignores shorter but more uncertain paths. PERT calculated mean project time is always an underestimate of the true project mean (Cho et al, 1997).

7-4-2 Monte Carlo simulation,

Construction projects are often associated with high degrees of uncertainty stemming from unpredictable and unexpected events. Varying weather conditions, learning development on repetitive operations and equipment breakdowns are some events that can be assumed as occurring randomly in a construction project. The use of simulation in construction is recognized in many areas because the construction environment is dynamic in nature and so the application of simulation has been seen as successful in construction industry (Halpin and Riggs, 1992).

Simulation models allow a concise representation of repetitive activities and sense simplicity of modelling (Senior and Halpin 1995).

In simulation analysis the system's model takes input in the form of random variables. The computer then performs calculations with many variations of the inputs and collects the sets of output which are presented to the engineers as statistical distributions. The output can then be statistically analysed to provide a a measure of uncertainty and risk. Monte Carlo simulation was one of the first simulation techniques to be used to simulate construction project networks. Monte Carlo simulation is a probabilistic method that includes randomness in its calculations, and is recommended for computer applications (AbouRizk et al, 1992).

Monte Carlo simulation can be summarized by the following steps (Ahuja, 1994):

- Generate a uniform random number on the interval (0-1)
- Transform the random number into an appropriate statistical distribution (Normal, beta...). The resulting number is referred to as a random alternative
- Substitute the random alternatives into the appropriate variables in the model
- Calculate the desired output parameters within the model
- Store the resulting output for further statistical analysis
- Repeat many times

- Analyse the collected sample of output and perform risk analysis.

In using Monte Carlo simulation in project networking, the estimate duration for each activity is estimated first as a random number. In each cycle in the simulation, random values in the range (0-1) are assigned to the probability of activity completion. Once the activity duration is probable estimate, the probability of completion for all activities is resulted. Then the same steps are used as in CPM and PERT to calculate the time indicators of finishing project time, start and end of each activity. These values of time indicators are probable values. The network duration is the duration of the longest path (Diaz and Fabian, 1993).

The whole process is repeated as many times as necessary. A large number of replication in needed to obtain accurate results. A simulation with 1,000 replications gives satisfactory resulted for construction networks purposes and is affordable in cost (Moder, et al 1983).

Network simulation was used in many applications in construction. Badri et al (1997) use simulation for modelling one of R and D projects in petroleum sector. Currie et al (2000) used simulation to model construction of mobile offshore base project (MOB). Shi and AbouRizk (1998) used combined discrete and continuous simulation to model construction of pipeline project as an example of linear construction projects. Nashwan (1998) evaluated the effect of many risk factors in estimate activity duration based on subjective level of influence. He used a simulation to predict the project duration based on the changing of activity duration.

The main difference between PERT and simulation is the way the activity duration is estimated. Monte Carlo simulation has advantages over PERT as it examines more than one critical path, it can use varied distribution types and it has an opportunity to make sensitivity analysis (Wendling and Lorance, 1999).

Ahuja (1994) gave a theoretical analysis and theoretical explanation of the PERT drawbacks and argued that the solution to the PERT's inherent problems is to perform the network through a formal stochastic simulation study.

To overcome the PERT drawbacks, many attempts to combine PERT with simulation in networks have been suggested. Van Slyke (1963) demonstrated several advantages of applying simulation techniques to PERT, including more accurate estimates of true project length, flexibility in selecting any distribution for activity times, and the ability to calculate the "criticality index", which are the probability of various activities being on the critical path (Ghomi, and Teimouri (2002). Partsker et al (1989) presented an approach to PERT simulation in which the calculation of the activity criticality is determined based on the total float from classic CPM.

7-4-3 Simplified Monte Carlo simulation (SMCS)

Simplified Monte Carlo simulation (SMCS) simplifies the scheduling network to those activities and paths that are more likely to cause delay of the construction project completion.

The SMCS method is similar to the Monte Carlo simulation method, but eliminates path(s) and activities in the network which have little opportunity to affect the project duration.

The first step in SMCS is the calculation of the expected duration of each activity. Then calculate the expected duration for the network *E(T)*. *E(T)* is the summation of expected values of the activities in the longest network paths. Those paths with an expected duration of bigger than *T min* are considered in further calculation (Diaz 1989)

$T_{min} = K * E(T)$ ....(7-5)

K = a coefficient that indicates how close a path must be to the critical path. And it can range from (0-1.0). The simulation continued to only activities that might be in the critical path.

The method is similar to Monte Carlo simulation but reducing the calculation and the advanced speed of for computer made this benefit non beneficial. In addition the coefficient of K is left to the user and this limits the application of this method.

7-4-4 Probabilistic Network Evaluation Technique (PNET).

PNET was introduced by Ang (1975). The algorithm used by PNET is based on different modes of network failures. Network failure means completion of a project beyond a certain target duration. Each path in the network may be a source of failure. The completion of project can be delayed by any one of the paths in the network. PNET uses simplified solution for modes combination to failure expectation. The calculation in this method starts by defining an expected value for each activity and standard deviation of each. The expected value for each is calculated by summation of the expected values for the path activities. The paths is ranked based on their longest duration. If two paths have the same duration, the more standard deviation is highly ranked. Correlation factor between any two paths is calculated based on standard deviation of the common activities in the two paths.

The probability of the network is no longer than a certain value is the combination that probability of its paths.

7-4-5 PETRI network schedule:

Petri nets are graphical and mathematical modelling tools that can be used to perform static and dynamics modelling (Sawhney, 1997). Petri Nets were developed by Carl Petri in 1966. The Petri net is a directed, weighted graph of four types of modelling elements called places, transitions, arcs and tokens (D'Souza and Khator 1994). *A place* -denoted by a circle- represents a condition such as input data, input signal, resource or condition. *A transition*-denoted by a solid bar- represents an event such as computation step, task, or activity. *Arcs* are utilized to connect places and transactions. *Token*-denoted- by a solid circle to provide the dynamic simulation capabilities. Tokens are initiated at a place and a place may contain tokens or not. With the use of tokens, the dynamic links between places and transactions can be constructed. Sawhney (1997) used the concept of Petri nets in a truck and excavator example project.

7-4-6 Comments for stochastic networking techniques

The most common technique used to deal with the stochastic networking is Mote Carlo simulation. The proposed PPD model will use the concept of simulation to predict the project delay in case of resource shortage occurs.

7-5 Model B: Predicting Project Delay Model(PPD)

As shown in Figure (2-3), model B: Predicting Project Delay (PPD) model is the second part of the delay hierarchy propagation model (DHPM). The PPD model is related to Model A: Resource Shortage Possibility (RSP) model. The RSP model results, which are the possibility of resource shortage, will be one of the inputs to the PPD model. The values of possibilities are assumed to be static values for the whole project life and represent the risk of resource shortage that might the project expose during its life (from start till finish).

The objective of the PPD model is to test the influence of these risk factors in the expected finish time for the project and to identify the most critical sources for delay in the project. Possibility values, which are the outputs of the RSP model, are estimates based on the uncertainty of the hierarchy lower levels of the RSP model. These possibility values are crisp values determining the uncertainty of resource shortage that might encountered in construction project life.

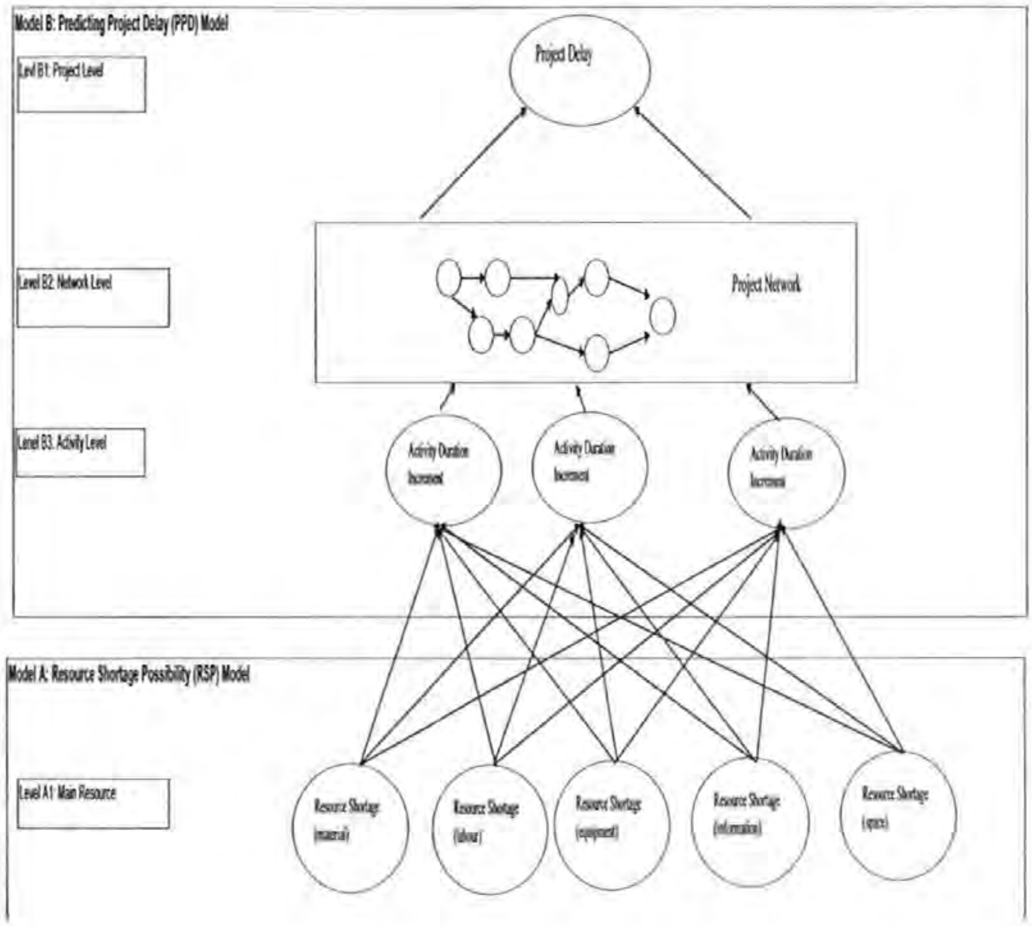
The PPD model assumes that the delay of any activity is a result of any shortage of any required resources to an activity. The model analyses how the resource shortage will progress until delay the whole project.

7-5-1 Model B: PPD model structure:

As shown in Figure 7-1, the PPD model consists of three levels. In level B3, the activity level, the level of performance is influenced by the inputs to it, which are the resources required to the activity to be performed. For the activity to be allowed to start and finish, it needs a series of resources: material, labour, equipment, information and available space. To finish the activity as scheduled, the resources should be available with certain level of supply rate during the whole activity duration. Any shortage or any deficiency of these resources will affect the activity to be delayed beyond what was expected.

The PPD model suggests that the resource supply to the activity is shorten by an uncertain value (possibility shortening value (Vi) that are resulted from Model A: RSP model) and hence a probable delay might occur to the activity. This delay is resulted from increasing the actual duration for the activity by a certain amount of time increment due to uncertain shortage of resources. This uncertain time increment depends on two elements:

a. Uncertainty value of the resource shortage
b. The level of influence of the resource type to the activity.



(Figure 7-1) Model B: Predicting Project Delay (PPD) model

This probable delay that occurs to the activity may have an effect on the project delay as a whole. This effect depends on the rank of this activity. This rank is determined by the level of activity criticality or the level of slack the activity has to delay without affects the finish date of the whole project. This effect is based on the position of the activity in the project network and the original float that the activity possesses. This float mainly depends on the location of activity in the network, which is the second level of the model (B2). If the activity is delayed or the time increment of its duration due to the resource shortage is bigger than its scheduled float, the project as a whole will be delayed (level B1).

7-5-2 Model Inputs:

1- List of project activities and their estimate duration. These values are the original estimate ones. As in a normal case of resource supply there is sufficient resources for the activity.
2- Project network program and initial activities sequence.
3- Probable shortage of resources- resulted from model A: RSP model as shown on Figure 7-1
4- Level of activity sensitivity to each type of resource shortage. This level can be determined by the model user. This input will be illustrated later in section 7-4-5.

These inputs are entered by the user except the probability values for resource shortage, which will result from the RSP model.

7-5-3 Model outputs:

1- Probability of project finish time due to probable resource shortage
2- Criticality level of project activities. This value will determine the level of activity slack.
3- Rank the sources of delay

The PPD model inputs and outputs will be described in detail in section 7-4-5.

7-5-4 Model Mathematical Formation

The model mathematical formulation will be in three steps:

1- Getting the probable increase for activity duration
2- Networking and simulation
3- Defining the delay critical areas

1- Getting the probable increment for activity duration

To apply the results of model RSP model in PPD model, the possibility values expressed as values form 0-1 will be used to represent the probability of resource shortage. In spite of the difference between the possibility value that results from a fuzzy application and the probability values, the results value of the RSP model treats the possibility value resulted from RSP model as the probability for resource shortage for PPD model. The possibility value is an uncertain value resulting from uncertain inputs which are the root delay causes (Vjk) and deterministic values for the relative weights as described in section 6-3. These relative weights are numerical scales and the result will be an uncertain value depends on the value of the root delay causes' indicators. These root delay causes' indicators are entered as fuzzy sets and the overall value of the resource shortage will be the crisp value of this combination of fuzzy set values of the root delay causes and the relative weights by using multi-attribute theory as shown in equation 6-5. This crisp value will be used as the probability of the resource shortage in the PPD model. Zadeh, (1968, 1978) introduced possibility theory to allow reasoning to be carried out on imprecise or vague knowledge, making it possible to deal with uncertainties result from fuzzy sets applications. This theory estimates that the value of probability for any fuzzy set is in general $\leq$ its possibility value.

In application of possibility theory, the PPD model will consider the maximum probability of resource shortage as the same value of shortage possibility value resulted in RSP model, so this equation can be derived:

$(Vi) = Pi$ ....(7-8)

where, Vi is the value of resource shortage possibility resulted from RSP model and Pi is the probability of resource (i) shortage.

These probabilities are estimated for the five resources: material, labour, equipment, information and required space. The relationship and effect of probable resource shortage in any activity can be represented by Figure 7-2. Where t_0 is the initial activity duration and Pm, Pl, Pq, Pf, and Ps are the probable shortage of resources resulted from RSP model and, $SDmn$, $SDln$, $SDqn$, $SDfn$ and $SDsn$ are the relative sensitivity degree of the activity (n) to the material, labour, equipment, information and space resources respectively. This degree is estimated by the user based on the activity type.

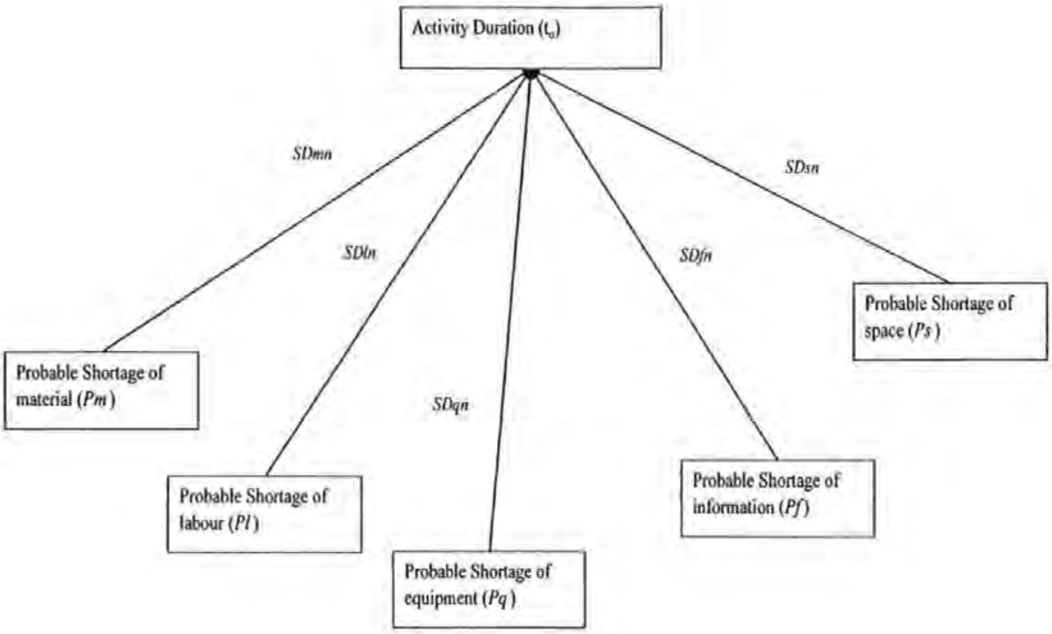


Figure (7-2): Relationship between Probable Resource Shortage and Activity Duration

This value is proportionally increased due to the level of sensitivity level to the type of resource. This degree is suggested to vary between (0.0 and1.0). Degree of 0.0 means there is no influence of this type of resource to the activity and 1.0 means that the activity is totally influenced by the resource shortage. These degrees will be defined by the project planner who is responsible for analyse the time estimate and risk analysis of project time completion.

In case of a probable shortage in resource (i), activity(n) time will be increased by an increment value Δt_{i-n} This time increment is a function of the probable shortage of a resource shortage (Pi) and the sensitivity degree to a resource shortage for activity (SD_{i-n}) , which represent the level of influence of resource (i) shortage to activity (n).

To get the relationship between Δt_{i-n} and probability of resource shortage, suppose that the original (normal or expected) rate of resource supply is (R_i); and the case of normal resource supply with no resource shortage. Suppose that the total resource consumption for the activity to finish is *(CR)*. Because of resource shortage, the rate of resource supply will be changed to be (R_{i1}) due to resource shortage as shown in Figure (7-3).

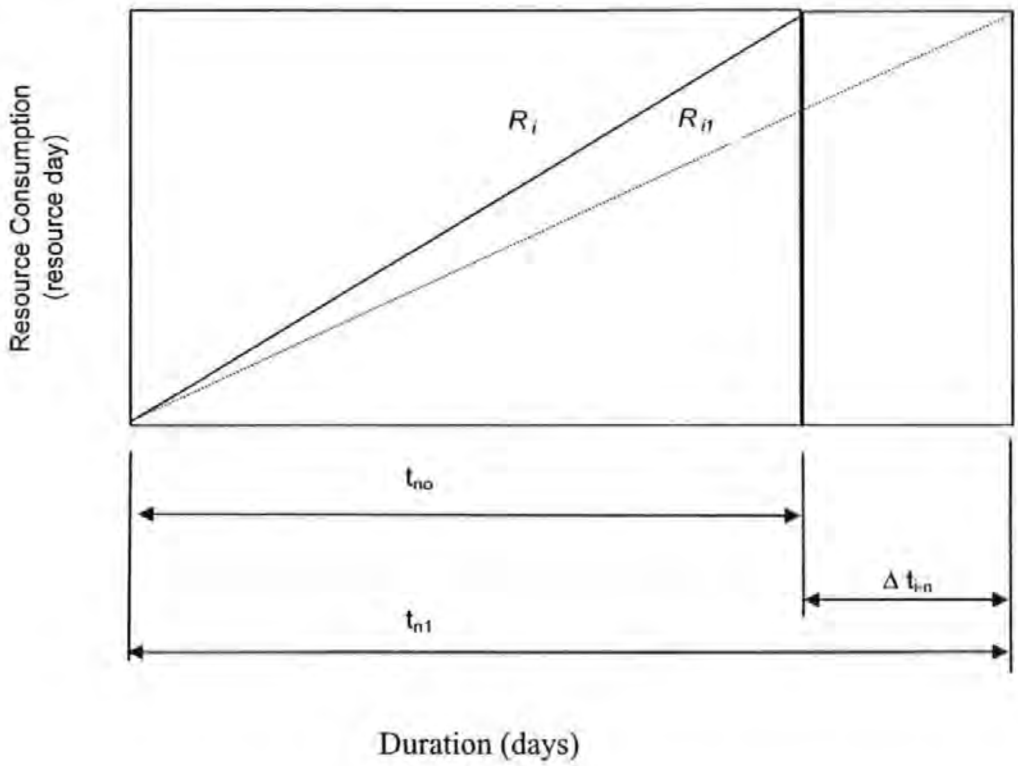


Figure (7-3) Resource Consumption for Activity and Rate of Resource Supply Rate

Suppose that the supply resource rates are linear, and then R_{i1} will be function of probable resource shortage (*Pi*). R_{i1} will be relatively influenced by the probability value of resource shortage *(Pi)*.

$R_{i1} = R_i - R_i * Pi$ .... (7-9)

Where; *(Pi)* is the probability of a resource shortage.

From the above figure, the resource consumption (*CR*) will be the same in the two cases of no shortage and resource shortage occurrence.

$R_i * t_{no} = R_{11} * t_{n1}$ .... (7-10)

$R_i * t_{no} = R_{11} * (t_{on} + \Delta t_{i-n})$ .... (7-11)

$R_i * t_{no} = R_{11} * t_{on} + R_{11} * \Delta t_{i-n}$ .... (7-12)

$$R_{ll} * \Delta t_{i-n} = R_i * t_{no} - R_{ll} * t_{no} \quad \text{(7-13)}$$

$$R_{ll} * \Delta t_{i-n} = t_{no} (R_i - R_{ll}) \quad \text{(7-14)}$$

$$\Delta t_{i-n} = t_{no} \left(\frac{(R_i - R_{il}}{R_{il}} \right) \quad \text{(7-15)}$$

$$\Delta t_{i-n} = t_{no} \left(\frac{R_i}{R_{il}} - 1 \right) \quad \text{(7-16)}$$

Substituting from equation(7-9)

$$\Delta t_{i-n} = t_{no} \left(\frac{R_i}{R_i(1 - Pi)} - 1 \right) \quad \text{(7-17)}$$

$$\Delta t_{i-n} = t_{no} \left(\frac{1}{(1 - Pi)} - 1 \right) \quad \text{(7-18)}$$

$$\Delta t_{i-n} = t_{no} \left(\frac{Pi}{(1 - Pi)} \right) \quad \text{(7-19)}$$

The time increment is relatively influenced to the probability of resource shortage and the original activity duration. This time increment is also affected by the sensitivity degree of activity to resource shortage, so the time increment will be adjusted according to the sensitivity degree (SD_{i-n}).

