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*An integrated framework for multi-project planning and control.*

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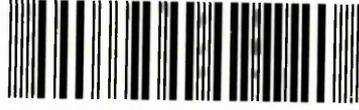
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Sheffield Hallam University

An Integrated Framework for Multi-Project Planning and  
Control

Ahmed Mohammad Almeraikhi

January 2010

## Preface

This thesis is presented as part of the requirements for the fulfilment of the award of the degree of Doctor of Philosophy from Sheffield Hallam University, UK. The reports of research and work carried out by the researcher were supervised by Professor Sameh Saad from the Faculty of Arts, Computing, Engineering and Sciences at Sheffield Hallam University, from April 2004 to January 2010 inclusive.

Ahmed Almeraikhi

January 2010

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## Abstract

The area of project management has been the focus of intensive research for the last three decades. There are a number of studies which have focused on multi-project management, but very few have tackled the need for a tracking system to control and monitor the project in an integrated environment. Some of these studies have covered the multi-project management from the contractor's perspective; or they have tackled one or two of its aspects, such as priority selection, resource allocation, or risk management.

The researcher has attempted to show the need for multi-project management systems in which an integrated framework for multi-project planning and control tracking systems (from the owner's perspective rather than the contractors' perspective) is developed; to planning and control under conditions of uncertainty and change.

Analytical hierarchy process, mathematical modelling and computer simulation techniques are applied to develop the proposed framework. In multi-project management, each project has its own objective(s) that should be optimised.

The analytical hierarchy process is applied to prioritise projects that are received from the applicant accordingly; so that decisions can be made on which project(s) should be launched first. The Mathematical modelling is another method used to solve complex problems, when many projects are running simultaneously. Goal programming is used to minimise the cost and manpower required in a multi-project environment which is usually subject to different constraints. Then simulation is used to manage and control the risk expected in running these projects. In addition, simulation allows project managers to obtain a wide spectrum system on the effects of local changes on the project.

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# 1 CHAPTER ONE

## Introduction

### 1.1 Introduction

Several research works focused on multi-project management, but very few of them tackled the need for a tracking system to control and monitor the project in an integrated environment. In addition, these studies covered the multi-project management from a contractor's perspective. They have only tackled one or two of its aspects, such as priority selection, resource allocation, or risk management and some of them have looked at priority selection with resource allocation without resorting to their integration with each other.

Thus, this research focuses on multi-project management to develop an integrated framework for multi-projects planning and control of the tracking system (from the owner's perspective rather than the contractor's one, where most studies focused on the commercial aspect) to planning and control under the conditions of uncertainty and change.

In today's rapidly changing world, a host of new developments take place daily, specifically in the construction industry and in other industries which are based on project management.

It is well established that project management could be divided into two categories, first, the single project management and second, the multi-project management. This research examines the multi-project management, where the complexity and uncertainty of various factors are the big issues that cause difficulties for the project manager in decision making. Thus, the simulation is a powerful tool to predict an acceptable solution that could be implemented; then the goal programme gives the optimum setup for budget and human resources planning.

This research focuses on multi-project management and how to build a simulation model that tracks the stages of multi-projects. Archer and Ghasemzadeh (1999) claim that there are many techniques that can be used to evaluate or estimate and choose the project, but the problem is that the tool is too complicated and cannot be used by anyone other than an expert. Through this research there is an attempt to build a user-friendly system for the decision makers to assist them in making the right decision and save their time, effort and reduce the total cost of projects.

For example, the case study presented in this research characterizes many applications for building projects, but because of the limitations in resources they cannot start all the projects at the same time. On these grounds the priority selection tool solves this issue according to the Analytical Process Hierarchy (AHP) which facilitates the prioritization of projects. This is also applicable, likewise, in the case of the allocation of resources and risk management.

## 1.2 Background History

The Awqaf (Endowments) Department is one of the most important departments in the Ministry of Endowments and Islamic affairs in Qatar. It is in charge of the management of all the real estate coming under the umbrella of the ministry, such as mosques and endowment buildings. The financial resource usually comes from donators contributions. The department manages these financial resources in a way that it guaranties return on investment in order to boost its budget. In addition of course, the government allocates an annual budget to the Awqaf (Endowments) Department.