Time increment will be adjusted by the user (SD_{i-n}) calculated by equation (7-20)

$$\Delta t_{i-n} = SD_{i-n} * t_{no} \left(\frac{Pi}{(1 - Pi)} \right) \quad \text{(7-20)}$$

Where Δt_{i-n} is the probable time increment in the activity duration because of probable resource shortage. There are five increment values due to the possibility of shortage of the five resources (material, labour, equipment, information and space).

The maximum increment the activity can extend can be calculated by equation (7-21):

$max\ (\Delta t_n)$ = max { Δt_{i-n} }= max { Δt_{m-n} , Δt_{l-n} , Δt_{q-n} , Δt_{f-n} and Δt_{s-n}) (7-21)

The maximum activity probable activity duration; (T_{ln}, max) is determined by equation (7-22):

$$(T_n,\ max) = t_{no} + max\ (\Delta t_n) \quad \text{(7-22)}$$

So, the value of any activity is varied between t_{no}, the normal or initial activity duration with no probability of resource shortage to (T_n, max) the maximum activity duration.

To apply the model in a project, the fundamentals of networking and simulation will be used. This activity duration is probable duration takes a random value from t_{no} to (T_n, max). The activity has a chance to project delay if it has a chance to be laid in the project network critical path. Introducing the phenomena of networking is essential to predict the project delay.

2- Networking and simulation

In project networking theoretical basis, for any activity (*n*) duration is (*Dn*), and predecessor (s) set is *P*, successor(s) set is *S* and *E* is a set of network ending activities.

The forward path is calculated as in a CPM schedule by the following equations:

$$ESn = \max_{p \in P}\{EFp\} \qquad (7\text{-}23)$$

$$EFn = ESn + Dn \qquad (7\text{-}24)$$

$$EFt = \max_{e \in E}(EFe) \qquad (7\text{-}25)$$

Where, *ESn* is the earliest start date for activity (*n*), *EFn* is the early finish date and *E* is the set for project ending activities. *Dn* will be a non-deterministic value between (t_{no} and T_n, max)

Monte Carlo simulation technique was used to predict the project finish date in stochastic networking schedule. This finish date depends on the probable duration of the activities in the network paths. The instant critical path may be changed due to the changes in the probable activity duration. The logical sequence of activities will remain with no changes. The changes will only be for the activity duration. The original critical path is defined as if the network has no chance to resources shortage. This path may change as the activity duration changes.

3- Defining the delay critical areas

To define the critical delay areas, there are two elements that should be defined. The level of activity criticality: to define the level of activity to time increment without affecting the project final duration. The second element is the resource contribution percentage: to define the contribution of each type of resource to project delay.
The level of activity criticality used to rank the activities based on their chance to be in the critical path, or that they have the chance to affect the project final completion time. The resource contribution in the project delay are used to rank the resource risks to project delay. If these areas are defined early, a management effort can be dedicated to control anticipated project delays in future project life.

The past research work regarding the stochastic networking focused on two main outputs of the network; the probability of the finishing time for the network and the possibility of criticality level of the network activities (Lu and AbouRizk, 2000).

In deterministic CPM, the criticality level is estimated by calculating the activities total floats (*TFn*), while In simulation networking, a criticality index (CI) measures the probability of activity to be in the critical path and it is calculated by this equation (Paritsker, 1989).

$$CI_n \text{ (critical Index)} = \frac{\text{Number of activity been in the longest path}}{\text{Number of simulation}} \qquad (7\text{-}26)$$

PPD model will use a form combining the CPM Total Float (TF_n) that can be calculated from an original CPM calculation for the initial activity duration, and the probable increase of time due to resource possible or probable shortage Δt_n *in addition to* the criticality index (CI_n) to define the activities' criticality issues in regard to the delay.

The model uses another new term called True Slack, (TS) to define the activity criticality first. This value is introduced to measure the true slack that the activity is allowed to delay without affecting project delay even of resource shortage occurs. This true slack (*TSn*) is calculated by comparing the maximum probable duration increment for activity (n); $max\ \Delta t_n$ with the CPM total float (TF_n) calculated from classic CPM for the original network. The original network contains the set of activities in their original duration. The true slack for an activity *(n)* (TS_n) can be calculated by using equation (7-27):

$$TS_n = TF_{n},\ -\ max\Delta t_n \ldots\ldots \qquad (7\text{-}27)$$

Where, TS_n is the true slack of activity n, TF_n is the total float of activity n resulted from CPM and $max\Delta t_n$ is the maximum increment that probable due to the probable shortage of resources (equation 7-21).

By using the TS_n equation, the uncertainty of non critical activities will be considered. As mentioned before, one of the shortcomings recorded for PERT is that it estimates the project duration as the sum of the mean expected values of the longest path in the network with no consideration for the level of uncertainty for the rest of activities.

TSn has three probable values; positive value bigger than 0.0, or negative value less than 0.0 or equal to 0. If the TS_n is less than or equal to 0, this activity has a highly probability to be in the critical path of the project and it needs a special method for control. If the TS_n is greater than 0 it means that this activity has no chance to be in the critical path of the network. These activities have *TSn* less than or equal to 0.0 will be checked their criticality index (*CIn*) to rank the project activities based on their criticality index. The higher the criticality index, the higher the chance of the activity being in the critical path.

The second element to be defined in analysing the probable project delay is the ranking of the resources contributing to project delay. To rank the sources of delay, a new term called Contribution Percentage (CP) is proposed to define the contribution of resources in critical path that controls project completion. *CPi* value for any resource type (i) defines the contribution of resource in controlling the project completion time. *CPi* represents the relative effect of the probable resource shortage in the project delay. *CPi* can be calculated by equation (7-28):

$$CPi = \frac{Fi}{\sum_{i=1}^{5} Fi} * 100 \quad \text{...} \quad .(7\text{-}28)$$

Where, *Fi* is the frequency number of the resource that affected the activities the critical path. For each activity in the critical path, there are many values for the activity duration. This duration varies from t_{on} to (T_n, max). (T_n, max) is determined by the time increment resulted from certain type of resource. Fi is the frequency numbers of resource *(i)* to control the duration of activities in the critical path. *CPi* value is ranging from 0 to 100. The higher the percentage, the more important the type of resource to be controlled as it will probably have a higher contribution in project delay.

7-5-5 Steps for PPD model calculations

In summary, the PPD model calculation steps are the following in a sequential order:

a) First the CPM network calculation based on the initial activity duration (t_{no}) and total float (TF_n) of each activity is presented.

b) Obtaining the probable resources shortage values from RSP model output

c) Calculate the probable increment of activity duration (Δt_n) for each type of resource from equation (7-20).

d) Estimate the maximum probable time increment ($max\ (\Delta t_n)$) from equation (7-21)

e) Calculate the True Slack (TS_n) value for all activities from equation (7-27). Then define the activities that have zero or negative values. These activities have the chance being delayed and they will be ranked based on their criticality index.

f) Generate random numbers for activity duration from t_{no} to T_n, *max*. Conduct Mont Carlo simulation by generating random numbers of activities duration based on the probable shortage of resource shortage. The time increment for each type of resource shortage is generated ($\Delta t_{i\text{-}n}$). The activity duration used in the network calculation will be the maximum activity time for each cycle as in equation (7-29).

$(T_n, max)_r = t_{no} + max\ (\Delta t_{i\text{-}n})$ ....(7-29)

Where, $(T_n, max)_r$ is the activity duration in the simulation cycle (r) , and $\Delta t_{i\text{-}n}$ is the randomly time increment generated based on equation (7-22) in the simulation number (r).

g) Calculate the finish date for the project by applying equations (7-23 to 7-25)
h) Estimate the probability of finish dates in case of resource shortage occur.
i) Calculate the criticality index –using equation (7-27)- for the activities that have TS<= 0.
j) Rank the resources effect on project probable delay by using the contribution percentage (CP) from equation (7-28).

To verify this PPD model basis and calculation, a numerical example will be used.

7-6 Numerical Example

In this example verification of the PPD model is presented. The numerical example contains a network of six activities with two parallel critical paths as shown in Figure 7-4. Table 7-1 shows the activities initial duration (t_{no}) and the probable resource shortage (Pi), that is arbitrary values and the degree of sensitivity for each activity to resource shortage ($SD_{i\text{-}n}$) that is pre-estimated by the user or project planner. Figure 7-4 and Table 7-1 define the required inputs to start application of PPD model calculations as presented before in section 7-4-2.

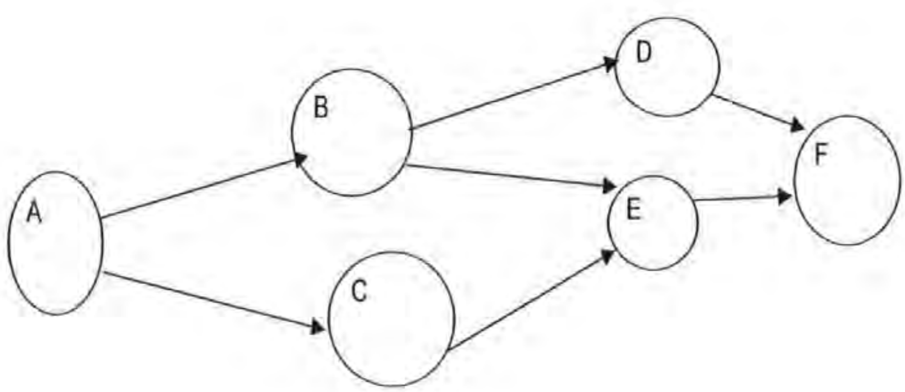


Figure (7-4) Numerical Network Example

Table 7-1: Numerical Example Initial Duration, Probable Resource Shortage

Activities	A	B	C	D	E	F
Initial Duration (Days)	3	5	5	3	2	3
Probability of material shortage (*Pm*)	0.2					
Sensitivity to Material Shortage	0.9	0.5	0.3	0.7	0.9	0.3
Probability of labour shortage (*Pl*)	0.1					
Sensitivity to Labour Shortage	0.7	0.5	0.7	0.5	0.5	0.5
Probability of equipment shortage (*Pq*)	0.06					
Sensitivity to Equipment Shortage	0.3	0.9	0.3	0.3	0.7	0.5
Probability of information shortage (*Pf*)	0.1					
Sensitivity to Information Shortage	0.7	0.9	0.5	0.5	0.3	0.7
Probability of space shortage (*Ps*)	0.2					
Sensitivity to Space Shortage	0.5	0.9	0.3	0.7	0.5	0.7

By applying the model in steps as presented in section 7-4-6::

a) *CPM network calculation based on the initial activity duration (t_{no})*

Table 7-2 represents the total floats for each activity based on original networking and original duration.

Table 7-2 Numerical Example original CPM total float

Activity	Total Float (TF_n)
A	0
B	0
C	0
D	0
E	1
F	0

b) *Obtaining the probable resources shortage values from RSPM application.*

It is shown in Table 7-1

c) *Calculate the probable increment of activity duration (Δt_{i-n}) for each type of resource*

By applying equation (7-20), the probable increment for each activity can be calculated. Table 7-3 shows the probable values for time increment for each activity due to the probable resource shortage. The values are in days.

Table 7-3: Effect of probable shortage of resources and duration increment

Activity	Material *(Δtm)*	Labour *(Δtl)*	Equipment *(Δtq)*	Informatio n *(Δtf)*	Space *(Δts)*	Max *(Δt)*
A	0.675	0.233	0.0574	0.2333	0.375	0.675
B	0.625	0.278	0.2872	0.5	1.125	1.125
C	0.375	0.389	0.0957	0.2778	0.375	0.389
D	0.525	0.167	0.0574	0.1667	0.525	0.525
E	0.45	0.111	0.0894	0.0667	0.25	0.45
F	0.225	0.167	0.0957	0.2333	0.525	0.525

d) *Estimate the maximum probable time increment*

Table 7-3 last column defines the maximum probable increment value for time increment for each activity by applying equation (7-21).

e) *Calculate the True Slack (TS_n) value for all activities from equation (7-27).*

Table 7-4 defines the true slack values. The only activity has a positive value is activity E, it means that there is no chance for activity E to be in the critical path or it will has no effect in the project completion time even in the case of resource shortage. From these TS values, there are no preferences for the activities which have negative values to be more important for control point of view. All the activities except E have a chance to be in the critical path.

Table 7-4: Activities Total Floats

Activity	TF	max Δ	TS
A	0	0.675	-0.675
B	0	1.125	-1.125
C	0	0.389	-0.389
D	0	0.525	-0.525
E	1	0.45	0.55
F	0	0.525	-0.525

f) *Generate random numbers for activity duration from t_0 to T, max.*

The random number generation that in very familiar software, Excel-Microsoft-2003 was used to generate the random values for time increment for each activity from (t_{no} to $T_{n,}$ *max*). For each activity, five random values were generated to represent the probable value of time increment. For example; the values of activity (A) duration in the first cycle is calculated by this equations:

DAm= 3 + RAND(0.675)*

DAl = 3 + RAND (0.233)*

DAq = 3 + RAND (0.0574)*

*DAf = 3+ RAND *(0.2333)*

DAs = 3 + RAND (0.375)*

Where, *DAm, DAl, DAq, DAf* and *DAs* are the duration of activity A due to probable shortage of material, labour, equipment, information and space respectively. The duration of activity A that will be considered is the maximum of the five calculated values for each simulation cycle.

DA = Max {Dam, DAl, DAq, DAf and *DAs}*

The simulation will be applied to all activities by the same way.

g) *Calculate the finish date for the project by applying equations (7-23 to 7-25).*

The step of generating random numbers for activities duration is repeated 1002 times and then applying equations (7-23 to 7-25) are applied to define the estimate finish date for each simulation cycle.

h) Estimate the probability of finish dates in case of resource shortage occur.

Figure (7-5) represents the changes of duration in project finish date due to probable shortage of resources.

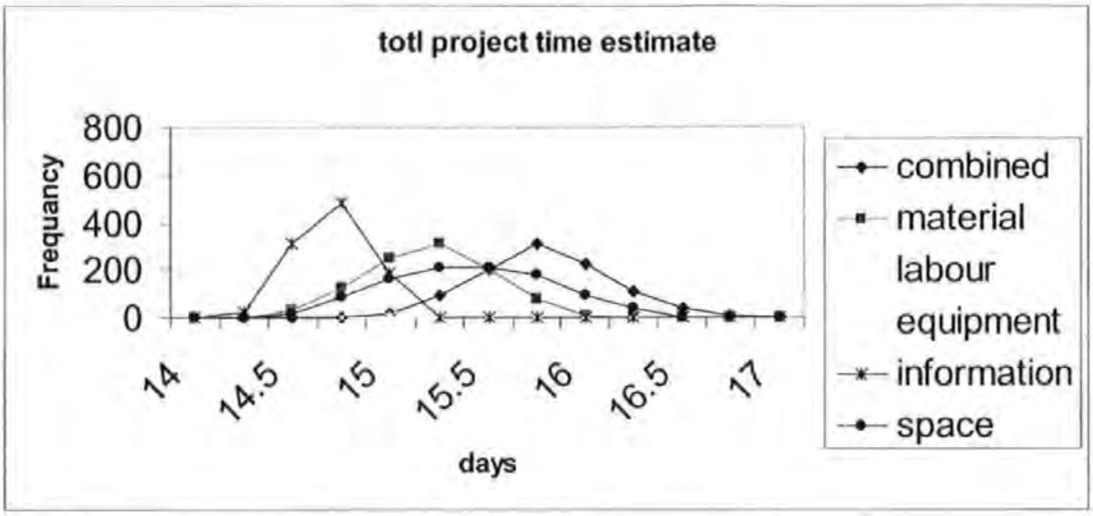


Figure 7-5: Probable finish dates of the example project

The curves represent the changes of finish project duration if:

- *Material: probable material shortage only- taking Δm only*
- *Labour: probable labour shortage only-taking Δl only*
- *Equipment: probable equipment only Δq only*
- *Information: probable information only Δf only*
- *Space: probable space only Δs only*
- *Combined- effect of combined effects of resources: taking the maximum of effect for each activity. Which will define the probable finish date of the project*

Table 7-5 represent the density function of the project completion probability for the combined effect of probable resource shortage.

Table 7-5: Project Completion Density Probability Function

Expected finish time (Days)	frequency	Probability	cumulative probability
14.00	0	0	
14.25	0	0	0.00
14.50	0	0	0.00
14.75	1	0	0.00
15.00	13	0.01	0.01
15.25	92	0.09	0.11
15.50	204	0.2	0.31
15.75	310	0.31	0.62
16.00	225	0.22	0.84
16.25	107	0.11	0.95
16.50	42	0.04	0.99
16.75	8	0.01	1.00
17.00	0	0	1.00

As it can be seen from Table 7-5, the most probable finish for the project will be from 15.5 days to 16.25 days, which represents about a probability of 85%.

i) Calculate the criticality index –equation (7-27)- for the activities have TS<=0.

Criticality index (CI) is calculated by applying equation (7-26) to define the probability of each activity to be in the critical path and to rank the activities based on their criticality. Table 7-4 shows the criticality Index for all example project activities. Activities A,F and D have a criticality index 100% , while activity B has 93% and activity C has only 7% of criticality index. E has 0% as its TS value is bigger than 0 as shown in Table 7-2. By this index, the activities that may expose to delay can be ranked.

Table 7-6: Criticality Index for the example project' activities.

Activity	CI
A	100%
B	93%
C	7%
D	100%
E	0%
F	100%

j) Rank the resources effect on project probable delay by using the contribution percentage (CPi) from equation (7-28).

Equation (7-28) is used to calculate the contribution percentage of each resource type to project delay. Table 7-7 represents the *CPi* values for each type of resource.

Table 7-7: Resource Contribution Values for Example Project

Resource Type	Frequency	(CPi) Contribution Percentage
Material	1319	32.91%
Labour	78	1.95%
equipment	87	2.17%
information	80	2.00%
space	2444	60.98%

For each Monte Carlo simulation cycle, there are four activities in the critical path; (A,D,F and either B, or C). For each activity in the critical path, the source of time increment is defined based on the equation (7-21). This increment may be due to any of the resources, material, labour, equipment, information or space shortage. The frequency contribution of each one of these resources is defined for each activity and then assed for all project critical activities. These values are shown in Table 7-7.

Table 7-7 shows that the shortage of space is the most critical risk for project delay as it has the highest CP value, and shortage of labour has the lowest influence in project delay.

To enhance the project time performance, management techniques are required to enhance space management in order to mitigate the effects of space shortage.

By understanding the rank of activities' criticality and ranking of resources contribution to project delay, the management techniques required to mitigate the effect of delay may be applied more efficiently.

The application of the PDM model in a numerical example revealed that the results of application can be very helpful to the management staff to achieve more efficient project performance.

Although the example was based on small number of activities, it can demonstrate the difference between the application of this proposed PPD model in networking scheduling calculation and the other networking techniques such as CPM, PERT and simulation

7-7 Comparison between Proposed model and other stochastic models

Table 7-8 shows the some of differences between the CPM, PERT, simulation and the PPD model.

Table 7-8 Comparison between the PPD model and other networking techniques

Comparison Criteria	CPM	PERT	Simulation	PPD model
Activity duration	deterministic	probable	Probable	Probable
Used in planning and scheduling	ok	ok	ok	ok
Uncertainty of non critical activities	no	no	yes	yes
Define critical path	yes	yes	yes	yes
Project level of criticality	yes	yes	yes	yes
Probable level of criticality	no	no	yes	yes
Rank activities based on their criticality	yes	yes	yes	yes
Rank sources of risks	no	no	no	yes

The PPD model uses non deterministic activity duration to overcome the problems of uncertainty recorded for CPM. It provides a means of defining the level of criticality for network activities. It overcomes the problem of PERT in that it takes into consideration the uncertainty of all activities not only that are laid in the critical path. It provides a new means to rank the resource that may influence the project to delay.

7-8 Summary:

The PPD model is used for determine the probable finish time for a project exposed to a probable resource shortage and to define the critical areas for this project. The PPD model uses stochastic networking to determine the probable completion time for a project. The PPD model ranks the activities in the project network based on their criticality index and their true slack values. The risk of resource shortage is ranked based on the resource contribution percentage. The application of the PPD model in a numerical example defined the most critical areas that can be used to define the management techniques required to efficient delay mitigation effort.

Chapter 8

Concluded Objectives and Future Work

8-1 Introduction:

This chapter summarises the whole research work, presents the conclusion, contribution to academic science and the suggested area for future work.

8-2 Research Work Discussion

The objectives of this research were to understand the root delay causes of the construction project, to extract the root delay causes, to model the construction project delays and then to predict the level of delays that the project can face during its life. The proposed model should also be generic and can applicable to any project.

This thesis is an predicative and applied study that models the propagation of delays in construction projects.

The model is built on three assumptions; these assumptions came from many notices and analysis of many aspects in the construction industry in chapter 3. These assumptions are that:

a) The recorded delays in the construction industry are real or ***direct delays***. This type of delay has many influences in the project performance, not only the time performance, but many of other effects. The usual method to mitigate the effect of delays is dedicated to how to deal with the real or direct delay. It is proposed that these ***direct delays*** are the outcomes of some earlier events that later become real or direct delays. These earlier events have been given the term "***root delay causes***". These ***root delay causes*** can become ***direct delays*** in the project life. These root delay causes should be identified and assessed before project starts. The process of management should be emphasis to the root delay causes more than the real or direct delay ones.

b) The project delay is a combination of processes that start by deficiencies in one or more of the ***root delay causes***, propagating to delay the project. The delay propagates from a root delay cause, then moves to become a direct delay. Direct delay will increase activity duration, accordingly delaying the whole project.

c) Any deficiency in any ***root delay causes*** will be reflected to a certain type of resource shortage i.e. the direct effect of the root delay causes deficiency is resource shortage. The resource shortage will then be the cause of increase the activity duration and hence increase the whole project time.

These assumptions gave the main entities for the proposed delay hierarchy propagation model (DHPM).

This research work has eight phases:

1- A literature review of construction project delays was carried out. It was noted that there was lack of research in the area of delay modelling. The majority of previous research only defined and measured the sources of delays in construction projects. All these studies focused on the ***direct delays*** that had already occurred in the project site. All these studies attempted to rank these direct delays. No research work had been carried out to model project delays and to model the philosophy of delay generation, propagation and occurrence in a construction project.

These ***direct delays*** that were studied in previous research work were collected to produce a list of 53 ***direct delays*** set out in chapter 2.

2- Propose a new methodology to model the delay propagation in a construction project was proposed. Delay Hierarchy Propagation Model (DHPM) consists of two interrelated models; Model A and Model B. Model A, Resource Shortage Possibility (RSP) model which has an objective of predicting the possibility of resource shortages. Model B: Predicating Project Delay (PPD) model has two objectives of predicting the probability of project delay and defining the anticipated critical sources of project delay. This model is generic for use in any construction project. This model is designed based on the predefined assumptions. The framework of the suggested model was presented in chapter 3.

3- Extraction of ***root delay causes***. The root delay causes were extracted by analysing the 53 direct delays gathered in chapter 2. The Cause-Effect technique was used to extract the root delay causes. The Cause-Effect technique is a technique used in quality management science to predict the root delay causes of recorded problems. The technique uses why-why method to define the root delay causes. Fourteen root delay causes were extracted from the direct delays. The root delay causes were from three main areas:

(4) Root delay causes due to project main player: designer(s), contractor(s) and owner.

(5) Root delay causes from inter-relationship working environment: communication, trust and agreement of project objectives.

(6) Root delay causes related to the specific project: design documents, site characteristics, project characteristics, project procurement strategy, interaction before project start and the level of project complexity.

To enable these root delay causes to be analysed or assessed before or shortly after the project start, indicators were derived to measure each one of these root delay causes. The indicators came from the previous research work regarding key performance indicators (KPI), contractor, designer choice and other studies. Most of the root delay causes' indicators are from the subjective qualitative aspects. The extracted root delay causes and their indicators are presented in chapter 4.

4- The thoughts and basis of model A: Resource Shortage Possibility (RSP) model were verified using an interview questionnaire with some of personnel of construction projects. The questionnaire was designed to collect data regarding the proposed delay model. The interviews were held on sites with project personnel. Fifty eight construction personnel were contacted to participate in this study and 30 accepted. The interview questionnaire was designed in four parts and consists of 18 pages. Each interview took about 1.5 hours starting by defining the objective of the questionnaire, describing the research background and the meanings of the words that are used in the questionnaire.

A copy of the questionnaire is presented in Appendix B.

5 - Statistical analysis of the interview questionnaires results were carried out to verify the thoughts and basis of the RSP model. This analysis used several statistical analysis techniques. It used the descriptive analysis to define the mean values and divergence of respondents' answers. Factor analysis was used to test the possibility of reducing the number of designed model variables. The level of normality of sample results was tested. Because of diversity of respondents' answers regarding many of questionnaire results, the Delphi method was then used to enhance the level of gathered data. A second round of interview questionnaires was used with six participants taken from the interviewed sample.

The analysis of the second round revealed that the thoughts and basis of the model basis were verified. The analysis of the second round eliminated some of the indicators that were originally suggested, so the original model was modified based on the results of the second round. The statistical analysis and Delphi results and the modified model are presented in chapter 5.

6- Defining the Model A, RSP in terms of model inputs, model mathematics and the anticipated outputs are presented before the design of a prototype computer program of the Model A: RSP. The prototype computer program can be used can be used to anticipate the probable or possibility of resource shortage.

The prototype computer model uses several techniques to evaluate the possibility of resource shortage. Fuzzy logic is used to evaluate the value for root delay causes' indicators which are the inputs for the model. Multi-attribute theory is used to calculate the resource shortage possibility value depending on the fuzzy values for the root delay causes' indicators and the relative weights between model levels. The relative weights between model levels are calculated based on the AHP.

The formation and the prototype program are shown in chapter 6.

7- Application of the proposed prototype program in a construction project was carried out to validate the RSP model. The prototype program designed in chapter 6 was applied to a construction project in Kuwait. A workshop was conducted with the project players; two from the contractor's party, two from the consultant's party and one from the owner party. A workshop was conducted on the project site. The workshop started by presenting the delay propagation model and the theoretical basis for it. To ease data collection, a questionnaire was designed for this workshop. The project parties were asked to evaluate each one of the root delay causes' indicators. These indicators were entered in the prototype program to calculate the values of the resource shortage possibility which are the outputs of RSP model. The application results are presented in chapter 6 and Appendices H and I.

8- Model B: PPD model formulation. This part of the model predicts the probability of the project finish time under the uncertainty of resource shortage and defines the critical areas of the project subject to delay. This model is in the area of networking calculation.

The model uses the output of the Model A: RSP as one of its inputs in addition to the other inputs required to carry out scheduling calculations such as activities list, estimate duration and logical sequence. The project finish date is determined by the duration of the project critical path. Model B: PPD uses probabilistic networking to define the probable project finish time. The value of each activity in the project varies between an original value which is in case of no resource shortage and a maximum value which depends on two conditions; the probability of resource shortage and the level of sensitivity of activity to resource shortage. The model introduced two new terms to define the critical areas of delay: true slack and contribution percentage. True slack is used in addition to the criticality index to identify the probability of the activity to be in the critical path, and the contribution percentage used to rank the contribution of each resource type to project delay. These new terms can be used to rank the activities and the resources and can be used to identify the proper management techniques that can be used to mitigate the effects of delay and enhance the efforts of to delay management. Model B: PPD was compared to deterministic and some non-deterministic probabilistic networking and showed that the proposed model is more efficient. An attempt to apply the equations and ideas in Model B: PPD was conducted in an arbitrary numerical example. The numerical example consists of six activities and two parallel critical paths. The application determined the critical areas for expected delay in the project in its future life. The principles and application of Model B: PPD model are presented. The principles and application of Model B: PPD model are presented in chapter 7.

8-3 Concluded Objectives

a) The root delay causes that are extracted from the Cause-Effect technique are:

   1. *Designer's management deficiencies:*
   2. *Quality of design work documents*
   3. *Contractor's management deficiencies*
   4. *Contractor's financial problems*
   5. *Owner's management deficiencies*
   6. *Owner's financial problems*
   7. *Efficiency level of communication between project parts*
   8. *Level of interactions between project parties in pre-construction phase*
   9. *Level of trust between project parties:*
   10. *Level of project complexity and required technology:*
   11. *Level of objectives harmony between project parties*
   12. *Specific site characteristics*
   13. *Specific project characteristics*
   14. *Project contract and procurement strategy*

b) This thesis presented a methodology for creating a generic model for construction project delay. The Delay Hierarchy Propagation Model is a generic predictive model. It is proposed that the basis for this model could be global applied.

c) DHPM model has been described with data from construction industry in Kuwait and design a prototype program to produce a useful tool for use in Kuwait located projects.

d) DHPM model can be applied with some modifications for the weights in the prototype program to enable it to be applied in any region.

e) Thirty interview questionnaires have been conducted with experts in construction projects to verify the model basis. The questionnaire results revealed that the model bases are verified.

f) Combining fuzzy sets, AHP and multi-attribute theory was used to predict the uncertain value possibility of resource shortage from the delay hierarchy model.

g) The application of the proposed model in the construction industry revealed that the application of the DHPM can predict the possibilities of resource shortage rank the resource effects on the project and rank the activities in the project.

h) Calculation in project scheduling and planning by probabilistic and uncertain phenomena is more efficient than the deterministic techniques.

8-4 Contribution in Science

a) This research has founded empirical evidence for construction delays in construction projects to be modelled.

b) Construction of a generic model of delay propagation in construction projects. This model can be used to predict the probable delays that may be enforced in the construction project life.

c) Defining the root delay causes of construction projects

d) Use of integrated techniques (Fuzzy logic, Multi-attribute and AHP)to estimate the probable delays in construction industry

e) Design of a tool that can be used in determining the expected areas for delay in future. These areas can be identified by activity Criticality Index (CI), True Slack (TS) and Contribution Percentage (CP).

8-5 Future Work

a) Propose a computer program using simulation shells and integrating planning software to apply the ideas that have been introduced in the PPD model

b) Design a knowledge based system. This knowledge based system will be linked to the PPD model to suggest the management techniques that can be used to mitigate the effects of probable resource shortage based on the resource ranking.

c) Connect the RSP and PPD models in one computer program

d) Modelling the supply chain methods and evaluate their effects on project delay

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Appendixes:

Appendixes:

Appendix A: Past Research work in Construction Delay Causes Measurement

Appendix A

Appendix A-1

Summary for Baldwin Study in USA 1971.

Delay Factor	Severity Index (contractors)	Severity Index (Architects)	Severity Index (Engineer)
Weather Conditions	90	53	66
Labour Supply	80	60	45
Subcontractors problems	77	74	54
Design Changes	70	26	28
Shop Drawing	59	35	26
Foundation Conditions	57	29	34
Material Shortage	54	37	30
Manufactured Items	51	53	41
Sample Approvals	46	19	11
Jurisdiction Disputes	44	21	26
Equipment Failure	32	12	19
Contracts	31	16	16
Construction Mistakes	27	22	19
Inspections	23	6	18
Finances	20	48	34
Permits	19	32	32
Building Codes	10	18	7

Notes:

- Results of posted questionnaire
- Severity index counts only the answers of very important and important respondents' answers.

Appendix A-2

Reasons for delay in public projects in Turkey [Arditi et al 1985].

Reason for Construction Delay	Contractors		Public Agencies		Average Weight
	Scores*	Relative Weight	Scores	Relative Weight	
Difficulties in obtaining construction materials	76	14.42%	133	20.49%	17.46%
contractors' difficulties in receiving monthly payment	80	15.18%	40	6.16%	10.67%
contractor's financial problems	58	11.01%	66	10.17%	10.59%
deficiencies in contractor's organisation	26	4.93%	75	11.56%	8.24%
deficiencies in public agency's organisation	55	10.44%	14	2.16%	6.30%
shortage of qualified workers	36	6.83%	35	5.39%	6.11%
large quantities of extra work	17	3.23%	49	7.55%	5.39%
shortage of technical personnel	24	4.55%	32	4.93%	4.74%
delay in design work	23	4.36%	31	4.78%	4.57%
Difficulties in planning and schedule	8	1.52%	49	7.55%	4.53%
Site inspections	35	6.64%	8	1.23%	3.94%
Change orders	17	3.23%	25	3.85%	3.54%
Equipment allocations	20	3.80%	12	1.85%	2.82%
Unrealistic contract duration	16	3.04%	15	2.31%	2.67%
Difficulties of obtaining energy (electricity and fuel)	8	1.52%	22	3.39%	2.45%
Disagreements on contract clauses	11	2.09%	3	0.46%	1.27%
Permits and licences	0	0.00%	10	1.54%	0.77%

* The score for each reason is calculated by summing up the scores assigned to it by each respondent (5 for the most important, 4 for less important and so on).

Appendix A-3

Results of Sullivan and Harris Survey, the UK and overseas

Problems leading to delays	Frequency of Occurrence	
	UK	Overseas
Waiting for Information	90	30
Design Complexity	15	15
Material Delivery or Approval	20	25
Shortage of Labour	10	10
Weather	40	5
Subcontractors Default	10	10
Ground Conditions	80	10
Physical Obstruction (Unexpected Services)	60	5
Disputes and Strikes	15	0
Variation Order	90	75
Plant Shortage	5	5
Breakdown	10	10
Co-ordination Problems	2	5
Contractual Disputes	0	0

Note:

- Study in big civil projects
- Mailed questionnaire to 20 participants
- Frequency value is the averaging of the 20 participants

Appendix A-4

Okpala and Aneikwa Results of Nigerian Delay Causes

N	Variable (Cause)	Engineers SI* (N=58)	Architects SI (N=52)	Q/Surveyors SI (N=46)
Delay Causes Variables				
1	Shortage of materials	93	100	88
2	Financing and payment of completed works	92	90	92
3	Poor contract management	86	81	88
4	Imported materials	73	73	62
5	Design changes	71	65	73
6	Non adherence to contract conditions	67	53	50
7	Labour supply	65	61	54
8	Labour management relations	65	45	68
9	Mistakes during construction	57	53	58
10	Disputes	55	45	57
11	Subcontractors and suppliers	55	63	69
12	Material transportation and equipment	54	52	46
13	Underground conditions (foundation)	52	47	39
14	Weather	52	32	35
15	Mistakes and discrepancy in documents	48	53	46
16	Negotiations and obtaining of contract	48	42	39
17	Preparation and approval of shop drawings	47	50	42
18	Preparation and approval of material test samples	46	43	35
19	Items manufactured off-site	43	34	39
20	Inspection	38	40	39

* SI = Severity Index

Appendix A-5

Reasons for Project Delays in Nigerian Public Projects (Dlakwa andCulpin 1990)

Reason for Time Overrun	Owners	Contractors	Consultants
	Mean*	Mean	Mean
Contractors' difficulties in receiving interim payment	3	3.5	3.9
Contractor's financial difficulties	2.6	2.4	3.3
Inadequate owner financial	2.4	2.6	3.3
Deficiencies in contractors organisation	2.1	1.1	2.5
Difficulties in planning and scheduling	2	1.3	2.3
Variation orders	1.8	1.9	2
Construction materials	1.7	1.9	1.7
Deficiencies in public agency' organisation	1.7	1.2	2
Unrealistic contractor tender	1.8	1.6	1.6
Design related factor	1.6	1.6	1.7
Unrealistic contract duration	1.3	1.8	1.9
Large quantities of extra work	1.4	1.6	1.8
Social events	1.2	1.2	1.9
Problems with equipment	1.5	1.1	1.3
Site inspection	1.4	1.3	1.3
Shortage of qualified worker	1.2	1	1.2
Disagreement for specifications and contract clauses	1	1.2	1.4

* average for respondents (1-5 scale for importance of delay factor)

Appendix A-6

The Rank for Delay Causes in Egyptian Construction Industry [Waheed 1994]

Delay Cause	Rank
Poor contractor management and unrealistic scheduling	1
Lack of finance and payment of completed work	2
Shortage of materials	3
Design modifications	4
Disputes and claims	5
Subcontractors and material suppliers' problems	6
Non- Adherence to contract conditions	7
Site inspection services	8
Weather conditions	9
Regularity and laws of municipality	10
Mistakes during construction	11
Equipment breakdown	12
Labour supply shortage	12
Training programs shortage	14
Material transportation	14

Appendix A-7-

Assaf et al , 1995 Saudi Arabia

(A) The Top Delay Causes Factors in Saudi Arabia

Factor of Delay	Owners Rank	Contractors Rank	A/Es Rank
Shortage of Construction Material	6	10	11
Material shortages in types and specifications during construction	10	10	6
Slow delivery of materials	14	7	16
Financing by contractor during construction	3	18	2
Delays in contractors' progress payments by owner	10	2	5
Cash problems during construction	6	5	1
Design changes by owner or his agent during construction	17	2	9
Design errors made by designers (due to unfamiliarity with local conditions and environment)	1	7	14
Excessive bureaucracy in project owner operation	2	13	11
Preparing and approval of shop drawings	17	1	11
The relationship between different sub-contractors' schedule in the execution of the project	17	18	2
The conflict between contractor and consultant	17	13	20
Uncooperative owner	17	12	9
Poor organization of the contractor or consultant	17	16	11
Slowdown of the owner decision making	10	5	2
Inadequacy early planning of the project	17	16	16

(B) Rank of Delay Causes Groups (**Assaf et al 1995**)

Delay Group Factors	Owners	Contractors	A/Es
	Rank	Rank	Rank
Financing	1	1	1
Material	6	8	6
Contractual Relationship	4	3	3
Design	3	4	4
Governmental regulations	4	5	8
Labour	2	8	6
Scheduling and controlling	8	6	5
Equipment	7	7	7
Environmental conditions	9	9	9

Appendix A-8

Ogunlana et al 1996 Rank of Delays in Thailand

Delay source-Group	Reason for delay	No. of projects.	% of total
owner	Change Orders	5	41.7
	Slow Decision Making	4	33.3
Designers	Incomplete Drawings	9	75
	Slow Response	8	66.7
CM or Inspector	Deficiencies in Organisation	4	33.3
	Deficiencies in co-ordination	3	25
	Uncompromising Attitude	3	25
	Delays in Work Approval	2	16.7
Contractors	Materials Management Problems	9	75
	Deficiencies in Organisation	9	75
	co-ordination deficiencies	8	66.7
	Planning and Scheduling Problems	7	58.3
	Equipment Allocation Problems	5	41.7
	Financial Difficulties	4	33.3
	Indecency of Site Inspection	4	33.3
Resource Suppliers	Shortage of Construction Materials	11	91.7
	Late Delivery	6	41.7
	Price Escalation	2	16.7
	Low Material Quality	2	08.3
	Shortage of Site Workers	9	75
	Shortage of Technical Personnel	6	41.7
	Insufficient numbers of Equipment	7	58.3
	Frequent Equipment breakdown	3	25
Others	Confined Site	6	41.7
	Problems with Neighbours	3	25
	Slow Permits by Government Agencies	2	16.7

Notes:

- **Total project number is 12**
- **The number of projects that recorded this reason of delay has occurred in project.**

Appendix A-9

Appendix A-9

Kumaraswamy and Chan, 1998 Rank of Delays for Hong Kong Construction Industry

(A) Top ten delay causes for building and civil works

Hypothesised Factor	**Factor Category**	**Building Works RANK**	**Civil Works RANK**
Poor site management and supervision	Contractor related	1	2
Unforeseen ground conditions	Project related	2	1
Delay in design information	Design team related	3	NS
Lack of communication between consultant and contractor	Project related	4	NS
Inadequate contractor experience	Contractor related	5	6
Low speed of decision making involving all project teams	Project related	6	3
Client-initiated variations	Client related	7	4
Necessary work variations	Project related	8	5
Delays in subcontractor's work	Contractor related	9	NS
Improper control over site resources allocation	Contractor related	10	NS
Unsuitable management structure and style of the contractor	Contractor related	NS	7
Contractor's deficiencies in planning and scheduling at pre-construction stage	Contractor related	NS	8
Shortage of managerial and supervisory staff	Contractor related	NS	9
Unsuitable leadership style of contractor's construction manager	Contractor related	NS	10

NS, not included in the top 10 delay causes

(B) Factor Category Rank (Kumaraswamy and Chan, 1998)

Factor category	**Building works RANK based on Weighted average (RII)**	**Civil works RANK based on Weighted average (RII)**
Project related	5	5
Client related	8	7
Design team related	2	2
Contractor related	1	1
Materials related	6	8
Labour related	3	3
Plant/ Equipment	7	6
External	4	4

Appendix A-10

Frimpong et al (2003) Ghana ground water construction projects

Delay and cost overrun Cause	Owners rank	Contractors rank	Constant rank
Planning and scheduling deficiencies	3	10.5	4
Deficiencies in cost estimates prepared	8.5	12.5	10
Inadequate control procedure	18	16.5	19.5
Delays in work approval	20	15	19.5
Waiting for information	24.5	23	22.5
Mistakes during construction	21.5	24	21
Delays in inspection and testing of work	24.5	25	24
Cash flow during construction	6	6	5.5
Frequent breakdown of construction plant and equipment	14	19.5	16
Shortage of technical personnel	21.5	19.5	17
Labour shortage	23	21	22.5
Monthly payments difficulties	5	1	1
Poor contactor management	1	7	2
Shortage of materials, plant/ equipment parts	13	16.5	11
Contractor's financial difficulties	12	3.5	3
Low bid	16	12.5	14
Material procurement	2	2	9
Imported materials	17	18	15
Late delivery of materials and equipment	11	14	12.5
Escalation of material prices	4	5	7.5
Slow decision making	26	26	26
Inflation	7	3.5	5.5
Difficulties in obtaining construction materials at officials current prices	15	10.5	12.5
Ground problems	19	22	25
Bad weather	8.5	9	7.5
Unexpected geological conditions	10	8	18

Appendix A-11

Appendix B: Interview Questionnaire for Construction Project Delays

Interview Questionnaire for Construction Project Delays

Introduction

The problem of project delays is dominant in most of construction projects. The need for project delay predictability is increased during last two decades. A prediction model can be used in project start up phase to highlight the anticipated sources of delays before project start to enable them to be better managed. In this case a remedial strategy may be suggested to reduce the effects of these delays.

This questionnaire plans to establish a generic delay prediction model in construction industry. This questionnaire survey is a part of my research work at University of Plymouth-UK.

The questionnaire consists of four parts:

1- Part 1: Participant General Information
2- Part 2: Root Delay Causes Evaluation.
3- Part 3: Evaluation of the root delay causes to possibility of main resources shortage
4- Part 4: Measuring indicators for root delay causes

I am seeking for your help in answering this questionnaire; the results of this research will be feeded back to you. If you are able to participate in this questionnaire, your help and effort are apperciated. Your answer is treated as strictly confidential.

.

Thank you for your effort and help.

Sincerely

Ehab SOLIMAN

University of Plymouth

Research Background:

In this part, the research background and assumptions will be presented and the meanings of terms used in questionnaire will be clarified.

Project delay completion is one of the major problems in construction industry that often leads to costly disputes and severe relationships between involved parties.
The problem of delays in construction projects is internationally significant. Many examples for causes of delays can be recorded and noticed during construction phase of the project such as: delay of material delivery, mistakes in drawings, delay in shop drawing approvals, inefficient planning and scheduling techniques.....etc.