The Awqaf (Endowments) Department is one among seven departments within the Ministry of Awqaf (Endowments) and Islamic Affairs (see Figure 1.1) and it has several responsibilities such as the following activities:

- Management of the Awqaf (endowments) affairs.
- Investment in the Awqaf (endowments) real estate.
- Supervision of the benefactor's bequeathed possessions and donations.
- Building and maintenance of mosques

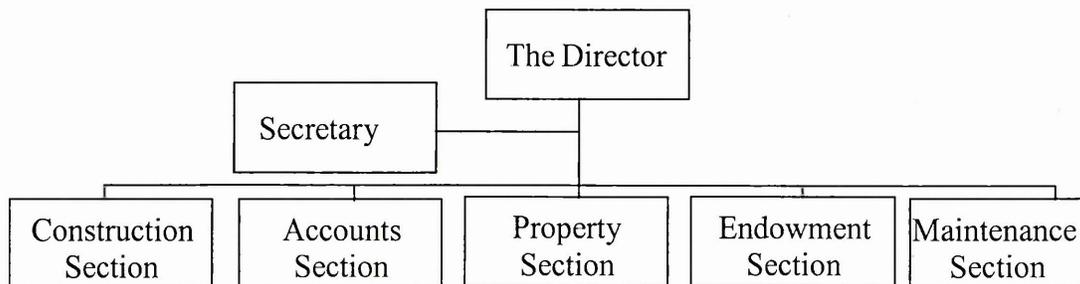


Figure 1.1 The Awqaf (Endowments) Department's organisational structure

This research focuses on the construction section which is in charge of building mosques and their maintenance. The construction section, according to the annual report of The Ministry of Awqaf (Endowments) and Islamic Affairs, has control over the following missions:

- Preparing technical and periodical reports, concerning mosques and Imams' (Muslim religious leaders) residences belonging to the Awqaf (Endowments) Department.
- Planning and scheduling works of maintenance, restoration and construction, and referral to those who are in charge of these tasks.
- Controlling new constructions in collaboration with authorized government bodies.
- Preparing, inviting tenders and engaging in negotiations related to buildings and their maintenance.
- Taking part in the setting up of architectural plans of new projects and the estimation of their cost.
- Conveying its point of view concerning the design of mosques and Imams' residences.
- Participating in committees in charge of the planning of new districts for the purpose of determining the locations of new mosques and Imams' residences.
- Establishing the Kiblah (the direction of prayer towards Mecca) of the mosque.
- Co-ordination with those who are in charge of implementing projects pertaining to the Ministry of Awqaf (Endowments) and Islamic Affairs and its benefactors.

- Curator of cadastral maps and aerial photographs of all the areas of the State of Qatar.
- Supervise the shifting of prefabricated mosques and residences to new locations according to different needs.
- Providing other departments with technical advice.

In general there are several projects running at the same time, and they are a blend of investment and non-investment projects. There is a mixture of large and small projects. The criteria for determining a small project is that the project must have a budget of less than three (3) million Qatari Riyals (approximately one million US Dollars). The criteria for determining the large projects are that the projects must have a budget of more than three (3) million Qatari Riyals. Small projects are fully supervised by engineers from the department while most of the large projects are assigned to the supervision of an external consultant; with project management from within the department.

The annual cost for supervision of projects is approximately nine hundred thousand Qatari Riyals. This amounts to the equivalent of the salary overheads for the civil engineers who supervise projects. There are a total of five civil engineers in the department as well as other engineers and they act as backup office engineers, consisting of three architects, two graphic designers, and two electrical engineers, two engineers in charge of costing, an accountant and a number of office clerks. All of their salaries are not inclusive in annual cost. It should be stressed that the engineers in charge of supervising projects are civil engineers.

In terms of supervision the minimum requirement for the large projects is two man hours; while for the small projects it is one man hour. In terms of cost of man hours for large projects, the annual cost of man hours per project amounts to 4,950 Qatari Riyals. Whereas, the annual cost of man hours for small projects amounts to 2,600 Qatari Riyals per project. In addition, there is an annual budget for the whole project which amounts to approximately 80 million Qatari Riyals; around 65% are dedicated to the large projects and the rest for the small ones.

### 1.3 The problem

In spite of the these functions within the department, there is still a lack of approaches and techniques to handle different problems such as prioritising the received projects, minimizing the incurred cost and most importantly the risks involved in planning, implementing and controlling the received projects. All of these problems should be considered (priority selection, resource allocation and risk management). It has been realised that this situation apparently exists almost in all organisation operating in such an environment.

It is acceptable to say that the appropriate strategy for the department is to solve problems. However, the department is busy with running day to day problems rather than developing the work strategy. That is due to the lack of a clear mission or vision. Consequently, the staff is short of motivation or initiative and they just show up to work each day.

The main problem is that the department has to manage numerous projects, which are running at the same time, but with inadequate resources and within a limited time. Therefore, there is a need for solutions and a need to prioritise these projects according to given criteria which will provide corresponding opportunities for all the projects at the same time, and ensure that the available resources are adequate for conducting these projects without causing any delay.

In order to make sure that the projects will be accomplished on time, without any delay, and within the budget; the risk management is essential for solving these problems; along with a tracking system.

For example, in the case study we have many applications for building projects, but because of the limitations in resources, it is impossible to start all the projects at the same time. There is a need to optimize the resources to make sure that they are evenly allocated to projects. It is also required to apply risk management to analyse the risks and to avoid or mitigate them. It is also important to optimise the resources with good attention to risk management that is involved in such an environment.

#### 1.4 Research objectives

The aim of this study is to develop an integrated framework for multi-project planning and control tracking system in order to help the decision makers, (from the owner's perspective rather than the contractor's one) under conditions of uncertainty. The following are the main objectives which will help achieve this goal:

- To identify the problems and the features of multi-project environment.
- To explore the type of uncertainties in multi-project environment.
- To develop a conceptual framework for multi-project planning and control under conditions of uncertainty.
- To propose a multi-project planning and control tracking system.
- To implement the proposed tracking system (proposed framework).

### 1.5 Expected outcome

This research is expected to add a considerable contribution to knowledge and help research students to be aware of the latest research in this area. In addition, and due to the implementation of the proposed framework to the Ministry of Awqaf (Endowments) and Islamic Affairs in Qatar, the research outcome will assist senior management in making the right decision in complex environments of multi-project management. The following are the expected key outcomes:

### 1.6 Research questions

#### Question 1

Is there a solution to ensure that the simultaneously run projects have equivalent opportunities to be launched as well as for their accomplishment within the allocated budget and without delay?

#### Question 2

Due to lack of resources and other limitations, is it possible to find a proper solution for the Awqaf (Endowments) Department to optimize the available resources to conduct the projects?

#### Question 3

As it is expected that the proposed framework is to be implemented at the Awqaf (Endowments) Department, so, there will be many changes in the projects specifications. Therefore, what is the key to avoid or mitigate these risks?

#### Question 4

What are the benefits that can be achieved through the provision of an integrated framework for the Awqaf (Endowments) Department as a case study?

In order to answer these questions, the research should concentrate on three main factors of the multi-project management which are; priority selection, resource allocation and risk management. The research focus will be defined in more detail in the next chapter which will present a review of the literature.

### 1.7 Outline of the thesis.

This research is divided into the following three main parts:

1. Overview of multi-projects.
2. Methodology and how it could help solve the problem under investigation.
3. Implementation of the methodology.

The research results are presented in this thesis in the following seven chapters:

Chapter one introduces the research problem that is to be tackled and presents the hypotheses. It includes a brief background about the Awqaf (Endowments) Department. It also summarises the research objectives and the expected outcomes. Further in the chapter, the research questions that form the foundation of the study are discussed in detail. Finally, an outline of the different chapters in the thesis is provided.

Chapter two provides an overview of the theory and recent academic research regarding the project and multi-project management. This chapter begins with the definition of the project management followed by an explanation of the multi-project environment and why it is important to know the environment of multi-projects in order to prepare to tackle the problem. The differentials between the single project and multi-projects are discussed; and finally the problems within the multi-project are highlighted as well as their impact upon the decision makers.

Chapter three describes the applied methodology to answer the research questions. A detailed explanation is presented about the Analytical Hierarchy Process (AHP) with some example of the applications of this process in many fields and sectors. Mathematical modelling and goal programming have been covered in the second part of the chapter which is ending with a simulation and findings. Finally, the proposed integrated framework and case study are elucidated.