It is important to note that these recorded delays are direct or real delays that actually occurred on the project. It is proposed that these real delays are the outcomes of some of earlier events or management deficiencies that are the root causes of these direct delays.

Root delay causes are these delay causes that may be under some conditions transferred by themselves or merged with others to be real delays. Root delay causes are either managerial or financial problems from any of project parties or special project related sources.

Root delay causes may be evaluated, assessed before or during project construction phase by measuring these root delay causes' indicators. Root delay causes' indicators are the indicators by which root delay causes is assessed.

This research aims to study the sources of delays in construction industry, analyse these delays, understand their root causes, and then build a generic model to predict delays in the construction project.

The delay in this model is theoretically born in one or more of the root delay causes. This deficiency in root delay cause will affect one or more of the main resources' availability. Any resource unavailability or shortage will permit project activities to delay. The delay is propagation from the root delay causes and goes until delay the whole project.

The model aims to answer these questions: why is delay occurrence, what is the probability of delay occurring, and what is the most efficient way to mitigate the effect of delay?

Participant Name: **Date of Interview: / /**

Part 1: Participant General Information

Please define

1- You are working for in construction industry
   - o Client
   - o Contractor
   - o Consultant-designer

2- Your position can be described as one of the following level of management:
   - o Site management
   - o Middle management
   - o Top management

3- How many years of experience in construction industry
   - o From 10-15 years
   - o From 15-20 years
   - o More than 20 years

4- Your experience in which of these areas
   - o Building projects
   - o Civil projects

5- You have past experience in (you can tick more than one)
   - o Design Work
   - o Site Management
   - o Cost Estimation
   - o Contract Analysis
   - o Site Supervision
   - o Quantity Survey
   - o Claim Analysis

Part 2: Root Delay Causes Evaluation

As mentioned before real delay causes are generating earlier before they occur in site. Root delay causes are the root causes that lead real delay causes to be triggered or occurred in site. From an intensive analysis of real delay causes, a set of root delay causes was resulted. The following is root delay causes set and their definitions:

1) Designer management deficiencies:

It is level of consultant and designer management efficiency in design and/or construction supervision work.

2) Quality of design work documents

Measures the level of accuracy and matching of design work documents such as drawings, specifications, calculations....etc

3) Contractor management deficiencies

Defines the level of contractor(s) technical and managerial capabilities to execute and finish project in project contractual time.

4) Contractor financial problems

This measures the ability of contractor(s) to fund the project and not to stop the project because of contractor financial problems.

5) Client management deficiencies

It is the efficiency level of client and/or client representative(s) to provide the required information and support to finish project as scheduled.

6) Client financial problems

This measures the ability of client(s) to fund the project and provide contractor(s) payments when required.

7) Efficiency level of communication between project parts

It measures the level of communication efficiency between project parties during construction phase.

8) Level of interactions between project parties in pre-construction phase

Measures level of interaction between project parties before project start to union project objectives and discuss project risks.

9) Level of Trust between project parties:

Measures the level of trust between project parties to complete project as contracted.

10) Level of project complexity and required technology:

It measures level of project complexity and required technology.

11) Level of objectives harmony between project parties

It measures level of matching between client and other project parties goals.

12) Specific site characteristics

13) Specific project characteristics

14) Project contract and procurement strategy

It measures level of familiarity of the used contract and project procurement techniques.

Part 2: Root Delay Causes Evaluation: For each one of these root delay causes, estimate its level of effect on delay project finish. The level of effect varies from Very High Effect to No Effect.

	Root delay cause	Level of influence on project delay					
		Very high effect	High effect	Average effect	Little effect	Very little effect	No effect
1	*Designer management deficiencies*						
2	*Quality of design work documents*						
3	*Contractor management deficiencies*						
4	*Contractor financial problems*						
5	*Client management deficiencies*						
6	*Client financial problems*						
7	*Efficiency level of communication between project parts*						
8	*Level of interactions between project parties in pre-construction phase*						
9	*Level of Trust between project parties*						
10	*Level of project complexity and required technology*						
11	*Level of objectives harmony between project parties*						
12	*Specific site characteristics*						
13	*Specific project characteristics*						
14	*Project contract and procurement strategy*						

Part 3: Evaluation of the root delay causes to possibility of main resources shortage

Introduction:

Project delay is resulted from finish critical activities beyond their late finish date. If any activity is allowed to start, the activity delay or take more time more than estimate is critically influenced by shortage of main sources.

The research assumes that any root delay cause inefficiency will reflect in resource shortage and then delay activity finish.

Main resources required to implement any construction activity are:

- Construction Material: The required material either individual, mixed or fabricated material resource required permitting activity to start and finish. Materials are always provided from places other than project site.
- Labour: Required technical, skilled and unskilled labour associated to execute project activities.
- Equipment: Any required piece of equipment associated to execute project activities.
- Information: Any required design, supervision, coordination, orientation information required to execute activity
- Work Space: The required space and environment facilities required to permit activity to start and finish.

In this part the level of influence of each root delay cause and resource shortage occurrence will be estimate.

Part 3:

For each one of the root delay causes, establish the relationship between these root delay causes and each of material, labour, equipment, information and space

1- Material Shortage:

	Root delay cause	**Material Resource Shortage**					
		VH	H	A	L	VL	N
1	***Designer management deficiencies***						
2	***Quality of design work documents***						
3	***Contractor management deficiencies***						
4	***Contractor financial problems***						
5	***Client management deficiencies***						
6	***Client financial problems***						
7	***Efficiency Level of Communication between Project Parts***						
8	***Level of interactions between project parties in pre-construction phase***						
9	***Level of Trust between project parties***						
10	***Level of Project Complexity and Required Technology***						
11	***Level of objectives harmony between project parties***						
12	***Specific characteristics (location, underground, weather, environmental,..)***						
13	***Specific site and project characteristics***						
14	***Project contract and procurement strategy***						

VH= Very High Effect
H= High Effect
A= Average Effect
L= Low Effect
VL= Very Low Effect
N = No effect

2: Labour Shortage:

	Root delay cause	Labour Resource Shortage					
		VH	H	A	L	VL	N
1	***Designer management deficiencies***						
2	***Quality of design work documents***						
3	***Contractor management deficiencies***						
4	***Contractor financial problems***						
5	***Client management deficiencies***						
6	***Client financial problems***						
7	***Efficiency Level of Communication between Project Parts***						
8	***Level of interactions between project parties in pre-construction phase***						
9	***Level of Trust between project parties***						
10	***Level of Project Complexity and Required Technology***						
11	***Level of objectives harmony between project parties***						
12	***Specific characteristics (location, underground, weather, environmental,..)***						
13	***Specific site and project characteristics***						
14	***Project contract and procurement strategy***						

VH= Very High Effect
H= High Effect
A= Average Effect
L= Low Effect
VL= Very Low Effect
N = No effect

3- Equipment Shortage:

	Root delay cause	**Equipment Resource Shortage**					
		VH	H	A	L	VL	N
1	***Designer management deficiencies***						
2	***Quality of design work documents***						
3	***Contractor management deficiencies***						
4	***Contractor financial problems***						
5	***Client management deficiencies***						
6	***Client financial problems***						
7	***Efficiency Level of Communication between Project Parts***						
8	***Level of interactions between project parties in pre-construction phase***						
9	***Level of Trust between project parties***						
10	***Level of Project Complexity and Required Technology***						
11	***Level of objectives harmony between project parties***						
12	***Specific characteristics (location, underground, weather, environmental,..)***						
13	***Specific site and project characteristics***						
14	***Project contract and procurement strategy***						

VH= Very High Effect
H= High Effect
A= Average Effect
L= Low Effect
VL= Very Low Effect
N = No effect

4- Information Shortage:

	Root delay cause	Required Information Shortage					
		VH	H	A	L	VL	N
1	***Designer management deficiencies***						
2	***Quality of design work documents***						
3	***Contractor management deficiencies***						
4	***Contractor financial problems***						
5	***Client management deficiencies***						
6	***Client financial problems***						
7	***Efficiency Level of Communication between Project Parts***						
8	***Level of interactions between project parties in pre-construction phase***						
9	***Level of Trust between project parties***						
10	***Level of Project Complexity and Required Technology***						
11	***Level of objectives harmony between project parties***						
12	***Specific characteristics (location, underground, weather, environmental,..)***						
13	***Specific site and project characteristics***						
14	***Project contract and procurement strategy***						

VH= Very High Effect
H= High Effect
A= Average Effect
L= Low Effect
VL= Very Low Effect
N = No effect

5- Space Shortage:

	Root delay cause	**Work Space Shortage**					
		VH	H	A	L	VL	N
1	***Designer management deficiencies***						
2	***Quality of design work documents***						
3	***Contractor management deficiencies***						
4	***Contractor financial problems***						
5	***Client management deficiencies***						
6	***Client financial problems***						
7	***Efficiency Level of Communication between Project Parts***						
8	***Level of interactions between project parties in pre-construction phase***						
9	***Level of Trust between project parties***						
10	***Level of Project Complexity and Required Technology***						
11	***Level of objectives harmony between project parties***						
12	***Specific characteristics (location, underground, weather, environmental,..)***						
13	***Specific site and project characteristics***						
14	***Project contract and procurement strategy***						

VH= Very High Effect
H= High Effect
A= Average Effect
L= Low Effect
VL= Very Low Effect
N = No effect

Part 4: Measuring Indicators for Root Delay Causes

In this part, we will evaluate and define the root delay indicators. Root delay causes' indicators those are the measures or evaluators that can be assessed before project start to give an evaluation of each root delay cause.

In this interview, some of suggested indicators will be presented; you can evaluate them and assess them as a measure for the related root delay cause. If you can define any other relevant indicators, please add them.

For the following root delay cause, please decide by ticking yes or no if the delay indictor is relevant as a measure for the related root delay cause. If yes, define its level of importance as a root delay cause' measure by choosing one level from very high to very low.

Part 4: Measuring Indicators for Root Delay Causes

Root delay cause indicator measurement		Is this relevant indicator to root cause		Level of Importance as a Measure for Root Delay Cause				
		yes	no	VH	H	A	L	VL
1	***Designer management efficiency***							
	1. Designer experience in current work							
	2. Quality of design revision policy							
	3. Task performance(1)							
	4. Percentage of outsourcing work(2)							
	5. Quality of design group leadership(3)							
	6. Designer general reputation							
	Other indicator, please define							
2	***Quality of design work documents***							
	1. Accuracy level of design documents							
	2. Usability of the design documents							
	3. Design constructability (4)							
	Other indicator, please define							
3	***Contractor financial stability***							
	1. Number of projects in hand							
	2. Value of work in hand							
	3. Working capital							
	4. Quality of bank arrangement							
	5. Liquidity ratio (5)							
	Other indicator, please define							

(1) Task performance is the designer proficiency and skill in job-specific tasks
(2) Percentage of design work done from third party not the designer
(3) Quality of design group leader in quality control and flexibility to deal with changes
(4) Flexibility of design
(5) Current assets / current liabilities

Root delay cause indicator measurement		Is this relevant indicator to root cause		Level of Importance as a Measure for Root Delay Cause				
		yes	no	VH	H	A	L	VL
4	***Contractor management capabilities***							
	1. Experience in general:(Measured by the years of work, value of work done)							
	2.Contractor possess the required experience in same type of projects (measured by no of jobs in similar projects)							
	3. Contractor past records in finishing project ahead or in schedule							
	4. Plant and equipment possession and maintenance strategy							
	5. Level of contractor staff experience and management capabilities							
	6. Contractor has a good document control strategy							
	7. Project team organization structure							
	8. Head office organization structure							
	9. History of past records of relationship with other project parties.							
	10. level of contractor staff overloading							
	Other indicator, please define							
5	***Client management efficiency:***							
	1. Client management experience in similar projects							
	2. Project organization structure from client party							
	3. Client's willingness to accept effective and positive ideas							
	4. Level of client team internal communication effectiveness							
	5. Client support to finish project as scheduled							
	Other indicator, please define							
6	***Client financial stability***							
	3-6-1 Type of client, public, private, one-off firm							
	3-6-2 Credit rating (6)							
	3-6-3 Number of financial sources							
	3-6-4 Market reputation							
	Other indicator, please define							

Part 4: Measuring Indicators for Root Delay Causes (Continue)

Root delay cause indicator measurement		

		root cause						
		yes	no	VH	H	A	L	VL
7	***Efficiency Level of communication between project parties***							
	3-7-1 Clearness of communication methods, documentation for all project parties							
	3-7-2 Communication channels number							
	3-7-3 Regular communication are timely relevant							
	3-7-4 Extensive communication paper work							
	3-7-5 Time to get information							
	3-7-6 Number of meetings per week during construction phase							
	3-7-7 Language, and wording							
	Other indicator, please define							
8	***Level of interactions between project parties in pre-construction phase***							
	3-8-1 Amount of sharing information between all project parties							
	3-8-2 *Number of meetings before project start*							
	3-8-3 Level of participation of project parties in pre-construction phase							
	3-8-4 *percentage of pre-construction time to construction phase*							
	3-8-5 relationship and integration during design work							
	Other indicator, please define							
9	***Level of Trust between project parties***							
	3-9-1 *Level of competence, fairness, helpful and honesty between project parties*							
	3-9-2 Speed of response							
	3-9-3 *Trust level from past interrelation work*							
	Other indicator, please define							

(6) Credit ability and banking facilities

Part 4: Measuring Indicators for Root Delay Causes (Continue)

Root delay cause indicator measurement		Is this relevant indicator to root cause		Level of Importance as a Measure for Root Delay Cause				
		yes	no	VH	H	A	L	VL
10	***Level of project complexity and required technology***							
	1- Differentiation: Number of organizations working in the construction project							
	2- Number of project sub-systems and interfaces between project elements							
	3- Level of familiarity for construction method							
	4- Required number of specialists and experts							
	5- Type and numbers of special equipment required							
	6- Level of rigidity of activities sequencing.							
	7- Size of project							
	Other indicator, please define							
11	***Level of objectives harmony between project parties***							
	1. Matching level between client objectives and other parties objectives							
	2- Clearness level of client objectives in pre-construction phase							
	3- Uncertainty of goal definition, goals are not frozen.[(7)]							
	Other indicator, please define							

Part 4: Measuring Indicators for Root Delay Causes (Continue)

Root delay cause indicator measurement			Is this relevant indicator to root cause		Level of Importance as a Measure for Root Delay Cause				
			yes	no	VH	H	A	L	VL
12	***Specific site characteristics (location, underground, weather, environmental,..)***								
		3-12-1 Level of site accessibility							
		3-12-2 Level of site hazardous							
		3-12-3 Transportation problems							
		3-12-4 Permits and licenses for equipment and labours							
		3-12-5 Level of site congestion							
		3-12-6 Level of risks anticipated due to underground conditions							
		3-12-7 Weather and climatic effects							
		3-12-8 Level of approvals from authorities							
		3-12-9 Social effects							
		Other indicator, please define							
13	***Specific project characteristics***								
		1. Percentage of long lead material items (8)							
		2. Design time to project time							
		3. Project profit margin							
		4. Project requires newness technology(9)							
		5. Contract time pressure (10)							
		Other indicator, please define							
14	***Project contract and procurement strategy***								
		1. Project parties familiarity with contract type and procurement strategy							
		2. Level of contract clauses clearness and completeness							
		3. Clauses regarding time performance- penalty in delay and reward in early finish							
		Other indicator, please define							

(7) Client objectives always changes during project life
(8) Percentage of imported materials
(9) Project needs new technology
(10) Project time estimate is optimistic

General Comments:

Appendix C: List of Experts Contacted and Participants

No	Name	Position/ part of	Contact no/ emails	Questionnaire &Interview First announcement	Interview date
1	Abdullah Badawi	Contractor	9576037	21/12/2003	16/03/2004
2	Ahmad Assad	Contractor	9789519	22/11/2003	
3	Ahmad Makwi	Consultant	9707453	22/11/2003	
4	Ahmad mofi	Contractor	6636261	01/12/2003	
5	Ahmad Roumi	Client	9399333	12/12/2004	10/12/2003
6	Ahmad Younes	Contractor	9738942	16/11/2003	25/01/2004
7	Ahmd Salama	Client	6551466	18/12/2003	26/01/2004
8	Alaa Gabr	Consultant	9836944	18/12/2003	09/01/2004
9	Alaa Tourek	Consultant	6634209	14/12/2003	
10	Amer Abdelaziz	Consultant	6658411	10/12/2003	22/01/2004
11	Amir Abdelsalam	Client	2421391	16/12/2003	
12	Amr Bedair	Consultant	6501475	15/11/2003	03/01/2004
13	Ashraf Refay	Contractor	9856206	12/11/2003	21/01/2004
14	Assad Shikha	Contractor	5613456	12/11/2003	20/11/2003
15	Ayman Farah	Contractor	9042984	17/11/2003	10/12/2003
16	Ehab Ismail	Contractor	9759475	07/01/2004	23/02/2004
17	Essam Adi	Consultant	9774531	22/12/2003	06/01/2004
18	Essam Shaaban	Contractor	9654098	09/01/2004	21/01/2004
19	Ez soror	Contractor	9001534	05/01/2004	25/02/2004
20	Felex , Edward	Client	4821320	01/03/2004	04/03/2004
21	Hamdi Eid	Contractor	9613952	23/11/2003	21/12/2003
22	Hamed Ghoulabi	Client	7881064	24/11/2003	25/11/2003
23	Hani Tardus	Contractor	9874901		
24	Hany Sabri	Contractor	4825178	22/11/2003	25/12/2003
25	Hashem Tabatbi	Client	9771340	24/11/2004	
26	Hesham Baz	Consultant	7950975	22/11/2003	26/11/2003
27	Hesham Mehawi-	Consultant	9542156	06/01/2004	
28	Hosam Rzk	Consultant	9613535	04/12/2003	21/01/2004

				Questionnaire &Interview	
No	Name	Position/ part of	Contact no/ emails	First announcement	Interview date
29	Hussain AlGhousain	Client	9550953	04/01/2004	
30	Ibrahim Mahdi	Consultant	9716405	30/10/2003	02/11/2003
31	Ibrahimn AlAnasari	Client	9238654	15/11/2003	
32	Khaled Rashed	Consultant	7933195	29/10/2003	20/11/2003
33	Khoudary Alam	Contractor	9633095	22/01/2004	10/02/2004
34	Mahmoud Hussain	Client	9895860	10/12/2003	
35	Mahmoud Hussain	Client	6785412	08/01/2004	13/03/2004
36	Mahoud Saker	Consultant	6695210	22/01/2004	
37	Mamdouh Hussain	Consultant	9762899	08/01/2004	04/03/2004
38	Mohamad Abo-Shadi	Contractor	9459358	15/12/2003	
39	Mohamad Hegazi	Contractor	9816181	23/12/2003	
40	Mohamad Kholey	Contractor	9721009	03/01/2004	
41	Mohamad Mosatafa	Contractor	9627168	25/11/2003	
42	Mohamad Omar	Contractor	9404110	29/11/2003	
43	Mohamed Bahari	Contractor	5732459	11/11/2003	
44	Mosbah Khalaf	Contractor	9824118	10/12/2003	
45	Nabil Alsaid	Contractor	6662496	29/11/2003	
46	Nabil Mahmoud	Consultant	9719202	01/12/2003	
47	Najeed Asfari	Client	9760183	21/12/2003	19/12/2003
48	Ramzy Razkahhah	Consultant	6048024	29/10/2003	
49	Rashed Sulaiman	Consultant	6776630-2457000	12/11/2003	
50	Safwan Soufi	Contractor	9706114	22/12/2003	
51	Said Dousouki	Contractor	9021762	10/11/2003	18/11/2003
52	Said Haroun	Consultant	9822289	05/01/2004	
53	Sami Ahmad	Contractor	9530873	22/12/2003	29/12/2003
54	Samir Altaher	Client	7882904	14/12/2003	
55	Serag Roshdi	Client	3901665-9604577	14/12/2003	24/12/2003
56	Talal Otabai	Client	9649899	17/11/2003	20/11/2003
57	Wahid Amer	Client	6637847	29/11/2003	
58	Zakari Makwi	Contractor	9705905	22/12/2003	

Appendix D: Coding System

Coding System

1- **Main Resources: in one character**
Material (m)
Labour (l)
Equipment (q)
Information (f)
Space (s)

2- **Two characters for root delay causes**
Designer' management deficiencies (DM)
Quality of design work documents (DD)
Contractor' Management deficiencies (CM)
Contractor' financial problems (CF)
Client' Management deficiencies (OM)
Client' Financial problems (OF)
Efficiency Level of Communication between Project Parts (MM)
Level of interactions before project start (NT)
Level of Trust between project parties (TR)
Level of Project Complexity and Required Technology (CT)
Level of objectives harmony between project parties (OB)
Specific Site Characteristics (SC)
Specific Project Characteristics (PP)
Project contract and procurement strategy (PS)

3- **Indicators, two characteristics of indicators**

Designer management efficiency (DM)
- Designer experience in current work (DM.01)
- Quality of design revision policy (DM.02)
- Task Performance (DM.03)
- Percentage of Outscoring Work (DM.04)
- Quality of Design Group Leadership (DM.05)
- Designer General Reputation (DM.06)

Quality of design work documents (DD)
- Accuracy Level of Design Documents (DD.01)
- Usability of the Design Document (DD.02)
- Design Constructability (DD.03)

Contractor management efficiency (CM)
- Experience in general (CM.01)
- Contractor possess the required experience in same type of projects (CM.02)
- Contractor past records in finishing project ahead or in schedule (CM.03)
- Plant and equipment possession and maintenance strategy (CM.04)

- Level of contractor staff experience and management capabilities (CM.05)
- Contractor has a good document control strategy (CM.06)
- Project team organization structure (CM.07)
- Head office organization structure (CM.08)
- History of past records of relationship with other project parties (CM.09)
- level of contractor staff overloading (CM.10)