Chapter four applies the first methodology which is priority selection modelling using AHP and its implementation and analysis of the case study as a part of the integrated framework; where the criteria have been driven from the accumulated experience. The findings are then discussed.

Chapter five proposes resource allocation modelling and analysis of the case study to optimize the resources where their lack and limitations are perceived in the Awqaf (Endowments) Department, by developing the mathematical goal programming and using LIND/LINGO to solve the problem through optimising staffing and budgeting. Then the findings are presented at the end of the chapter.

Chapter six develops risk management modelling and analysis by applying Arena simulation software to conduct the quantitative and qualitative analysis using Project Management Institute (2004), Project Management Body of Knowledge (PMBOK) as a guide to approach the result with a simple user friendly system.

Chapter seven provides the conclusion and discussion of the research results. It includes a review of the relevant literature and conducted research. It also provides the contribution of the research to knowledge in the field of multi-projects as an integrated framework, the limitations of the research and the future research work.

What is important in this research is that it proposes a user friendly system so that the decision makers in the organisation can make the right decisions and predict the future

according to the existing information, and what is unique is that it is looking at the projects from the owner's perspective rather than the contractor's one.

The information is the key issue here in terms of how it is used to clarify the vision for all projects. Sometimes the information is available but it is not appropriately used. The owner does not use it to improve the workload as well as it is used inefficiently whenever it is used. This research proposes a tracking system which helps the owner to manage the implementation of several projects at the same time, thus helping to manage both time and resources to optimize both efforts and financial resources.

This research tests a case study where two types of projects, charity and investment type of projects, but in the case of investment projects, which always receive more attention than others as they bring incomes and are considered as fuel for charity projects. Most of the investment projects income is allocated for running and building charity projects.

## 2 CHAPTER TWO

### Literature review

#### 2.1 Introduction

An extensive literature review has been carried out to understand the nature of multi-project management. The sections of this chapter outline the history of project management and the diverse ways and sectors in which it can be utilized; from personal life to the world of engineering, science, and arts.

There are many thoughts about programme management which can be confusing, for instance what is the difference between project portfolio management and multi-project management. It is useful for the purposes of this thesis to clarify definitions for project management and multi-project management.

#### 2.2 Definition

What is the project(s)? The Project Management Institute (2004) defined it as "Projects are often implemented as a means of achieving an organisation's strategic plan". Another definition from the same source "A project can thus be defined in terms of its distinctive characteristics: a project is a temporary endeavour undertaken to create a unique product or service. Temporary means that every project has a definite beginning and a definite end. Unique means that the product or service is different in some distinguishing way from all other products or services." There are several articles that

rely on Project management institute definitions such as Thiry (2002), Rozenes (2004), Olsson (2006) and others.

Lowell and Pennypacker (2000) stated that "Project management is the application of knowledge, skills, tools, and techniques to project activities to meet project requirements. Project management is accomplished through the use of the following processes such as: initiating, planning, executing, controlling, and closing."

Kurtulus and Davis (1982) claimed that since the critical path method was developed since the 1950s many research studies have been conducted in multi-project scheduling and in their conclusion they state "This research provides one possible scheme for categorising the performance of scheduling rules in a multi-project environment. It also shows that rules based on a true multi-project approach perform better than rules based on the single-project approach of artificially combining projects. Future researchers may wish to replicate the cell values (i.e. ARLF/AUF combinations) used in this study and to test the strength of our ARLF/AUF classification. However in this process they will also have to develop their own nonparametric statistical methodology. In general, the research topic of multi-project scheduling is one which has been surprisingly neglected in recent years - a situation we hope that will not continue." Since that date till present, there are many studies that have explored the multi-project and what it is about and the studies have been carried out in many perspectives where portfolio management and programme management have proposed as other perspectives of the multi-project.

Wiley et al. (1998) emphasise the proper information and control system for coordinating all the project activities as the main responsibility and duty of the programme manager, where the decisions made when the programme is established dictate how the programme will be managed throughout its lifetime. Therefore, a clear tracking system for all projects helps the decision maker to form a clear picture of all the projects that are running simultaneously. This gives the programme managers a better position to effectively develop, control and manage the multi projects. There are usually some changes in the specification of the projects life, this change will be less acute if it is tackled at the conception stage, but it would be more severe if it is tackled at the design stage and even more sensitive if we tackle the change at the production or implementation stages. Thus, pre-empting these effects on programme costs and duration, due to funding and other resource constraints, before a programme has been established is essential.