Contractor financial stability (CF)

- Number of Projects in Hand (CF.01)
- Value of Work in Hand (CF.02)
- Working Capital (CF.03)
- Quality of Bank Arrangement (CF.04)
- Liquidity Ration (CF.05)

Client-Owner Management efficiency (OM)

- Client management experience in similar projects (OM.01)
- Project organization structure from client party (OM.02)
- Client's willingness to accept effective and positive ideas (OM.03)
- Level of client team internal communication effectiveness (OM.04)
- Client support to finish project as scheduled (OM.05)

Client-Owner Financial Stability (OF)

- Type of client, public, private, one-off firm (OF.01)
- Credit rating (OF.02)
- Number of financial sources (OF.03)
- Market reputation (OF.04)

Efficiency Level of Communication between Project Parts (MM)

- Clearness of communication methods, documentation for all project parties (MM.01)
- Communication channels number (MM.02)
- Regular communication are timely relevant (MM.03)
- Extensive communication paper work (MM.04)
- Time to get information (MM.05)
- Number of meetings per week during construction phase (MM.06)

Level of interactions before project start (NT)

- Amount of sharing information between all project parties (NT.01)
- Number of meetings before project start (NT.02)
- Level of participation of project parties in pre-construction phase (NT.03)
- percentage of pre-construction time to construction phase (NT.04)
- relationship and integration during design work (NT.05)

Level of trust between project parties (TR)

- Level of competence, fairness, helpful and honesty between project parties (TR.01)
- Speed of response (TR.02)
- Trust level from past interrelation work (TR.03)

Level of Project Complexity and Required Technology (CT)

- Differentiation: Number of organizations working in the construction project (CT.01)
- Number of project sub-systems and interfaces between project elements (CT.02)
- Level of familiarity for construction method (CT.03)
- Required number of specialists and experts (CT.04)
- Type and numbers of special equipment required (CT.05)
- Level of rigidity of activities sequencing (CT.06)
- Size of project (CT.07)

Level of objectives harmony between project parties (OB)

- Matching level between client objectives and other parties objectives (OB.01)
- Clearness level of client objectives in pre-construction phase (OB.02)
- Uncertainty of goal definition, goals are not frozen (OB.03)

Specific Site Characteristics (SC)

- Level of site accessibility (SC.01)
- Level of site hazardous (SC.02)
- Transportation problems (SC.03)
- Permits and licenses for equipment and labours (SC.04)
- Level of site congestion (SC.05)
- Level of risks anticipated due to underground conditions (SC.06)
- Weather and climatic effects (SC.07)
- Level of approvals from authorities (PS.08)
- Social effects (SC.09)

Specific Project Characteristics (PP)

- Percentage of long lead material items (PP.01)
- Design time to project time (PP.02)
- Project profit margin (PP.03)
- Project requires newness technology (PP.04)
- Contract time pressure (PP.05)

Project contract and procurement strategy (PS)

- Project parties familiarity with contract type and procurement strategy (PS.01)
- Level of contract clauses clearness and completeness (PS.02)
- Clauses regarding time performance- penalty in delay and reward in early finish (PS.03)

Appendix E: First Round Questionnaire Answers

	Name	Position	management Level	Yearrs of experience	Projects	Past ex. In
1	Essam Adi	consultant	middle	>20	building	2,6
2	Amr Abdelaziz	consultant	Middle	<15	building	2,6
3	Khaled Rasheed	consultant	middle	15-20	building	2,6
4	Ashraf Refi	Contractor	top	15-20	building	1,2,3,4,6
5	Ibrahim Mahdi	consultant	middle	15-20	building	2,5,6
6	said Dfousouky	contractor	top	15-20	building	2,3,4,6
7	ESAM SHABBAN	contractor	top	>20	building	1,2,3,4,5,6
8	HAMED GHAULBY	client	middle	>20	building	2,4,6
9	EHAB ISMAIL	contractor	middle	<15	building	2,4,6
10	AHMED YOUNIS	contractor	middle	15-20	buiding	2,4,6
11	Ahmad Salama	client	middle	15-20	building	2,4,6,7
12	ALLA GABER	consultant	middle	>20	building	2,3,4,5,6,7
13	Ezz Soror	Contractor	Middle	>20	Buildings	2,3,4,5,6
14	Hesham AlBaz	Consultant	top	<15	building	2,4,6,7,5
15	Serag Roshdi	client	top	15-20	building	1,2,4,6,,7
16	Abdallah Badway	contractor	middle	15-20	building	1,3,4,6,7
17	sami ahmad	contractor	middle	15-20	building	2,4
18	Mahmoud Hussain	client	middle	>20	building	2,4,6,7
19	Mamdouh Hussain	consultant	middle	>20	building	2,6
20	Felex Mark	client	top	15-20	building	2,3,5,6,7
21	Khoudary Alam	Contractor	top	>20	building	2,4,6,7
22	hosam Rozak	consultant	top	15-20	building	2,4,6,7
23	Tala Otabi	client	middle	15-20	building	2,4
24	Najeed ASFARI	client	middle	15-20	building	2,4,6
25	Ayman Farah	contractor	top	15-20	building	2,4,6
26	hani Sabri	contractor	top	15-20	building	2,4,6
27	Hamdi Eid	Contractor	top	15-20	building	2,4,5,6,7
28	Assad Shiekha	Contractor	top	15-20	building	2,4,6,7
29	Amr Bedair	consultant	middle	<15	building	2,4,6,7
30	Ahmad Romi	Client	middle	<15	building	2,4

Paricpants' Answers for Root Delay Causes

		Participant's Name																													
	Root Delay Cause	Essam Adi	Amr Abdelaziz	Khaled Rasheed	Ashraf Refi	Ibrahim Mahdi	said Dousouky	ESAM SHABBAN	HAMED GHAULBY	EHAB ISMAIL	AHMED YOUNIS	Ahmad Salama	ALLA GABER	Ezz Soror	Hesham AlBaz	Serag Roshdi	Abdallah Badway	sami ahmad	Mahmoud Hussain	Mamdouh Hussain	Felex Mark	Khoudary Alam	hosam Rozak	Tala Otabi	Najeed ASFARI	Ayman Farah	hani Sabri	Hamdi Eid	Assad Shiekha	Amr Bedair	Ahmad Romi
1	*Designer management deficiencies*	3	2	4	5	4	3	4	5	4	2	5	4	3	4	1	0	5	3	3	5	3	1	4	5	4	4	4	2	4	3
2	*Quality of design work documents*	4	4	4	5	3	3	4	4	4	3	4	4	3	5	1	1	3	3	3	3	3	1	3	4	4	4	4	3	5	3
3	*Contractor management deficiencies*	4	3	5	4	5	5	4	5	5	5	5	5	2	4	4	3	3	4	4	4	4	4	5	5	4	4	5	5	4	4
4	*Contractor financial problems*	5	4	4	4	3	5	5	5	4	4	5	5	3	4	5	4	1	5	4	2	5	5	3	5	5	5	5	4	4	5
5	*Client management deficiencies*	2	4	4	4	4	4	3	5	4	3	4	4	2	4	4	4	2	3	4	4	3	4	4	5	3	3	4	3	4	4
6	*Client financial problems*	4	5	5	4	5	4	5	5	5	3	5	5	4	5	1	4	3	4	4	3	4	1	5	5	5	5	5	3	5	4
7	*Efficiency level of communication between project parts*	4	2	4	4	5	4	4	5	4	4	4	4	2	4	3	3	5	3	3	3	3	3	5	5	4	4	4	4	4	4
8	*Level of interactions between project parties in pre-construction phase*	3	3	3	5	4	3	3	5	3	2	3	3	0	3	2	2	1	2	4	3	2	2	4	5	3	3	3	2	3	3
9	*Level of Trust between project parties*	3	4	5	3	3	3	3	5	3	1	3	3	2	3	0	1	1	2	2	4	2	0	3	5	3	3	3	1	3	3
10	*Level of project complexity and required technology*	3	3	3	4	4	3	3	4	3	5	4	2	3	3	0	1	2	2	2	3	2	0	4	4	3	3	2	5	3	3
11	*Level of objectives harmony between project parties*	3	4	3	4	5	3	3	5	3	2	3	3	4	3	1	3	1	3	2	5	3	1	5	5	3	3	3	2	3	3
12	*Specific site characteristics*	4	4	5	4	4	2	2	4	5	4	2	3	3	5	4	3	3	4	4	3	4	4	4	4	2	2	3	4	5	2
13	*Specific project characteristics*	4	3	4	5	4	3	2	4	5	3	2	4	3	5	4	3	3	4	4	3	4	4	5	4	2	2	3	4	3	2
14	*Project contract and procurement strategy*	4	3	4	4	4	4	3	5	4	5	3	4	0	5	4	4	2	4	4	4	4	4	4	5	3	3	4	5	5	4

Paricpants' Answers for Root Delay Causes and Effects on Material Shortage

	Root Delay Cause	Participant's Name																													
		Bassam Adi	Amr Abdelaziz	Khaled Rasheed	Ashraf Refi	Ibrahim Mahdi	said Dousouky	ESAM SHABBAN	HAMED GHAULBY	EHAB ISMAIL	AHMED YOUNIS	Ahmad Salama	ALLA GABER	Ezz Soror	Hesham AlBaz	Serag Roshdi	Abdallah Badway	sami ahmad	Mahmoud Hussain	Mamdouh Hussain	Felex Mark	Khoudary Alam	hosam Romk	Tala Otabi	Najeed ASFARI	Ayman Farah	hani Sabri	Hamdi Eid	Assad Shiekha	Amr Bedair	Ahmad Romi
1	*Designer management deficiencies*	2	1	3	4	4	2	3	4	3	1	5	2	1	2	1	1	1	4	3	1	4	1	4	4	3	3	2	4	2	2
2	*Quality of design work documents*	4	1	4	4	5	2	4	1	4	3	4	2	4	3	2	1	3	2	3	4	2	2	5	1	4	4	2	1	3	2
3	*Contractor management deficiencies*	4	5	5	3	2	5	4	1	5	5	5	5	4	5	4	4	1	5	5	4	5	4	2	1	4	4	5	1	5	5
4	*Contractor financial problems*	3	1	5	4	5	3	3	5	5	4	5	5	4	5	5	4	5	4	5	4	4	5	5	5	3	3	5	5	5	3
5	*Client management deficiencies*	2	1	4	4	2	3	3	4	4	1	4	2	2	4	3	4	1	2	4	1	2	3	2	4	3	3	2	4	4	3
6	*Client financial problems*	1	4	3	4	5	4	5	5	3	3	5	4	4	4	3	4	1	4	4	4	4	3	5	5	5	5	4	5	4	4
7	*Efficiency level of communication between project parts*	2	1	4	4	4	4	3	5	4	1	4	3	1	3	3	4	3	4	4	4	4	3	4	5	3	3	3	5	3	4
8	*Level of interactions between project parties in pre-construction phase*	3	1	2	1	4	2	3	4	2	1	5	3	3	3	1	4	3	4	5	3	4	1	4	4	3	3	3	4	3	2
9	*Level of Trust between project parties*	1	1	2	5	5	3	3	5	2	1	4	3	1	3	1	1	4	3	2	3	3	1	5	5	3	3	3	5	3	3
10	*Level of project complexity and required technology*	3	1	2	3	4	3	3	5	2	4	4	4	4	3	4	1	5	3	2	3	3	4	4	5	3	3	4	5	3	3
11	*Level of objectives harmony between project parties*	1	1	2	4	5	4	4	1	2	1	3	4	4	3	3	1	4	3	2	1	3	3	5	1	4	4	4	1	3	4
12	*Specific site characteristics*	3	4	5	4	4	3	3	3	2	1	4	3	3	4	5	2	4	4	5	4	4	5	4	3	3	3	3	3	4	3
13	*Specific project characteristics*	3	3	3	5	4	5	3	3	2	3	4	3	3	4	5	2	4	4	5	4	4	5	4	3	3	3	3	3	4	3
14	*Project contract and procurement strategy*	3	2	5	4	5	5	4	5	3	5	3	3	3	4	4	2	2	3	4	2	3	4	5	5	4	4	3	5	4	5

Paricpants' Answers for Root Delay Causes and Effects on labour Shortage

	Root Delay Cause	Essam Adi	Amr Abdelaziz	Khaled Rasheed	Ashraf Refi	Ibrahim Mahdi	said Dousouky	ESAM SHABBAN	HAMED GHAULBY	EHAB ISMAIL	AHMED YOUNIS	Ahmad Salama	ALLA GABER	Ezz Soror	Hesham AlBaz	Serag Roshdi	Abdallah Badwy	sami ahmad	Mahmoud Hussain	Mamdouh Hussain	Felex Mark	Khoudary Alam	hosam Rozak	Tala Otabi	Najeed ASFARI	Ayman Farah	hani Sabri	Hamdi Eid	Assad Shiekha	Amr Bedair	Ahmad Romi
		Paericipant's Name																													
1	*Designer management deficiencies*	4	1	1	4	1	3	3	4	1	1	2	1	1	2	3	1	1	3	3	1	3	3	1	4	3	3	1	4	2	3
2	*Quality of design work documents*	4	1	3	3	3	4	4	1	2	1	2	1	3	3	3	1	1	2	3	3	2	3	3	1	4	4	1	1	3	4
3	*Contractor management deficiencies*	4	5	6	2	4	4	6	5	3	4	5	4	4	5	5	4	4	5	5	4	5	5	4	5	4	4	4	5	6	4
4	*Contractor financial problems*	4	1	4	4	5	4	3	4	3	3	5	5	4	6	5	4	5	4	5	4	4	6	5	4	4	4	5	4	5	4
5	*Client management deficiencies*	1	2	3	4	2	2	3	6	1	1	3	1	1	3	2	2	2	3	3	1	3	2	2	5	2	2	1	5	3	2
6	*Client financial problems*	2	3	2	4	4	3	5	5	1	1	4	2	3	4	3	4	2	4	3	5	4	3	4	5	3	3	2	5	4	3
7	*Efficiency level of communication between project parts*	2	4	3	4	4	3	4	4	1	1	4	1	3	2	3	4	2	2	2	1	2	3	4	4	3	3	1	4	2	3
8	*Level of interactions between project parties in pre-construction phase*	3	1	4	5	3	2	3	6	1	1	5	1	3	3	1	2	3	2	6	4	2	1	3	5	2	2	1	5	3	2
9	*Level of Trust between project parties*	2	1	4	3	4	2	2	5	1	1	4	1	1	4	3	1	3	2	1	3	2	3	4	5	2	2	1	5	4	2
10	*Level of project complexity and required technology*	3	3	5	3	5	3	3	5	2	1	5	2	4	4	3	1	4	3	3	3	3	3	5	5	3	3	2	5	4	3
11	*Level of objectives harmony between project parties*	3	3	1	3	3	3	2	1	1	1	3	2	1	3	2	1	3	2	1	1	2	3	3	1	3	3	2	1	3	3
12	*Specific site characteristics*	4	1	5	4	6	2	5	2	2	1	4	3	4	4	6	1	4	3	3	4	3	5	6	2	2	2	3	2	4	2
13	*Specific project characteristics*	3	3	6	4	3	3	2	3	3	2	5	5	3	4	4	2	2	2	3	4	1	4	4	2	3	2	2	2	4	3
14	*Project contract and procurement strategy*	3	3	6	4	4	4	3	6	2	1	2	2	3	4	6	2	1	2	1	3	2	0	4	5	4	4	2	5	4	4

Partcipants' Answers for Root Delay Causes and Effects on Equipment Shortage

	Root Delay Cause	Essam Adi	Amr Abdelaziz	Khaled Rasheed	Ashraf Refi	Ibrahim Mahdi	said Dousouky	ESAM SHABBAN	HAMED GHAULBY	EHAB ISMAIL	AHMED YOUNIS	Ahmad Salama	ALLA GABER	Ezz Soror	Hesham AlBaz
1	*Designer management deficiencies*	4	1	1	4	1	3	3	4	1	1	2	1	1	2
2	*Quality of design work documents*	4	1	3	3	3	4	4	1	2	1	2	1	3	3
3	*Contractor management deficiencies*	4	5	5	2	4	4	5	5	3	4	5	4	4	5
4	*Contractor financial problems*	4	1	4	4	5	4	3	4	3	3	5	5	4	5
5	*Client management deficiencies*	1	2	3	4	2	2	3	5	1	1	3	1	1	3
6	*Client financial problems*	2	3	2	4	4	3	5	5	1	1	4	2	3	4
7	*Efficiency level of communication between project parts*	2	4	3	4	4	3	4	4	1	1	4	1	3	2
8	*Level of interactions between project parties in pre-construction phase*	3	1	4	5	3	2	3	5	1	1	5	1	3	3
9	*Level of Trust between project parties*	2	1	4	5	4	2	2	5	1	1	4	1	1	4
10	*Level of project complexity and required technology*	3	3	5	3	5	3	3	5	2	1	5	2	4	4
11	*Level of objectives harmony between project parties*	3	3	1	3	3	3	2	1	1	1	3	2	1	3
12	*Specific site characteristics*	4	1	5	4	5	2	5	2	2	1	4	3	4	4
13	*Specific project characteristics*	4	2	5	4	5	2	5	2	2	2	4	3	4	4
14	*Project contract and procurement strategy*	3	3	5	4	4	4	3	5	2	1	2	2	5	4

Participant's Name (continued)

	Root Delay Cause	Serag Roshdi	Abdallah Badway	sami ahmad	Mahmoud Hussain	Mamdouh Hussain	Felex Mark	Khoudary Alam	hosam Rozak	Tala Otabi	Najeed ASFARI	Ayman Farah	hani Sabri	Hamdi Eid	Assad Shiekha	Amr Bedair	Ahmad Romi
1	*Designer management deficiencies*	3	1	1	3	3	1	3	3	1	4	3	3	1	4	2	3
2	*Quality of design work documents*	3	1	1	2	3	3	2	3	3	1	4	4	1	1	3	4
3	*Contractor management deficiencies*	5	4	4	5	5	4	5	5	4	5	4	4	4	5	5	4
4	*Contractor financial problems*	5	4	5	4	5	4	4	5	5	4	4	4	5	4	5	4
5	*Client management deficiencies*	2	2	2	3	3	1	3	2	2	5	2	2	1	5	3	2
6	*Client financial problems*	3	4	2	4	3	5	4	3	4	5	3	3	2	5	4	3
7	*Efficiency level of communication between project parts*	3	4	2	2	2	1	2	3	4	4	3	3	1	4	2	3
8	*Level of interactions between project parties in pre-construction phase*	1	2	3	2	5	4	2	1	3	5	2	2	1	5	3	2
9	*Level of Trust between project parties*	3	1	3	2	1	3	2	3	4	5	2	2	1	5	4	2
10	*Level of project complexity and required technology*	3	1	4	3	3	3	3	3	5	5	3	3	2	5	4	3
11	*Level of objectives harmony between project parties*	3	1	3	2	1	1	2	3	3	1	3	3	2	1	3	3
12	*Specific site characteristics*	5	1	4	3	3	4	3	5	5	2	2	2	3	2	4	2
13	*Specific project characteristics*	5	1	4	3	3	4	3	5	5	1	2	2	3	2	5	2
14	*Project contract and procurement strategy*	5	2	1	2	1	3	2	0	4	5	4	4	2	5	4	4

Paricpants' Answers for Root Delay Causes and Effects on Information Shortage

	Root Delay Cause	Essam Adi	Amr Abdelaziz	Khaled Rasheed	Ashraf Refi	Ibrahim Mahdi	said Dousouky	ESAM SHABBAN	HAMED GHAULBY	EHAB ISMAIL	AHMED YOUNIS	Ahmad Salama	ALLA GABER	Ezz Soror
1	*Designer management deficiencies*	5	5	4	6	6	4	6	5	4	3	6	3	3
2	*Quality of design work documents*	5	4	5	5	6	4	2	3	6	4	4	3	4
3	*Contractor management deficiencies*	3	1	4	6	4	4	3	4	4	1	4	3	1
4	*Contractor financial problems*	4	4	4	4	5	5	2	4	4	3	4	5	3
5	*Client management deficiencies*	1	4	3	4	5	4	3	6	3	2	5	3	2
6	*Client financial problems*	2	3	2	1	4	2	3	6	2	1	5	1	2
7	*Efficiency level of communication between project parts*	2	3	4	4	5	4	3	4	4	4	5	1	4
8	*Level of interactions between project parties in pre-construction phase*	2	4	4	4	5	4	3	5	4	1	6	1	3
9	*Level of Trust between project parties*	2	1	3	1	5	6	2	6	3	1	6	3	1
10	*Level of project complexity and required technology*	3	3	4	5	4	4	3	5	4	5	6	4	4
11	*Level of objectives harmony between project parties*	3	3	1	5	4	6	2	1	1	2	4	4	4
12	*Specific site characteristics*	4	1	3	3	5	2	6	3	3	1	4	2	1
13	*Specific project characteristics*	3	1	3	3	4	2	6	3	3	2	4	2	3
14	*Project contract and procurement strategy*	3	3	4	6	4	4	1	5	4	1	4	3	1