Viktorsson et al. (2006) conducted a study that investigated the psychosocial aspects of working in multi-projects, and they claim that “working in multi-projects is a complicated situation in terms of tight schedules, multi-tasking, increased coordination expenditures, etc”. And they also stated “The results show that almost one-third of the respondents were under a perceived project overload, and that 21% of the variance on this variable could be explained by four factors. In order of magnitude, these factors were (1) lack of opportunities for recuperation, (2) inadequate routines, (3) scarce time resources, and (4) a large number of simultaneous projects. Further, the study indicated that there are associations between high level of project overload and (a) high levels of psychological stress reactions, (b) decreased competence development, and (c) deviations from time schedules.” This article has explored very important aspects which

are psychosocial and said where there is a lack of study in that even though it is important and it is effect on the multi-project.

### 2.3 Multi-project Environment

This section gives a brief review about project management and its methodology. Khamooshi (1999) reviewed the history of the project where Dye and Pennypacker (2000) explained multi-project and the link between multi-project environment and management.

Blismas et al. (2004) claimed that there was a lack of research in the multi-project environment area, particularly in the construction field. They argue that most research in this area is derived from other disciplines like manufacturing, communications, retail, organisational management and software development, although there is a poor understanding of this concept in the construction industry and they used the phrase the “multi-project environment’. They also defined the following four main characteristics of a programme:

“In general, a programme is a framework that

- (a) consists of multiple interdependent projects,
- (b) is long-term or indefinite,
- (c) focuses on the benefits or strategic aims of an organisation
- (d) it provides common purpose between projects; and is usually a large undertaking.

Essentially, all programmes involve a number of projects run within groups and exhibit some form of interaction between projects.”

Speranza and Vercellis (1993) and Blismas et al. (2004) discussed the nature of the multi-project, because of its complexity and dynamic nature they are usually modified, and uncertainty is higher than in a single project. Anavi-Isakow and Golany (2003) proposed a new approach: constant time in progress and constant number of projects in process. They propose these approaches to manage the dynamic, stochastic and complexity of multi-project environment. They also demonstrate their advantages. They state the following four benefits of applying these approaches to multi-projects:

“First, an easier monitoring of the projects in the system. Second, an easier forecasting of completion times. Third, positive effects on productivity. Finally, the backlog list adds an important dimension of flexibility to the management of the multi-project environment, as it enables the re-ordering of projects before they enter the system according to various ordering criteria”.

Dooley et al. (2005) contended that organisations could achieve great efficiency and less conflict by an understanding of the intricacies of the structure of the organisation; on the other hand that will reduce the pressure of the organisation staff where the matrix structure are applied to add an “increased awareness of risk of conflict between the function and project coordinators”. It is important to have coordination between the implementation and the implementer this understanding creates more efficiency which leads to mitigating the risk or avoid it before it happens.

The project environment is a significant issue in multi-projects as it has a direct impact on projects. Eskerod (1996) claims that the literature on multi-project management puts a strong emphasis on planning, scheduling and control; because the perception of the multi-project environment is based on stability and predictability, etc. She concluded by stressing that: “My empirical research has shown that the image of the work in the multi-project environment is the image of a zero-sum game”

Artto and Dietrich (2007) reached the conclusion that different project types have different strategic importance, at the same time each type has different management approaches, here the influence of the project environment is cleared where decision makers can decide which approach should be taken.

They cited that “the challenge of successful strategic management may lie in managing the tension between creative innovation and predictable goal achievement. This tension occurs by:

- reconciling unlimited opportunities with the managers’ limited attention;
- implementing top-down strategies while allowing bottom-up strategies to emerge;
- creating predictable environments while maintaining innovativeness; and
- controlling actions while simultaneously allowing the organisation to learn new ones.

They also pointed out that each project has its own characteristics, thus these are features for multi-projects which will be covered in the next chapter.