	Root Delay Cause	Hesham AlBaz	Serag Roshdi	Abdallah Badway	sami ahmad	Mahmoud Hussain	Mamdouh Hussain	Felex Mark	Khoudary Alam	hosam Rozak	Tala Otabi	Najeed ASFARI	Ayman Farah	hani Sabri	Hamdi Eid	Assad Shiekha	Amr Bedair	Ahmad Romi
1	*Designer management deficiencies*	5	6	4	6	4	6	5	4	6	6	6	6	6	3	6	5	4
2	*Quality of design work documents*	4	4	4	5	4	5	4	4	4	5	3	2	2	3	3	4	4
3	*Contractor management deficiencies*	3	1	3	3	1	3	1	1	1	4	4	3	3	3	4	3	4
4	*Contractor financial problems*	5	1	4	3	3	3	4	3	1	5	4	2	2	5	4	5	5
5	*Client management deficiencies*	4	3	3	2	4	6	6	4	3	5	6	3	3	3	5	4	4
6	*Client financial problems*	4	1	3	1	1	2	1	1	1	4	5	3	3	1	5	4	2
7	*Efficiency level of communication between project parts*	5	4	4	3	4	2	5	4	4	5	4	3	3	0	4	5	4
8	*Level of interactions between project parties in pre-construction phase*	3	4	2	4	4	4	4	4	4	6	5	3	3	0	5	3	4
9	*Level of Trust between project parties*	5	4	1	4	3	2	4	3	4	6	5	2	2	3	5	5	5
10	*Level of project complexity and required technology*	3	4	3	6	2	3	3	2	4	4	5	3	3	4	5	3	4
11	*Level of objectives harmony between project parties*	4	4	1	4	3	1	4	3	4	4	1	2	2	4	1	4	5
12	*Specific site characteristics*	3	5	1	6	2	2	1	2	5	6	3	6	5	2	3	3	2
13	*Specific project characteristics*	3	5	2	6	2	2	1	3	5	6	3	6	6	2	2	2	2
14	*Project contract and procurement strategy*	4	4	2	3	2	1	3	2	4	4	5	1	1	3	5	4	4

Paricpants' Answers for Root Delay Causes and Effects on Space Shortage

	Root Delay Cause	Parricipant's Name														
		Essam Adi	Amr Abdelaziz	Khaled Rasheed	Ashraf Refi	Ibrahim Mahdi	said Dousouky	ESAM SHABBAN	HAMED GHAULBY	EHAB ISMAIL	AHMED YOUNIS	Ahmad Salama	ALLA GABER	Ezz Soror	Hesham AlBaz	Serag Roshdi
1	*Designer management deficiencies*	4	1	3	5	5	2	3	4	1	1	3	2	1	4	1
2	*Quality of design work documents*	3	1	3	5	4	3	3	1	3	1	3	1	1	3	1
3	*Contractor management deficiencies*	4	1	3	5	4	3	2	3	3	1	3	2	3	5	1
4	*Contractor financial problems*	4	4	3	4	5	3	1	4	1	1	3	3	4	5	4
5	*Client management deficiencies*	1	3	4	4	3	2	1	4	1	1	3	1	2	3	3
6	*Client financial problems*	1	1	3	5	3	2	3	5	1	1	3	1	1	3	1
7	*Efficiency level of communication between project parts*	2	5	4	5	4	2	3	4	1	1	3	2	2	4	3
8	*Level of interactions between project parties in pre-construction phase*	2	2	4	5	5	2	2	5	1	1	3	1	3	4	4
9	*Level of Trust between project parties*	2	1	3	3	1	2	1	5	1	1	3	1	1	3	3
10	*Level of project complexity and required technology*	3	1	2	4	5	2	1	5	2	1	3	2	1	5	1
11	*Level of objectives harmony between project parties*	3	1	1	4	4	2	1	1	2	1	2	2	4	4	4
12	*Specific site characteristics*	4	4	5	3	5	2	5	2	3	5	5	2	3	5	5
13	*Specific project characteristics*	3	3	4	4	5	2	3	2	3	4	5	2	3	5	5
14	*Project contract and procurement strategy*	3	3	4	5	1	4	2	5	2	1	4	1	1	5	4

	Root Delay Cause	Abdallah Badway	sami ahmad	Mahmoud Hussain	Mamdouh Hussain	Felex Mark	Khoudary Alam	hosam Rozak	Tala Otabi	Najeed ASFARI	Ayman Farah	hani Sabri	Hamdi Eid	Assad Shiekha	Amr Bedair	Ahmad Romi
1	*Designer management deficiencies*	1	1	1	2	1	1	1	5	4	3	3	1	4	4	2
2	*Quality of design work documents*	2	1	1	1	1	1	1	4	1	3	3	1	1	3	3
3	*Contractor management deficiencies*	2	2	2	5	1	2	1	4	3	2	2	3	3	5	3
4	*Contractor financial problems*	3	4	3	5	1	3	4	5	4	1	1	4	4	5	3
5	*Client management deficiencies*	2	2	4	2	1	4	3	3	4	1	1	2	4	3	2
6	*Client financial problems*	3	1	2	4	1	2	1	3	5	3	3	1	5	3	2
7	*Efficiency level of communication between project parts*	4	2	4	2	1	4	3	4	4	3	3	2	4	4	2
8	*Level of interactions between project parties in pre-construction phase*	2	2	4	1	1	4	4	5	5	2	2	3	5	4	2
9	*Level of Trust between project parties*	1	2	2	2	1	2	3	1	5	1	1	1	5	3	2
10	*Level of project complexity and required technology*	1	4	2	4	5	2	1	5	5	1	1	1	5	5	2
11	*Level of objectives harmony between project parties*	1	2	4	2	1	4	4	4	1	1	1	4	1	4	2
12	*Specific site characteristics*	2	5	4	5	5	4	5	5	2	5	5	3	2	5	2
13	*Specific project characteristics*	2	3	4	3	4	4	5	5	2	5	5	3	2	5	2
14	*Project contract and procurement strategy*	2	2	2	2	3	2	4	1	5	2	2	1	5	5	4

		Participant's Name																													
		Essam Adl	Amr Abdelaziz	Khaled Rashwan	Ashraf Refi	Ibrahim Mahdi	said Dousouky	ESAM SHABBAN	HAMED GHAULBY	EHAB ISMAIL	AHMED YOUNIS	Ahmed Salama	ALLA GABER	Ezz Sorur	Hesham AlBaz	Serag Roshdi	Abdallah Badway	sami ahmed	Mahmoud Hussain	Mamdouh Hussain	Felex Mark	Khoudary Alam	hosam Rozak	Tala Otabi	Najeed ASFARI	Ayman Farah	hani Sabri	Hamdi Eid	Assad Shiekha	Amr Bedair	Ahmad Romi
1	*Designer management efficiency*																														
	1. Designer experience in current work	4	5	5	5	5	4	4	5	5	4	4	4	4	5	5	5	2	4	5	4	4	5	5	5	4	4	4	5	5	4
	2. Quality of design revision policy	4	3	3	5	5	4	4	4	3	3	4	4	4	3	5	4	0	4	4	3	4	5	5	4	4	4	4	4	3	4
	3. Task performance[1]	4	3	5	5	5	4	4	4	5	2	5	4	4	5	5	4	0	3	4	3	3	5	5	4	4	4	4	4	5	4
	4. Percentage of outsourcing work[2]	3	1	2	0	0	4	5	0	2	3	4	2	4	2	2	0	3	3	1	4	3	2	0	0	5	5	2	0	2	4
	5. Quality of design group leadership[3]	4	4	3	4	5	5	4	4	3	0	4	4	5	3	4	4	4	3	4	4	3	4	5	4	4	4	4	4	3	5
	6. Designer general reputation	4	3	4	3	4	3	2	2	4	0	0	2	3	4	3	0	5	0	3	3	0	3	4	0	2	2	2	0	4	3
	Other indicator, please define																				4										
2	*Quality of design work documents*																														
	1. Accuracy level of design documents	4	4	5	4	5	4	4	0	5	4	4	4	5	5	4	0	1	4	5	4	4	4	5	0	4	4	4	0	5	4
	2. Usability of the design documents	4	4	4	4	3	0	4	0	4	0	4	3	0	4	3	0	0	4	4	3	4	3	3	0	4	4	3	0	4	0
	3. Design constructability[4]	4	5	4	3	5	3	4	3	4	2	5	4	4	4	2	3	3	4	1	3	4	2	5	3	4	4	4	3	4	3
	Other indicator, please define																														
3	*Contractor financial stability*																														
	1. Number of projects in hand	4	5	3	4	4	0	0	0	3	2	4	2	0	3	5	0	1	3	3	5	3	5	4	0	0	0	2	0	3	0
	2. Value of work in hand	4	5	3	4	4	0	0	0	3	4	5	3	3	3	0	0	1	5	3	4	5	0	4	0	0	0	3	0	3	0
	3. Working capital	5	5	4	5	0	0	4	0	4	0	5	5	4	4	5	0	4	3	5	4	3	5	0	0	4	4	5	0	4	0
	4. Quality of bank arrangement	4	4	5	4	5	4	3	5	5	3	4	5	4	5	5	5	5	4	5	4	4	5	5	5	3	3	5	5	5	4
	5. Liquidity ratio[5]	4	4	4	3	2	4	3	5	4	5	3	5	3	4	5	5	4	5	5	3	5	5	2	5	3	3	5	5	4	4
	Other indicator, please define																														
4	*Contractor management capabilities*																														
	1. Experience in general: (Measured by the years of work, value of work done)	4	5	4	4	5	3	4	4	4	5	5	5	5	4	5	4	5	3	5	4	3	5	5	4	4	4	5	4	4	3
	2. Contractor possess the required experience in same type of projects (measured by no of jobs in similar projects)	4	4	3	5	5	4	4	4	3	4	4	5	5	3	5	4	3	4	5	5	4	5	5	4	4	4	5	4	3	4
	3. Contractor past records in finishing project ahead or in schedule	4	4	0	5	4	4	0	4	0	3	5	4	5	0	0	4	1	0	0	4	0	0	4	4	0	0	4	4	0	4
	4. Plant and equipment possession and maintenance strategy	4	3	3	4	4	4	3	4	3	4	4	5	4	3	5	4	0	4	2	3	4	5	4	4	3	3	5	4	3	4
	5. Level of contractor staff experience and management capabilities	5	4	4	4	5	5	5	5	4	5	5	5	5	4	5	5	0	5	5	4	5	5	5	5	5	5	5	5	4	5
	6. Contractor has a good document control strategy	5	5	3	5	5	5	4	5	3	3	4	5	5	3	3	5	2	4	5	3	4	3	5	5	4	4	5	5	3	5
	7. Project team organization structure	4	3	4	4	4	5	3	5	4	2	5	5	5	4	4	5	0	3	4	3	3	4	4	5	3	3	5	5	4	5
	8. Head office organization structure	4	4	2	4	4	5	3	5	2	0	4	4	4	2	4	5	0	3	4	3	3	4	4	5	3	3	4	5	2	5
	9. History of past records of relationship with other project parties	4	3	3	3	3	4	0	5	3	0	3	3	4	3	4	5	0	0	0	3	0	4	3	5	0	0	3	5	3	4
	10. level of contractor staff overloading	5	4	3	0	4	3	3	4	3	1	4	5	4	3	4	4	5	4	5	4	4	4	4	4	3	3	5	4	3	3
	Other indicator, please define																				0										
5	*Client management efficiency:*																														
	1. Client management experience in similar projects	4	5	4	4	5	4	4	5	4	4	5	4	4	4	4	5	0	5	5	5	5	4	5	5	4	4	4	5	4	4
	2. Project organization structure from client party	4	4	3	4	3	4	4	2	3	3	4	2	3	3	4	2	0	4	2	5	4	4	3	2	4	4	2	2	3	4
	3. Client's willingness to accept effective and positive ideas	5	5	3	5	4	4	3	4	3	0	5	3	4	3	2	4	5	4	2	5	4	2	4	4	3	3	3	4	3	4
	4. Level of client team internal communication effectiveness	4	4	1	4	4	4	3	4	1	4	4	3	4	1	4	4	0	4	5	5	4	4	4	4	3	3	3	4	1	4
	5. Client support to finish project as scheduled	4	5	4	5	3	5	4	2	4	5	4	4	5	4	2	2	5	5	5	5	5	2	3	2	4	4	4	2	4	5
	Other indicator, please define																														

6	*Client financial stability*																														
	1. Type of client, public, private, one-off firm	1	5	3	4	4	4	5	3	3	5	5	5	4	3	0	3	5	3	0	5	3	0	4	3	5	5	5	3	3	4
	2. Credit rating [iii]	4	4	3	4	4	3	4	3	3	3	4	6	5	3	0	3	0	4	4	5	4	0	4	3	4	4	6	3	3	3
	3. Number of financial sources	3	5	4	4	3	0	4	4	4	0	4	4	0	4	4	4	3	4	5	5	4	4	3	4	4	4	4	4	4	0
	4. Market reputation	4	3	5	4	3	4	0	4	5	1	4	4	4	5	5	4	0	0	4	4	0	5	3	4	0	0	4	4	5	4
	Other indicator, please define																														
7	*Efficiency Level of communication between project parts*																														
	1. Clearness of communication methods, documentation for all project parties	5	4	5	4	6	4	4	6	6	4	5	4	4	5	4	5	4	3	3	4	3	4	6	5	4	4	4	6	5	4
	2. Communication channels	3	3	4	4	4	3	4	4	4	0	4	3	4	4	4	4	0	3	1	4	3	4	4	4	4	4	3	4	4	3
	3. Regular communication are timely relevant	4	3	4	5	5	4	4	4	4	2	3	4	3	4	3	4	2	3	2	4	3	3	5	4	4	4	4	4	4	4
	4. Extensive communication paper work	4	4	0	5	5	4	4	4	0	3	3	4	2	0	3	4	3	2	2	4	2	5	6	4	4	4	4	4	0	4
	5. Time to get information	4	5	4	4	5	5	4	4	4	5	5	4	4	4	4	4	5	3	2	5	3	4	5	4	4	4	4	4	4	5
	6. Number of meetings per week during construction phase	3	4	5	4	0	4	4	4	2	3	5	4	3	5	3	4	0	0	3	4	0	3	0	4	4	4	4	4	5	4
	7. Language, and wording	4	3	5	5	4	0	3	4	5	0	4	1	3	5	0	4	1	0	0	4	0	0	4	4	3	3	1	4	5	0
	Other indicator, please define																														
8	*Level of interactions between project parties in pre-construction phase*																														
	1. Amount of sharing information between all project parties	4	5	5	5	4	4	3	4	5	5	5	4	4	5	4	4	4	4	4	4	4	4	4	4	3	3	4	4	5	4
	2. Number of meetings before project start	4	4	3	5	6	4	3	4	3	3	4	4	4	3	4	4	0	0	4	3	0	4	5	4	3	3	4	4	3	4
	3. Level of participation of project parties in pre-construction phase	4	3	4	5	4	3	3	3	4	0	5	4	0	4	2	3	3	3	3	4	3	2	4	3	3	3	4	3	4	3
	4. percentage of pre-construction time to construction phase	4	3	0	3	0	0	3	0	0	0	4	2	0	0	2	0	0	0	4	4	0	2	0	0	3	3	2	0	0	0
	5. relationship and integration during design work	4	5	4	5	4	4	4	3	4	0	4	4	3	4	5	3	0	0	0	4	0	5	4	3	4	4	4	3	4	4
	Other indicator, please define																														
9	*Trust between project parties:*																														
	1. Level of competence, fairness, helpful and honesty between project parties	2	4	5	4	4	4	3	3	5	4	5	4	4	5	5	3	4	5	4	5	5	5	4	3	3	3	4	3	5	4
	2. Speed of response	4	4	5	5	4	4	4	3	5	4	5	4	5	5	5	3	5	3	0	5	3	5	4	3	4	4	4	3	5	4
	3. Trust level from past interrelation work	3	3	5	4	5	4	3	3	5	1	4	4	4	5	5	3	0	3	3	5	3	5	5	3	3	3	4	3	5	4
	Other indicator, please define																														
10	*Level of project complexity and required technology*																														
	1- Differentiation: Number of organizations working in the construction project	4	4	5	4	4	5	3	5	5	5	4	4	3	5	5	5	4	3	2	4	3	5	4	5	3	3	4	5	5	5
	2- Number of project sub-systems and interfaces between project elements	3	3	5	4	3	5	4	5	5	4	3	3	3	5	5	5	3	2	3	4	2	5	3	5	4	4	3	5	5	5
	3- Level of familiarity for construction method	0	3	4	4	5	4	4	4	4	3	5	5	4	4	5	4	2	4	4	4	4	5	5	4	4	4	5	4	4	4
	4- Required number of specialists and experts	0	4	0	4	4	3	3	5	0	3	4	5	3	0	5	5	5	4	4	4	4	5	4	5	3	3	5	5	0	3
	5- Type and numbers of special equipment required	4	3	3	3	4	0	4	5	3	4	4	5	4	3	5	5	4	3	4	3	3	5	4	5	4	4	5	5	3	0
	6- Level of rigidity of activities sequencing.	0	3	4	0	3	3	4	5	4	0	4	4	4	4	5	5	0	5	2	4	0	5	5	5	4	4	4	5	4	3
	7- Size of project	4	4	3	4	4	2	3	0	3	0	3	4	2	3	5	0	3	0	3	4	0	5	4	0	3	3	4	0	3	2
	Other indicator, please define																														

11	*Level of objectives harmony between project parties*																														
	1. Matching level between client objectives and other parties objectives	4	3	3	4	0	4	3	2	3	3	5	4	4	3	0	2	0	3	3	3	3	0	0	2	3	3	4	2	3	4
	2- Clearness level of client objectives in pre-construction phase	4	4	4	4	4	3	3	2	4	5	4	5	4	4	4	2	0	4	4	4	4	4	4	2	3	3	5	2	4	3
	3- Uncertainty of goal definition, goals are not frozen (7)	0	3	0	0	4	5	4	0	0	5	3	5	5	0	0	0	3	3	4	4	3	0	4	0	4	4	5	0	0	5
	Other indicator, please define																														
12	*Specific site characteristics (location, underground, weather, environmental...)*																														
	1. Level of site accessibility	4	4	4	5	5	5	3	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	5	4	3	3	4	4	4	5
	2. Level of site hazardous	4	4	3	4	4	5	3	4	3	2	4	4	4	3	4	4	0	3	5	3	3	4	4	4	3	3	4	4	3	5
	3. Transportation problems	5	5	3	4	5	3	3	5	3	0	4	4	3	3	4	5	0	4	4	3	4	4	5	5	3	3	4	5	3	3
	4. Permits and licenses for equipment and labours	4	4	3	4	4	0	3	4	3	3	3	5	4	3	5	4	2	2	4	3	2	5	4	4	3	3	5	4	3	0
	5. Level of site congestion	0	4	3	4	4	4	3	0	3	0	4	4	4	3	0	0	2	4	4	3	4	0	4	0	3	3	4	0	3	4
	6. Level of risks anticipated due to underground conditions	0	5	5	4	4	4	3	0	5	4	5	5	4	5	3	0	4	4	4	3	4	3	4	0	3	3	5	0	3	4
	7. Weather and climatic effects	0	5	3	3	5	2	3	2	3	3	4	4	3	3	4	2	2	2	2	4	2	4	5	2	3	3	4	2	3	2
	8. Level of approvals from authorities	0	3	4	4	5	3	2	0	4	2	3	4	3	4	2	0	0	2	2	4	2	2	5	0	2	2	4	0	4	3
	9. Social effects	0	3	2	5	3	0	2	2	2	0	3	4	1	2	4	2	0	2	0	3	2	4	3	2	2	2	4	2	2	0
	Other indicator, please define																														
13	*Specific Project characteristics*																														
	1. Percentage of long lead material items (8)	2	5	4	4	4	0	3	4	4	5	4	3	4	4	4	4	0	3	5	3	3	4	4	4	3	3	3	4	4	0
	2. Design time to project time	4	1	3	4	0	0	0	0	3	0	4	1	0	3	0	0	3	0	2	3	0	0	0	0	0	0	1	0	3	0
	3. Project profit margin	4	2	4	3	4	3	0	0	4	0	5	3	1	4	4	0	0	3	5	0	3	4	4	0	0	0	3	0	4	3
	4. Project requires newness technology (9)	4	2	2	4	3	4	0	4	2	4	4	4	4	2	4	4	2	2	4	4	2	4	3	4	0	0	4	4	2	4
	5. Contract time pressure (10)	4	4	2	4	4	4	0	0	2	4	4	5	0	2	5	0	5	4	2	4	4	5	4	0	0	0	5	0	2	4
	Other indicator, please define																														
14	*Project contract and procurement strategy*																														
	1. Project parties familiarity with contract type and procurement strategy	4	4	3	5	5	3	3	0	3	5	4	4	3	3	5	0	5	4	3	3	4	5	5	0	3	3	4	0	3	3
	2. Level of contract clauses clearness and completeness	4	5	4	5	4	3	2	0	4	4	5	4	4	4	5	0	0	4	2	4	4	5	4	0	2	2	4	0	4	3
	3. Clauses regarding time performance- penalty in delay and reward in early finish	4	3	4	5	5	4	0	4	4	3	5	4	4	4	4	4	4	4	2	4	4	4	5	4	0	0	4	4	4	4
	Other indicator, please define																														

Appendix F: Delphi Sample of Second Round Questionnaire

Interview Questionnaire Survey
Construction Project Delays
(Round-2)

Introduction

First, I would like to express many thanks for you as you were one of the participants of this questionnaire. Thirty of construction industry experts participated in round one questionnaire.
The objective of this second round questionnaire is to validate your round one answers with comparison with all participants. . Average results of round one will be provided, your round one answers will be presented in comparison with the results of average and your work employer type (contractors, clients and consultants). The average was calculated based on Likert scale, that is a scale to change your subjective prospective to a numerical number. The scale was in 5 points, 5 for very high effect, 4 for high, 3 for average, 2 for low and 1 for very low. Please, check the averages and compare with your round one answer.

Just for refreshing your mind about questionnaire, the questionnaire was consisted of four parts; the first part of general information will be excluded from this round.
The rest of parts are:

1- Part two: root delay causes. In this part, Fourteen delay causes were gathered as root delay causes and you were asked to assess their level of effect on project delay.
2- Part three: Effect of root delay causes in main resource availability. In this part the level of effect of root delay causes on the unavailability of the main resources (material, labour, equipment, information and space) were assessed.
3- Part four: Measuring indicators for root delay causes. In this part a survey of indicators of the root delay causes were presented. You were asked to evaluate if these indicators are correct or not. If they are relevant as indicators, you were asked to assess the level of presentation as indicator.