## 2.4 The Features

A number of features are to be reviewed, in order to develop an effective tracking system that could help the decision makers to have a clear view of the features of the multi project programme. There are some features for multi-projects, which demonstrate how they are different from single projects, through the survey carried out by Lova et al. (2000) in the Valencian Region, Spain, which was conducted in 1997 in two sectors with small and medium size companies from the fields of construction, textile, computers, information systems, and public administration. The survey showed that 90% of all project work in a multi-projects context, this survey gives an indication of how often multi-projects are applied by companies.

Blismas et al. (2004) revealed that “a review of the top 25 client organisations in the UK for 1998 and 1999 conservatively shows that multi-projects accounted for 10% of the entire industry’s output or as much as 30% of contractors’ output (Blismas, 2001). Similar figures for 2000–2002 (Construction News, 2001–2003) show that the top clients’ multi-project construction portfolios alone continue to procure between £7–9bn of construction work per annum. Hence, knowing the feature of the multi-project is important where appropriate solutions could be provided accordingly.

The first feature of multi-projects is uncertainty and it is at the same time one of the problems of multi-projects. Whereas all multi-projects have this feature, therefore it is in the nature of multi-projects and it should be a matter of concern.

Herroelen and Leos (2002) stated in their research that “the vast majority of the research efforts in project scheduling assume complete information about the scheduling problem to be solved and a static deterministic environment within which the pre-computed baseline schedule will be executed. However, in the real world, project activities are subject to considerable uncertainty, that is gradually resolved during project execution.” And in their conclusion the mentioned information about the scheduling problem to be solved, assumes a static deterministic environment.

Basically the research efforts aim to generate feasible baseline schedules that 'satisfy' or optimize single or multiple objective functions. The literature on project scheduling under risk and uncertainty is rather sparse. In this research there is a review of the major approaches to deal with scheduling risk and uncertainty, many of which have been mainly or solely studied in a machine scheduling environment.

The second feature is that resources are shared between individual projects. Yang and Sum (1993) mentioned that the resources are controlled by a high authority that determined allocated resources among critical projects.

Lova et al. (2000) argued that the availability of the resources is limited and often not sufficient; therefore the sharing of resources is a must and should be controlled by senior management to ensure the running of projects. On the other hand mismanagement of resource allocation may cause delays in multi-projects; at the same time using resource allocation in the proper way could reduce the total time of multi-projects and increase performance.

Third, there is a priority selection from one project to another project and this is connected to the second feature, because the correct selection of priorities of a project leads to very detailed planning, therefore it should guarantee resource availability. However, if changes in a project are made this will affect the duration and resources, thus schedules should be customized according to the new changes, but if the modification is not resolved in a systematic perspective, these will escalate into a drastic conflict and uneven performance.

Engwall and Jeebrant (2003) in their literature on multi-project management found that the primary theme is the issue of allocation of resources between simultaneous projects. Most of the literature addresses multi-projects resource allocation as a problem of portfolio composition planning and scheduling. Engwall and Jeebrant (2003) in their conclusion state that “this study explores management challenges that are general to multi-project management and discusses some plausible underlying mechanisms that cause these challenges.”. However, since the two cases (Signaling systems, Contract Division Telecom operator R&D Division which has been examine by the authors) are taken from significantly different contexts, but still illustrated significant commonalities, they believe that the findings indicate something important.

The identified resource allocation syndrome validates the established theoretical picture. However, while past research has treated this syndrome primarily as a planning and scheduling issue, current findings illustrate that this explanation is too simplistic. As shown, the allocation of resources to (and between) simultaneous and successive projects is a process of politics, horse trading, interpretation, and sense making that is

far more complex than it has traditionally been discussed. The implication is that research on multi-project management has to go beyond resource allocation and start addressing incentive structures, accounting systems and other deeply embedded features of the organisation. As shown, managing a business structured as multiple projects does not mean to superimpose an extra level of coordination on traditional business systems and structures. Instead of more scheduling, progress reports, or more time spent on review meetings, the whole system of managerial procedures has to be reconceptualised from its roots. As current findings indicate, the resource allocation syndrome of multi-project management is not an issue in itself; it is rather an expression of many other, more profound, organisational problems of the multi-project setting.

Priority is also linked with cost and time, where senior management state projects according to the project with high income, in some occasions the cost of the project is more important than the time, in other cases finishing the project on time is more important than the cost. Finally, the complexity of multi-projects and the interactions that arise between projects makes them the most identifiable features of the multi projects.

Baccarini (1996) argued that the construction projects become progressively more complex and the construction process, he argued, may be considered the most complex undertaking in any industry. Therefore understanding the complexity of the projects helps with their management. He sees that complexity is important to the project management process in many ways such as the following:

- Project complexity helps determine planning, coordination and control requirements
- Project complexity hinders the clear identification of goals and objectives of major projects;
- Complexity is an important criteria in the selection of an appropriate project organisational form;
- Project complexity influences the selection of project inputs, e.g. the expertise and experience requirements of management personnel;
- Complexity is frequently used as a criteria in the selection of a suitable project procurement arrangement;
- Complexity affects the project objectives in terms of time, cost and quality.  
Broadly, the higher the project complexity the greater the time and cost;

In his conclusion he states that: "Projects have certain critical characteristics that determine the appropriate actions to manage them successfully. It is accepted that project complexity - organisational, technological, informational, etc. - is one such project dimension. It is proposed that project complexity is to be interpreted and measured in terms of differentiation and interdependencies. The corollary to project complexity is integration by coordination, communication and control. It is considered that the concept of project complexity is worthy of further consideration. The intention of this paper has been to provide a review of the theory on project complexity and to stimulate debate on the topic".

As projects have become more and more complex there will be increasing concern about the concept of project complexity and its influence upon the project management process. The next stage is to create an operational concept of project complexity and integration. Projects can then be analysed in order to ascertain whether there are correlations between the level of project complexity and the degree of integration.

Williams (1999) divided the project complexity in two sections. First, it is structural uncertainty which depends on a number of elements and interdependence of elements. Second, section is uncertainty where it depends on uncertainty in goals and uncertainty in methods.

Dietrich and Lehtonen (2005) studied 288 organisations in an empirical survey to analyse practices that organisations use in managing projects and they identified two profound results. They were single project level characteristics and activities, multi-project level characteristics and activities, and the linkage between projects and the strategy process. Dietrich and Lehtonen (2005) cited that

“The most successful organisations tend to organize at least many of their development projects into programs or other fixed entities. They also evaluate and compare their project ideas consistently when selecting new projects to be implemented. Statistically significant correlations were also found in examining the methods used in the evaluation of projects and project ideas. Regular use of discounting-based financial methods, structured discussion and group work methods correlates positively with success. However, the correlations detected could simply mean that some

more formal methods than just unstructured discussion are needed.” Dietrich and Lehtonen (2005) conclude that “some organisations succeed with formal practices and some with more informal ones. Instead of formality, the flexibility of multi-project management practices seems related to success. Also the regularity of reviews correlates positively with success, so apparently some order is needed in the process.”

See appendix 3 for the results of the statistical tests which are presented in table F. Values as well as the significance levels are presented along with the results of whether or not a correlation was found between each variable and success.

## 2.5 The Problems in Multi-Projects

There are many problems which face the project manager to manage multi projects, but most of the problems arise from three main sources: firstly we find priority selection, secondly resource allocation and thirdly risk management. Dealing with multi projects, usually implies that there are many projects running at the same time and they may be using the same resources. This section highlights the most problematic issue in running multi projects simultaneously.

Most research found that the main problem in multi projects is resource allocation; on the other hand there is a connection between resources allocation, priority selection and risk management. Speranza (1993) argued that planning and scheduling in multi projects is a problem for which a solution should be found, as well as uncertainty in

dynamics environment. Their methodology based upon a hierarchy of integer programming optimization models.

Arnaboldi et al. (2004) saw that the top management commitment could be one of multi project problems, where it can help in driving the project to its completion and this also is related to political guarantees. Lova et al. (2000) stated that the scheduling problem is interrelated with resources constraints, which has been dealt with in two approaches. Namely, in single project management and in multi project management, where a multi-criteria heuristic algorithm has been developed, by taking into account aspects such as time.

Abdel-Hamid (1993) pointed out that the two primary facts of the multi project problem, were coordinating schedules and allocating resources. Whereas Merwe (1997) saw that the organisation structure, if it is functionally structured, would be one of the multi project problems. He also considered the absence of a clear transition from one stage to the next as one of the major problems.