You will be asked to validate your round one result and feel free to change any one of them. Your First round is attached and you will be asked to validate your round one answer.

Your help and effort are sincerely appreciated.

Sincerely

Ehab SOLIMAN

University of Plymouth

Project Root Delay Causes

	Root delay cause	Round-1 Average RESPONSE *	Round-1 your evaluation	Level of influence on project delay					
				Very high effect	High effect	Average effect	Little effect	Very little effect	No effect
1	*Designer management efficiency*	*3.467*	*low*						
2	*Quality of design work documents*	*3.400*	*average*						
3	*Contractor management capabilities*	*4.300*	*very high*						
4	*Contractor financial stability*	*4.233*	*high*						
5	*Client management efficiency*	*3.633*	*average*						
6	*Client financial stability*	*4.167*	*average*						
7	*Efficiency level of communication between project parts*	*3.800*	*high*						
8	*Level of interactions between project parties before project start*	*2.900*	*low*						
9	*Trust between project parties*	*2.667*	*very low*						
10	Level of project complexity and required technology	*2.867*	very high						
11	*Level of objectives harmony between project parties*	*3.133*	*low*						
12	*Specific project site characteristics (location, underground, weather, environmental,..)*	*3.533*	*high*						
13	*Project contract and procurement strategy*	*3.533*	*high*						
14	*Project contract and procurement strategy*	*3.833*	*very high*						

**** average value is based on five points rank; i.e. 5 is the very high effect and 0 for no***

Effect of Root Delay Causes on Material Shortage

	Root delay cause	Round-1 Average RESPONSE *	Round-1 your evaluation	Effect on matreial shortage					
				Very high effect	High effect	Average effect	Little effect	Very little effect	No effect
1	*Designer management efficiency*	*2.567*	*very low*						
2	*Quality of design work documents*	*2.867*	*average*						
3	*Contractor financial stability*	*3.900*	*very high*						
4	*Contractor management capabilities*	*4.233*	*high*						
5	*Client management efficiency*	*2.833*	*very low*						
6	*Client financial stability*	*3.933*	*average*						
7	*Efficiency level of communication between project parts*	*3.400*	*very low*						
8	*Level of interactions between project parties before project start*	*2.933*	*very low*						
9	*Trust between project parties*	*2.833*	*very low*						
10	Level of project complexity and required technology	*3.333*	high						
11	*Level of objectives harmony between project parties*	*2.833*	*very low*						
12	*Specific site characteristics (location, underground, weather, environmental,..)*	*3.500*	*very low*						
13	*Specific project characteristics*	*3.567*	*very low*						
14	*Project contract and procurement strategy*	*3.767*	*very high*						

** average value is based on five points rank; i.e. 5 is the very high effect and 0 for no*

Effect of Root Delay Causes on Labour Shortage

	Root delay cause	Round-1 Average RESPONSE *	Round-1 your evaluation	Effect on labour shortage					
				Very high effect	High effect	Average effect	Little effect	Very little effect	No effect
1	*Designer management efficiency*	*1.867*	*very low*						
2	*Quality of design work documents*	*1.800*	*low*						
3	*Contractor financial stability*	*3.767*	*very high*						
4	*Contractor management capabilities*	*4.433*	*very high*						
5	*Client management efficiency*	*2.400*	*very low*						
6	*Client financial stability*	*3.433*	*average*						
7	*Efficiency level of communication between project parts*	*2.767*	*very low*						
8	*Level of interactions between project parties before project start*	*1.700*	*very low*						
9	*Trust between project parties*	*2.100*	*very low*						
10	Level of project complexity and required technology	*2.733*	*average*						
11	*Level of objectives harmony between project parties*	*2.367*	*very low*						
12	*Specific project site characteristics (location, underground, weather, environmental,..)*	*2.967*	*average*						
13	*Project contract and procurement strategy*	*2.933*	*average*						
14	*Project contract and procurement strategy*	*2.933*	*low*						

** average value is based on five points rank; i.e. 5 is the very high effect and 0 for no*

Effect of Root Delay Causes on Equipment Shortage

	Root delay cause	Round-1 Average RESPONSE *	Round-1 your evaluation	Effect on Equipment shortage					
				Very high effect	High effect	Average effect	Little effect	Very little effect	No effect
1	*Designer management efficiency*	*2.267*	*very low*						
2	*Quality of design work documents*	*2.467*	*very low*						
3	*Contractor financial stability*	*4.367*	*high*						
4	*Contractor management capabilities*	*4.167*	*average*						
5	*Client management efficiency*	*2.400*	*very low*						
6	*Client financial stability*	*3.333*	*very low*						
7	*Efficiency level of communication between project parts*	*2.767*	*very low*						
8	*Level of interactions between project parties before project start*	*2.767*	*very low*						
9	*Trust between project parties*	*2.600*	*very low*						
10	Level of project complexity and required technology	*3.367*	*very low*						
11	*Level of objectives harmony between project parties*	*2.167*	*very low*						
12	*Specific site characteristics (location, underground, weather, environmental,..)*	*3.200*	*very low*						
13	*Specific project characteristics*	*3.267*	*very low*						
14	*Project contract and procurement strategy*	*3.100*	*very low*						

** average value is based on five points rank; i.e. 5 is the very high effect and 0 for no*

Effect of Root Delay Causes on Information Shortage

	Root delay cause	Round-1 Average RESPONSE *	Round-1 your evaluation	Effect on Information shortage					
				Very high effect	High effect	Average effect	Little effect	Very little effect	No effect
1	*Designer management efficiency*	*4.500*	*average*						
2	*Quality of design work documents*	*3.900*	*high*						
3	*Contractor financial stability*	*2.867*	*very low*						
4	*Contractor management capabilities*	*3.667*	*average*						
5	*Client management efficiency*	*3.633*	*low*						
6	*Client financial stability*	*2.500*	*very low*						
7	*Efficiency level of communication between project parts*	*3.667*	*high*						
8	*Level of interactions between project parties before project start*	*3.533*	*very low*						
9	*Trust between project parties*	*3.300*	*very low*						
10	Level of project complexity and required technology	*3.767*	very high						
11	*Level of objectives harmony between project parties*	*3.000*	*low*						
12	*Specific site characteristics (location, underground, weather, environmental,..)*	*3.033*	*very low*						
13	*Specific project characteristics*	*3.067*	*very low*						
14	*Project contract and procurement strategy*	*3.133*	*very low*						

*** average value is based on five points rank; i.e. 5 is the very high effect and 0 for no***

Effect of Root Delay Causes on Space Unavailability

	Root delay cause	Round-1 Average RESPONSE *	Round-1 your evaluation	Effect on Space shortage					
				Very high effect	High effect	Average effect	Little effect	Very little effect	No effect
1	*Designer management efficiency*	*2.467*	*very low*						
2	*Quality of design work documents*	*2.100*	*very low*						
3	*Contractor financial stability*	*2.767*	*very low*						
4	*Contractor management capabilities*	*3.300*	*very low*						
5	*Client management efficiency*	*2.467*	*very low*						
6	*Client financial stability*	*2.433*	*very low*						
7	*Efficiency level of communication between project parts*	*3.033*	*very low*						
8	*Level of interactions between project parties before project start*	*3.000*	*very low*						
9	*Trust between project parties*	*2.100*	*very low*						
10	Level of project complexity and required technology	*2.733*	*very low*						
11	*Level of objectives harmony between project parties*	*2.400*	*very low*						
12	*Specific site characteristics (location, underground, weather, environmental,..)*	*3.900*	*very high*						
13	*Specific project characteristics*	*3.567*	*very high*						
14	*Project contract and procurement strategy*	*2.900*	*very low*						

** average value is based on five points rank; i.e. 5 is the very high effect and 0 for no*

Root Delay Causes Indicators

** average value is based on five points rank; i.e. 5 is the very high effect and 0 for no effect*

		Round-1 Average RESPONSE *	Round-1 your evaluation	Level of Importance as a Measure for Root Delay Cause					
				VH	H	A	L	VL	No effect
Designer management efficiency									
1	*1. Designer experience in current work*	*4.433*	*high*						
	2. Quality of design revision policy	*3.800*	*average*						
	3. Task performance	*4.000*	*low*						
	4. Percentage of outsourcing work	*2.267*	*average*						
	5. Quality of design group leadership	*3.833*	*no effect*						
	6. Designer general reputation	*2.400*	*no effect*						
Quality of design work documents									
2	*1. Accuracy level of design documents*	*3.633*	*high*						
	2. Usability of the design documents	*2.567*	*no effect*						
	3. Design constructability	*3.533*	*low*						
Contractor financial stability									
3	*1. Number of projects in hand*	*2.267*	*low*						
	2. Value of work in hand	*2.300*	*high*						
	3. Working capital	*3.033*	*no effect*						
	4. Quality of bank arrangement	*4.400*	*average*						
	5. Liquidity ratio	*4.033*	*very high*						

Root Delay Causes Indicators

** average value is based on five points rank; i.e. 5 is the very high effect and 0 for no effect*

		Round-1 Average RESPONSE *	Round-1 your evaluation	Level of Importance as a Measure for Root Delay Cause					
				VH	H	A	L	VL	No effect
Contractor management capabilities									
4	*1. Experience in general: (Measured by the years of work, value of work done)*	*4.267*	*very high*						
	2. Contractor possess the required experience in same type of projects (measured by no of jobs in similar projects)	*4.167*	*high*						
	3. Contractor past records in finishing project ahead or in schedule	*2.367*	*average*						
	4. Plant and equipment possession and maintenance strategy	*3.633*	*high*						
	5. Level of contractor staff experience and management capabilities	*4.600*	*very high*						
	6. Contractor has a good document control strategy	*4.167*	*average*						
	7. Project team organization structure	*3.900*	*low*						
	8. Head office organization structure	*3.467*	*no effect*						
	9. History of past records of relationship with other project parties.	*2.667*	*no effect*						
	10. level of contractor staff overloading	*3.633*	*very low*						
Client management efficiency:									
5	*1. Client management experience in similar projects*	*4.267*	*high*						
	2. Project organization structure from client party	*3.167*	*average*						
	3. Client's willingness to accept effective and positive ideas	*3.567*	*no effect*						
	4. Level of client team internal communication effectiveness	*3.367*	*high*						
	5. Client support to finish project as scheduled	*3.900*	*very high*						

Appendix F

Root Delay Causes Indicators

** average value is based on five points rank; i.e. 5 is the very high effect and 0 for no effect*

		Round-1 Average RESPONSE *	Round-1 your evaluation	Level of Importance as a Measure for Root Delay Cause					
				VH	H	A	L	VL	No effect
Client financial stability									
6	*1. Type of client, public, private, one-off firm*	3.500	*very high*						
	2. Credit rating	3.367	*average*						
	3. Number of financial sources	3.433	*no effect*						
	4. Market reputation	3.200	*very low*						
Efficiency Level of communication between project parts									
7	*1. Clearness of communication methods, documentation for all project parties*	4.300	*high*						
	2. Communication channels number	3.367	*no effect*						
	3. Regular communication are timely relevant	3.600	*low*						
	4. Extensive communication paper work	3.133	*average*						
	5. Time to get information	4.167	*very high*						
	6. Number of meetings per week during construction phase	3.200	*average*						
Level of interactions between project parties in pre-construction phase									
8	*1. Amount of sharing information between all project parties*	4.167	*very high*						
	2. Number of meetings before project start	3.400	*average*						
	3. Level of participation of project parties in pre-construction phase	3.200	*no effect*						
	4. percentage of pre-construction time to construction phase	1.300	*no effect*						
	5. relationship and integration during design work	3.300	*no effect*						

Root Delay Causes Indicators

** average value is based on five points rank; i.e. 5 is the very high effect and 0 for no effect*

		Round-1 Average RESPONSE *	Round-1 your evaluation	Level of Importance as a Measure for Root Delay Cause					
				VH	H	A	L	VL	No effect
Trust between project parties:									
9	*1.Level of competence, fairness, helpful and honesty between project parties*	*4.033*	*high*						
	2. Speed of response	*4.033*	*high*						
	3.Trust level from past interrelation work	*3.667*	*very low*						
Level of project complexity and required technology									
10	*1- Differentiation: Number of organizations working in the construction project*	*4.167*	*very high*						
	2- Number of project sub-systems and interfaces between project elements	*3.933*	*high*						
	3- Level of familiarity for construction method	*3.967*	*average*						
	4- Required number of specialists and experts	*3.400*	*average*						
	5- Type and numbers of special equipment required	*3.700*	*high*						
	6- Level of rigidity of activities sequencing.	*3.167*	*no effect*						
	7- Size of project	*2.600*	*no effect*						
Level of objectives harmony between project parties									
11	*1. Matching level between client objectives and other parties objectives*	*2.667*	*average*						
	2- Clearness level of client objectives in pre-construction phase	*3.533*	*very high*						
	3- Uncertainty of goal definition, goals are not frozen.	*2.433*	*very high*						

Appendix F

Root Delay Causes Indicators

** average value is based on five points rank; i.e. 5 is the very high effect and 0 for no effect*

		Round-1 Average RESPONSE *	Round-1 your evaluation	Level of Importance as a Measure for Root Delay Cause					
				VH	H	A	L	VL	No effect
Specific project site characteristics (location, underground, weather, environmental...)									
12	*1. Level of site accessibility*	*4.033*	*average*						
	2. Level of site hazardous	*3.567*	*low*						
	3. Transportation problems	*3.633*	*no effect*						
	4. Permits and licenses for equipment and labours	*3.333*	*average*						
	5. Level of site congestion	*2.600*	*no effect*						
	6. Level of risks anticipated due to underground conditions	*3.400*	*high*						
	7. Weather and climatic effects	*2.967*	*average*						
	8. Level of approvals from authorities	*2.500*	*low*						
	9. Social effects	*2.100*	*no effect*						
Specific project site characteristics (location, underground, weather, environmental...)									
13	*1. Percentage of long lead material items*	*3.367*	*very high*						
	2. Design time to project time	*1.167*	*no effect*						
	3. Project profit margin	*2.333*	*no effect*						
	4. Project requires newness technology	*3.000*	*high*						
	5. Contract time pressure	*2.767*	*high*						
Project contract and procurement strategy									
14	*1. Project parties familiarity with contract type and procurement strategy*	*3.300*	*very high*						
	2. Level of contract clauses clearness and completeness	*3.100*	*high*						
	3. Clauses regarding time performance- penalty in delay and reward in early finish	*3.600*	*average*						

Appendix F

Appendix G: sample of the Matlab editor file

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Type='mamdani'
Version=2.0
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NumOutputs=1
NumRules=231
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OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

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MF2='A':'trimf',[0 1 2]
MF3='H':'trimf',[1 2 3]
MF4='VH':'trimf',[2 3 3]

[Input2]
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MF2='A':'trimf',[0 1 2]
MF3='H':'trimf',[1 2 3]
MF4='VH':'trimf',[2 3 3]

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Range=[0 2]
NumMFs=3
MF1='HIGH':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='LOW':'trimf',[1 2 2]

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NumMFs=3
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MF2='AVERAGE':'trimf',[0 1 2]
MF3='LOW':'trimf',[1 2 2]

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MF3='H':'trimf',[1 2 3]
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MF3='H':'trimf',[1 2 3]
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MF3='H':'trimf',[1 2 3]
MF4='VH':'trimf',[2 3 3]

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MF2='A':'trimf',[0 1 2]
MF3='H':'trimf',[1 2 3]
MF4='VH':'trimf',[2 3 3]

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Name='CM.03'
Range=[0 3]
NumMFs=4
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MF2='A':'trimf',[0 1 2]
MF3='H':'trimf',[1 2 3]
MF4='VH':'trimf',[2 3 3]

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Name='CM.05'
Range=[0 2]
NumMFs=3
MF1='no-LOW':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

[Input11]
Name='CM.06'
Range=[0 2]
NumMFs=3
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MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

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MF2='AVERAGE':'trimf',[0 1 2]
MF3='GOOD':'trimf',[1 2 2]

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MF2='AVERAGE':'trimf',[0 1 2]
MF3='GOOD':'trimf',[1 2 2]

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MF3='HIGH':'trimf',[1 2 2]

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MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]


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MF2='AVERAGE':'trimf',[0 1 2]
MF3='GOOD':'trimf',[1 2 2]

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MF3='HIGH':'trimf',[1 2 2]

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MF2='AVERAGE':'trimf',[0 1 2]
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MF2='ACCEPTED':'trimf',[0 1 2]
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MF3='MANY':'trimf',[1 2 2]

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MF2='ACCEPTED':'trimf',[0 1 2]
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NumMFs=3
MF1='n/a-low':'trimf',[0 0 1]
MF2='average':'trimf',[0 1 2]
MF3='high':'trimf',[1 2 2]

[Input39]
Name='TR.01'
Range=[0 2]
NumMFs=3
MF1='N/A-LOW':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 3]

[Input40]
Name='TR.02'
Range=[0 2]
NumMFs=3
MF1='N/A-LOW':'trimf',[0 0 1]
```

```
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 3]

[Input41]
Name='TR.03'
Range=[0 2]
NumMFs=3
MF1='N/A-LOW':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 3]

[Input42]
Name='CT.01'
Range=[0 2]
NumMFs=3
MF1='LOW-N/A':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

[Input43]
Name='CT.02'
Range=[0 2]
NumMFs=3
MF1='LOW-N/A':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

[Input44]
Name='CT.03'
Range=[0 2]
NumMFs=3
MF1='LOW-N/A':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

[Input45]
Name='CT.04'
Range=[0 2]
NumMFs=3
MF1='LOW-N/A':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

[Input46]
Name='CT.05'
Range=[0 2]
NumMFs=3
MF1='LOW-N/A':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

[Input47]
Name='CT.06'
Range=[0 2]
NumMFs=3
MF1='LOW-N/A':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

[Input48]
Name='OB.02'
Range=[0 2]
NumMFs=3
MF1='LOW':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

[Input49]
```

```
Name='OB.03'
Range=[0 2]
NumMFs=3
MF1='LOW':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

[Input50]
Name='SC.01'
Range=[0 2]
NumMFs=3
MF1='difficult':'trimf',[0 0 1]
MF2='ACCEPTED':'trimf',[0 1 2]
MF3='EASY':'trimf',[1 2 2]

[Input51]
Name='SC.02'
Range=[0 2]
NumMFs=3
MF1='highly HAZARD':'trimf',[0 0 1]
MF2='average':'trimf',[0 1 2]
MF3='not hazard':'trimf',[1 2 2]

[Input52]
Name='SC.03'
Range=[0 2]
NumMFs=3
MF1='high':'trimf',[0 0 1]
MF2='average':'trimf',[0 1 2]
MF3='low':'trimf',[1 2 2]

[Input53]
Name='SC.04'
Range=[0 2]
NumMFs=3
MF1='HIGH':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='LOW':'trimf',[1 2 2]

[Input54]
Name='SC.05'
Range=[0 2]
NumMFs=3
MF1='HIGH':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='NO-LOW':'trimf',[1 2 2]

[Input55]
Name='SC.06'
Range=[0 2]
NumMFs=3
MF1='HIGH':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='LOW-NO':'trimf',[1 2 2]

[Input56]
Name='SC.07'
Range=[0 2]
NumMFs=3
MF1='HIGH':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='LOW':'trimf',[1 2 2]

[Input57]
Name='CM.08'
Range=[0 2]
NumMFs=3
MF1='HIGH':'trimf',[0 0 1]
```

```
MF2='AVERAGE':'trimf',[0 1 2]
MF3='LOW':'trimf',[1 2 2]

[Input58]
Name='PP.01'
Range=[0 2]
NumMFs=3
MF1='HIGH':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='LOW-N/A':'trimf',[1 2 2]
[Input59]
Name='PP.03'
Range=[0 2]
NumMFs=3
MF1='NO-LOW':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

[Input60]
Name='PP.04'
Range=[0 2]
NumMFs=3
MF1='NO-LOW':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

[Input61]
Name='PP.05'
Range=[0 2]
NumMFs=3
MF1='NO-LOW':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 2]

[Input62]
Name='PC.01'
Range=[0 2]
NumMFs=3
MF1='N/A-LOW':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 3]

[Input63]
Name='PC.02'
Range=[0 2]
NumMFs=3
MF1='N/A-LOW':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 3]

[Input64]
Name='PC.03'
Range=[0 2]
NumMFs=3
MF1='N/A-LOW':'trimf',[0 0 1]
MF2='AVERAGE':'trimf',[0 1 2]
MF3='HIGH':'trimf',[1 2 3]


[Output1]
Name='output1'
Range=[0 1]
NumMFs=3
MF1='LOW':'trimf',[0 0 0.5]
MF2='AVERAGE':'trimf',[0 0.5 1]
MF3='HIGH':'trimf',[0.5 1 1]

[Rules]
```

```
4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.007827) : 1
3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  1 (0.007827) : 1
2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.007827) : 1
1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.007827) : 1
0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.003236) : 1
0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.003236) : 1
0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.003236) : 1
0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.003236) : 1
0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.002965) : 1
0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.002965) : 1
0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.002965) : 1
0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.002914) : 1
0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.002914) : 1
0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.002914) : 1
0 0 0 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.006416) : 1
0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.006416) : 1
0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.006416) : 1
0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.006416) : 1
0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.006416) : 1
0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.006416) : 1
0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.006416) : 1
0 0 0 0 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.006416) : 1
0 0 0 0 0 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.024665) : 1
0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.024665) : 1
0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.024665) : 1
0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.024665) : 1
0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.024665) : 1
0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.024665) : 1
0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.024665) : 1
0 0 0 0 0 0 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.024665) : 1
0 0 0 0 0 0 0 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.008533) : 1
0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.008533) : 1
0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.008533) : 1
0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.008533) : 1
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0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.024931) : 1
0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.024931) : 1
0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.024931) : 1
0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.024931) : 1
0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.024931) : 1
0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.008533) : 1
0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.008533) : 1
0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.008533) : 1
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.008533) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.008533) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.008533) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.024559) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.024559) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.024559) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.024559) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.024559) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.024559) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.058711) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.058711) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.058711) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.136609) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.136609) : 1
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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.136609) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.136609) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.006565) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.006565) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.006565) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.002168) : 1
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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.002168) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.002168) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.002168) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.002168) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.002168) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 3 (0.002198) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 2 (0.002198) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0, 1 (0.002198) : 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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Appendix H: Copy of the Questionnaire that Distributed in the Workshop

	Indicator definition	From your point of view, the best representation for the indicator for this project is			
Designer management efficiency					
1	*1. Designer experience in current work* خبرة المصمم في المشاريع المشابهة	Very High	High	Accepted	Less Than Accepted
	2.Quality of design revision policy جودة عمليات مراجعة التصميم	Very Good	Good	Accepted	Less Than Accepted
	3. Task performance level المصمم عنده المؤهلات البشرية و التكنولوجيا لاتمام التصميم بشكل جيد	high	average	low	
	5. Quality of design group leadership جودة القيادة في فريق التصميم	High	average	low	
Quality of design work documents					
2	*1. Accuracy level of design documents* مستوي مستنات المشروع - المخططات و المواصفات	Very Good	Good	Accepted	Less Than Accepted
	3. Design constructability مرونة المستندات و تكاملها	Very Good	Good	Accepted	Less Than Accepted
Contractor management capabilities					
3	*1. Experience in general:(Measured by the years of work, value of work done)* خبرة المقاول بشكل عام	Very High	High	Accepted	Less Than Accepted
	2.Contractor possess the required experience in same type of projects (measured by no of jobs in similar projects) خبرة المقاول في الاعمال المشابهة	Very High	High	Accepted	Less Than Accepted
	3. Contractor past records in finishing project ahead or in schedule خبرة المقاول في اتمام المشاريع في وقتها	Very High	High	Accepted	Less Than Accepted
	5. Level of contractor staff experience and management capabilities مستوي الخبرة و الكفأة لطاقم الاشراف للمقاول	High	Average	Low	
	6. Level of contractor document control strategy المقاول يملك نظام جيد لمتابعة المشروع فنيا و اداريا	High	Average	Low	
	7. Project team organization structure طاقم الاشراف من قبل المقاول	Good	average	low	
	8. Head office organization structure	Good	average	low	
	10. level of contractor staff overloading مستوي انشغال طاقم المقاول	Normal	Accepted	Overloaded	

	Indicator definition	From your point of view, the best representation for the indicator for this project is			
Contractor financial stability					
4	*1. Number of projects in hand* عدد المشروعات الحالية مع المقاول	high	average	low	
	2. Value of work in hand قيمة الاعمال الحالية مع المقاول	high	average	low	
	3. Working capital راس مال شركة المقاول	high	average	low	
	4. Quality of bank arrangement جودة العلاقة بين المقاول و البنوك	high	average	low	
	5. Liquidity ratio السيولة المالية المتوفرة مع المقاول	high	average	low	
Client management efficiency:					
5	*1. Client management experience in similar projects* خبرة المالك /ممثل المالك في ادارة مشاريع مشابهة	High	Average	Low	
	2. Project organization structure from client party طاقم ادارة المشروع من قبل المالك	Good	average	low	
	3. Client's willingness to accept effective and positive ideas مستوي تقبل المالك/ممثل المالك للافكار الايجابية لانهاء المشروع	High	Average	Low	
	4. Level of client team internal communication effectiveness مستوي الاتصال و التفاعل مع اطراف العقد الاخري	High	Average	Low	
	5. Client support to finish project as scheduled دعم المالك انهاء المشروع في الوقت المحدد	High	Average	Low	
Client financial stability					
6	*1. Type of client, public, private, one-off firm* نوعية المالك	private	public	one-off firm	
	2. Credit rating مستوي المالك من حيث التمويل	High	Average	Low	
	3. Number of financial sources عدد مصادر التمويل لدي المالك	Many	Few	one	
	4. Market reputation سمعة المالك من حيث التمويل	Very Good	Good	Accepted	Less Than Accepted

	Indicator definition	From your point of view, the best representation for the indicator for this project is		
Efficiency Level of communication between project parts				
7	*1. Clearness level of communication methods, documentation for all project parties* وضوح طرق و مستندات الاتصال بين اطراف العقد	Clear	Accepted	not clear
	2. Communication channels number عدد قنوات التصال بين اطراف العقد	Many	Accepted	Less than accepted
	3. Regular communication are timely relevant الاتصال الدوري يتم في اوقات مناسبةللمشروع	Relevant	Accepted	No
	4. Extensive communication paper work الاتصال يتم عن طريق ورق كثير	Normal	Accepted	Extensive
	5. Time to get information الوقت المطلوب للحصول على معلومة	Fast	Accepted	Lengthly
	6. Number of meetings per week during construction phase عدد الاجتماعات الموقعية السبوعية	Relevant	Accepted	Less than accepted
Level of interactions between project parties in pre-construction phase				
8	*1. Amount of sharing information between all project parties* كمية المعلومات المتاحة قبل تنفيذ المشروع	sufficient	less than sufficient	rare
	2. Number of meetings before project start عدد الاجتماعات التي تمت لمناقشة المشروع قبل التنفيذ	sufficient	less than sufficient	rare
	3. Level of participation of project parties in pre-construction phase نسبة مشاركة اطراف العقد في التصميم	high	average	low
	5. relationship and integration during design work المشاركة لاطراف العقد قبل التنفيذ	High	average	Low
Trust between project parties:				
9	*1. Level of competence, fairness, helpful and honesty between project parties* نسبة الالتزام و الامانة و المساعدة بين اطراف العقد	High	average	Low
	2. Speed of response سرعة الاستجابة للمطالب بين اطراف العقد	High	average	Low
	3. Trust level from past interrelation work مستوي الثقة بين اطراف العقد المتولدة من مشاريع سابقة	High	average	Low

	Indicator definition	From your point of view, the best representation for the indicator for this project is		
	Level of project complexity and required technology			
10	*1- Differentiation: Number of organizations working in the construction project عدد المقاولين و الهيئات المشاركة في المشروع*	High	average	Low
	2- Number of project sub-systems and interfaces between project elements عدد النظم الفرعية للمشروع	High	average	Low
	3- Level of familiarity for construction method مستوي المعرفة بطريقة التنفيذ	High	average	Low
	4- Required number of specialists and experts عدد الخبراء و الاختصاصين المطلوبة للمشروع	High	average	Low
	5- Type and numbers of special equipment required عدد و حجم المعدات الخاصة المطلوبة للمشروع	High	average	Low
	6- Level of rigidity of activities sequencing. مستوي صعوبة تسلسل الاعمال	High	average	Low
	Level of objectives harmony between project parties			
11	*2- Clearness level of client objectives in pre-construction phase وضوح اهداف المالك من المشروع في مرحلة قبل التنفيذ*	High	average	low
	3- Uncertainty of goal definition, goals are not frozen. اهداف المالك من المشروع غير متغيرة	low	average	high
	Specific site characteristics (location, underground, weather, environmental...)			
12	*1. Level of site accessibility مستوي الدخول الي المشروع*	Easy	Accepted	Difficult
	2. Level of site hazardous مستوي الخطورة في الدخول الي المشروع او بيئة المشروع	Not Hazard	average	highly hazard
	3. Transportation problems level مشاكل في المواصلات	low	average	high
	4. Permits and licenses for equipment and labours مستوي الصعوبة لادخال العمال و المعدات الي المشروع	High	average	Low
	5. Level of site congestion ضيق المشروع	low	average	high
	6. Level of risks anticipated due to underground conditions مستوي الصعوبة المتوقعة في اعمال تحت الارض	low	average	high
	7. Weather and climatic effects تأثير المناخ	low	average	high
	8. Level of approvals from authorities مستوي الموافقات المطلوبة من السلطات	low	average	high

	Indicator definition	From your point of view, the best representation for the indicator for this project is		
Specific project characteristics				
13	*1. Percentage of long lead material items* نسبة المواد المستوردة	low	average	high
	3. Project profit margin مستوي الربحية المتوقعة للمشروع- من وجهة نظر المقاول	High	average	Low
	4. level of newness technology used in the project المشروع يتكلب تكنولوجيا جديدة	low	average	high
	5. level of contract time pressure وقت المشروع حرج (10)	low	average	high
Project contract and procurement strategy				
14	*1. Project parties familiarity with contract type and procurement strategy* درجة معرفة و الاعتياد ببنود العقد	High	average	Low
	2. Level of contract clauses clearness and completeness درجة وضوح بنود العقد و تكاملها	High	average	Low
	3. Clauses regarding time performance- penalty in delay and reward in early finish البنود الخاصة بالوقت و انتهاء المشروع في الوقت المحدد	High	average	Low

Appendix I: Workshop Results

			respondent:	Respondent 1	Respondent 2	Respondent 3	Respondent 4	Respondent 5
			Name	Adel Ibrahim	Mohammed Badwi	Hamada Maghori	Majed Nasef	Sami Abdelhamid
			Part of	Client	Consultant	Contractor	Consultant	Contractor
DM	***Designer management efficiency (DM)***							
	DM.01	*1. Designer experience in current work* خبرة المصمم في المشاريع المشابهة		HIGH	HIGH	HIGH	HIGH	ACCEPTED
	DM.02	*2.Quality of design revision policy* جودة عمليات مراجعة التصميم		GOOD	VERY GOOD	GOOD	GOOD	ACCEPTED
	DM.03	*3. Task performance* المصمم عنده المؤهلات البشرية و التكنولوجيا لاتمام التصميم بشكل جيد		YES	YES	YES	YES	YES
	DM.05	*5. Quality of design group leadership* جودة القيادة في فريق التصميم		HIGH	HIGH	HIGH	HIGH	HIGH
DD	***Quality of design work documents***							
	DD.01	*1. Accuracy level of design documents* مستوى مستندات المشروع - المخططات و المواصفات		ACCEPTED	VERY GOOD	HIGH	HIGH	ACCEPTED
	DD.03	*3. Design constructability* مرونة المستندات و تكاملها		VERY GOOD	GOOD	GOOD	GOOD	ACCEPTED
CM	***Contractor management capabilildes***							
	CM.01	*1. Experience in general:(Measured by the years of work, value of work done)* خبرة المقاول بشكل عام		ACCEPTED	HIGH	HIGH	HIGH	HIGH
	CM.02	*2.Contractor possess the required experience in same type of projects (measured by no of jobs in similar projects)* خبرة المقاول في الاعمال المشابهة		ACCEPTED	HIGH	VERY HIGH	HIGH	HIGH
	CM.03	*3. Contractor past records in finishing project ahead or in schedule* خبرة المقاول في اتمام المشاريع في وقتها		ACCEPTED	HIGH	HIGH	HIGH	HIGH
	CM.05	*5. Level of contractor staff experience and management capabilities* مستوي الخبرة و الكفأة لطاقم الاشراف للمقاول		AVERAGE	HIGH	AVERAGE	AVERAGE	ACCEPTED
	CM.06	*6. Contractor has a good document control strategy* المقاول يملك نظام جيد لمتابعة المشروع فنيا و اداريا		YES	YES	YES	YES	YES
	CM.07	*7. Project team organization structure* طاقم الاشراف من قبل المقاول		AVERAGE	GOOD	AVERAGE	AVERAGE	GOOD
	CM.08	*8. Head office organization structure*		GOOD	GOOD	GOOD	GOOD	GOD
	CM.10	*10. level of contractor staff overloading* مستوي انشغال طاقم المقاول		NORMAL	NORMANL	NORMAL	NORMAL	OVERLOADED

			respondent:	Respondent 1	Respondent 2	Respondent 3	Respondent 4	Respondent 5
			Name	Adel Ibrahim	Mohammed Badwi	Hamada Maghori	Majed Nasef	Sami Abdelhamid
			Part of	Client	Consultant	Contractor	Consultant	Contractor
CF	*Contractor financial stability*							
	CF.01	*1. Number of projects in hand* عدد المشروعات الحالية مع المقاول		AVERAGE	AVERAGE	N/A	AVERAG	AVERAGE
	CF.02	*2. Value of work in hand* قيمة الاعمال الحالية مع المقاول		AVERAGE	AVERAGE	HIGH	AVERAG	AVERAGE
	CF.03	*3. Working capital* رأس مال شركة المقاول		AVERAGE	HIGH	N/A	AVERAG	AVERAGE
	CF.04	*4. Quality of bank arrangement* جودة العلاقة بين المقاول و البنوك		HIGH	HIGH	HIGH	HIGH	HIGH
	CF.05	*5. Liquidity ratio* السيولة المالية المتوفرة مع المقاول		HIGH	HIGH	HIGH	AVERAGE	HIGH
OM	*Client management efficiency:*							
	OM.01	*1. Client management experience in similar projects* خبرة المالك /ممثل المالك في ادارة مشاريع مشابهة		HIGH	HIGH	HIGH	AVERAGE	AVERAGE
	OM.02	*2. Project organization structure from client party* طاقم ادارة المشروع من قبل المالك		GOOD	GOOD	GOOD	AVERAGE	AVERAGE
	OM.03	*3. Client's willingness to accept effective and positive ideas* مستوى تقبل المالك/ممثل المالك للافكار الايجابية لانهاء المشروع		HIGH	HIGH	HIGH	HIGH	HIGH
	OM.04	*4. Level of client team internal communication effectiveness* مستوى الاتصال و التفاعل مع اطراف العقد الاخرى		HIGH	HIGH	HIGH	AVERAGE	AVERAGE
	OM.05	*5. Client support to finish project as scheduled* دعم المالك النهاء المشروع في الوقت المحدد		HIGH	HIGH	HIGH	AVERAGE	AVERAGE
OF	*Client financial stability*							
	OF.01	*1. Type of client, public, private, one-off firm* نوعية المالك		PRIVATE	PRIVATE	PRIVATE	PRIVATE	PRIVATE
	OF.02	*2. Credit rating* مستوى المالك من حيث التمويل		HIGH	HIGH	HIGH	HIGH	HIGH
	OF.03	*3. Number of financial sources* عدد مصادر التمويل لدي المالك		MANY	MANY	MANY	MANY	N/A
	OF.04	*4. Market reputation* سمعة المالك من حيث التمويل		VERY GOOD	VERY GOOD	HIGH	VERY GOOD	VERY HIGH
MM	*Efficiency Level of communication between project parts*							
	MM.01	*1. Clearness of communication methods, documentation for all project parties* وضوح طرق و مستندات الاتصال بين اطراف العقد		CLEAR	CLEAR	CLEAR	CLEAR	CLEAR
	MM.02	*2. Communication channels number* عدد قنوات التصال بين اطراف العقد		MANY	ACCEPTED	ACCEPTED	ACCEPTED	ACCEPTED
	MM.03	*3. Regular communication are timely relevant* الاتصال الدوري يتم في اوقات مناسبةللمشروع		RELEVANT	RELEVANT	RELEVANT	RELEVANT	RELEVANT
	MM.04	*4. Extensive communication paper work* الاتصال يتم عن طريق ورق كثير		ACCEPTED	ACCEPTED	ACCEPTED	ACCEPTED	ACCEPTED
	MM.05	*5. Time to get information* الوقت المطلوب للحصول على معلومة		ACCEPTED	FAST	ACCEPTED	ACCEPTED	ACCEPTED
	MM.06	*6. Number of meetings per week during construction phase* عدد الاجتماعات الموقعية السبوعية		ACCEPTED	ACCEPTED	ACCEPTED	ACCEPTED	ACCEPTED

			respondent:	Respondent 1	Respondent 2	Respondent 3	Respondent 4	Respondent 5
			Name	Adel Ibrahim	Mohammed Badwi	Hamada Maghori	Majed Nasef	Sami Abdelhamid
			Part of	Client	Consultant	Contractor	Consultant	Contractor
NT	***Level of interactions between project parties in pre-construction phase***							
	NT.01	*1. Amount of sharing information between all project parties كمية المعلومات المتاحة قبل تنفيذ المشروع*		SUFFICIENT	SUFFICIENT	SUFFICIENT	SUFFICIENT	SUFFICIENT
	NT.02	*2. Number of meetings before project start عدد الاجتماعات التي تمت لمناقشة المشروع قبل التنفيذ*		SUFFICIENT	SUFFICIENT	SUFFICIENT	SUFFICIENT	SUFFICIENT
	NT.03	*3. Level of participation of project parties in pre-construction phaseنسبة مشاركة اطراف العقد في التصميم*		HIGH	AVERAGE	HIGH	AVERAGE	AVERAGE
	NT.05	*5. relationship and integration during design work المشاركة لاطراف العقد قبل التنفيذ*		HIGH	AVERAGE	HIGH	AVERAGE	HIGH
TR	***Trust between project parties:***							
	TR.01	*1. Level of competence, fairness, helpful and honesty between project parties نسبة الالتزام و الامانة و المساعدة بين اطراف العقد*		HIGH	HIGH	HIGH	HIGH	HIGH
	TR.02	*2. Speed of responseسرعة الاستجابة للمطالب بين اطراف العقد*		HIGH	HIGH	HIGH	AVERAGE	AVERAGE
	TR.03	*3. Trust level from past interrelation work مستوي الثقة بين اطراف العقد المتولدة من مشاريع سابقة*		HIGH	HIGH	HIGH	HIGH	HIGH
CT	***Level of project complexity and required technology***							
	CT.01	*1- Differentiation: Number of organizations working in the construction project عدد المقاولين و الهيئات المشاركة في المشروع*		AVERAGE	HIGH	AVERAGE	AVERAGE	AVERAGE
	CT.02	*2- Number of project sub-systems and interfaces between project elements عدد النظم الفرعية للمشروع*		AVERAGE	AVERAGE	LOW	AVERAGE	AVERAGE
	CT.03	*3- Level of familiarity for construction method مستوي المعرفة بطريقة التنفيذ*		HIGH	HIGH	AVERAGE	HIGH	AVERAGE
	CT.04	*4- Required number of specialists and experts عدد الخبراء و الاختصاصين المطلوبة للمشروع*		HIGH	AVERAGE	HIGH	AVERAGE	AVERAGE
	CT.05	*5- Type and numbers of special equipment required عدد و حجم المعدات الخاصة المطلوبة للمشروع*		AVERAGE	HIGH	HIGH	AVERAGE	AVERAGE
	CT.06	*6- Level of rigidity of activities sequencing. مستوي صعوبة تسلسل الاعمال*		AVERAGE	LOW	LOW	AVERAGE	AVERAGE
OB	***Level of objectives harmony between project parties***							
	OB.02	*2- Clearness level of client objectives in pre-construction phase وضوح اهداف المالك من المشروع في مرحلة قبل التنفيذ*		CLEAR	CLEARR	CLEAR	NOT CLEAR	NOT CLEAR
	OB.03	*3- Uncertainty of goal definition, goals are not frozen.اهداف المالك من المشروع غير متغيرة*		CHANGING	CHANGING	CHANGING	CHANGING	CHANGING

			respondent	Respondent 1	Respondent 2	Respondent 3	Respondent 4	Respondent 5
			Name	Adel Ibrahim	Mohammed Badwi	Hamada Maghori	Majed Nasef	Sami Abdelhamid
			Part of	Client	Consultant	Contractor	Consultant	Contractor
SC	***Specific project site characteristics (location, underground, weather,***							
	SC.01	*1. Level of site accessibility مستوى الدخول الى المشروع*		EASY	EASY	EASY	EASY	ACCEPTED
	SC.02	*2. Level of site hazardous مستوى الخطورة في الدخول الى المشروع او بيئة المشروع*		NOT HAZRD	NOT HAZARD	NOT HAZARD	NOT HAZRD	NOT HAZARD
	SC.03	*3. Transportation problems مشاكل في المواصلات*		NO	NO	NO	NO	NO
	SC.04	*4. Permits and licenses for equipment and labours مستوى الصعوبة لادخال العمال و المعدات الى المشروع*		LOW	N/A	AVERAGE	AVERAGE	AVERAGE
	SC.05	*5. Level of site congestion ضيق المشروع*		LOW	AVERAGE	AVERAGE	HIGH	HIGH
	SC.06	*6. Level of risks anticipated due to underground conditions مستوى الصعوبة المتوقعة في اعمال تحت الارض*		LOW	AVERAGE	LOW	AVERAGE	AVERAGE
	SC.07	*7. Weather and climatic effects تأثير المناخ*		AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
	SC.08	*8. Level of approvals from authorities مستوى الموافقات المطلوبة من السلطات*		AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
PC	PC.01	*1 Percentage of long lead material items* نسبة المواد المستوردة		HIGH	HIGH	HIGH	HIGH	AVERAGE
	PC.02	*2 Design time to project time وقت التصميم الى وقت تنفيذ المشروع*		RELEVENT	RELEVANT	RELEVANT	RELEVANT	RELEVANT
	PC.03	*3 Project profit margin مستوى الربحية المتوقعة للمشروع- من وجهة نظر المقاول*		AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
	PC.04	*4. Project requires newness technology*[9] المشروع يتطلب تكنولوجيا جديدة		YES	YES	YES	YES	YES
	PC.05	*5. Contract time pressure*[10] وقت المشروع حرج		YES	YES	YES	YES	YES
PS	***Project contract and procurement strategy***							
	PS.01	*1. Project parties familiarity with contract type and procurement strategy درجة معرفة و الاعتياد ببنود العقد*		HIGH	HIGH	HIGH	AVERAGE	AVERAGE
	PS.02	*2. Level of contract clauses clearness and completeness درجة وضوح بنود العقد و تكاملها*		HIGH	HIGH	AVERAGE	HIGH	AVERAGE
	PS.03	*3. Clauses regarding time performance- penalty in delay and reward in early finish البنود الخاصة بالوقت و انتهاء المشروع في الوقت المحدد*		HIGH	AVERAGE	AVERAGE	AVERAGE	AVERAGE