Yuhong et al. (2000) stated another problem in multi project management namely, unforeseen problems as well as problems of resources allocation. Badiru (1998) represented uncertainty and how it affects risk management analysis. Dooley et al. (2005) summed up the key problems in managing multi-projects as shown in Table 2.1:

Table 2.1 Multi-project management issue (Dooley et al. 2005)

Term	Definition
Alignment management	<p>Balancing individual project objectives with overall organisational objectives.</p> <p>Managing the issues of a rolling development plan (parallel project generation, implementation or closure). Inability to adapt to emergent shifts in environment. Increasing visibility of projects relative to day-to-day operations.</p>
Control & communication	<p>Responsibility of individuals within functional structure. Maintaining effective communication in both vertical and lateral dimensions.</p> <p>Maintaining motivation across multiple project teams.</p> <p>Management overload from too many issues to control. Maintain optimal resource allocation across the portfolio.</p>
Learning and knowledge management	<p>Inability to learn from past projects.</p> <p>Loss of valuable information due to temporary nature of project. Lack of timely information to allow intervention.</p>

Cohen et al. (2004) tried to obtain new insights on the Critical Chain methodology where they mention that Critical Chain methodology for project management applies

the theory of constraints to multi-project scheduling and control. They pointed out that the environment of multi-project is considered where the projects compete for the same resources; and then the nature of multi-project environment proves to be random, in other words stochastic in uncertainty. They declared the fundamentals of critical chain methodology in several steps to get the result that the most important trade-off that an organisation's management should consider is that between resource utilization and project throughout time.

Thus this research tried to introduce a system that helps senior management to utilize the resources in multi-projects.

## 2.6 Programme Management

This section highlights Programme Management where is it more comprehensive than the multi-project, this gives the reader more view in what available.

Suvi and Artto (2003) quoted by their literature that, the concept of project portfolio management appears in various guises. Programme management and multi-project management are examples of closely related terms. Archer and Ghasemzadeh (1999) defined a project portfolio as a group of projects that compete for scarce resources and are conducted under the sponsorship or management of a particular organisation. The three well-known objectives of portfolio management are: maximising the value of the portfolio. Platje et al. (1994) stated that a portfolio is a set of projects which are managed in a co-ordinated way to deliver increased benefits. The definitions of portfolio management are similar to many definitions introduced for a project

programme management. For example, Payne and Turner (1999) emphasised that in programme management, projects form a coherent group of projects that are managed in a coordinated way, for added benefit. According to Payne and Turner (1999) programme management includes, among others, management of interfaces between projects, prioritisation of resources and balancing responsibilities against corporate objectives.

The Project Management Institute (2004) pointed out that project management in a broader context, includes programme management, portfolio management and project management office. Then the following brief descriptions for these three contexts were presented as:

“A program is a group of related projects managed in a coordinated way to obtain benefits and control not available from managing them individually.”

“In contrast with project management, program management is the centralized, coordinated management of a group of projects to achieve the program’s strategic objectives and benefits.” And also stated that “A portfolio is a collection of projects or programs and other work that are grouped together to facilitate management of that work to meet strategic business objectives. The projects or programs in the portfolio may not necessarily be interdependent or directly related. One goal of portfolio management is to maximise the value of the portfolio by careful examination of candidate projects and programs for inclusion in the portfolio and the timely exclusion of projects not meeting the portfolio’s strategic objectives.” The Project Management Institute (2004) defined “A project management office (PMO) is an organisational unit to centralise and coordinate the management of a project under its domain.”

Shehu and Akintoye (2010) argued that there are many challenges facing programme management where they consider it as a new initiative to march the uncertainties. Some of those challenges can be faced during the implementation or at practice stage in order to have successful implementation and practice programme management, the knowledge of the challenges now and prepare for it. The following are the some challenges they found:

- Lack of commitment from business leaders
- Late delivery of projects, lack of cross-functional working, lack of coordination between projects and lack of alignment of projects to strategy
- Lack of knowledge of portfolio management techniques, risk management and financial skills
- Lack of cross-functional communication
- Lack of an appropriate way to measure project benefits, lack of resources (human/financial) to analyse project data and people constraints
- Financial constraints and lack of relevant training

Pellegrinelli et al. (2007) claimed that programme management is a widely used approach to plan to change, to implement strategy, to develop and maintain new capabilities, to manage complex information system and other business change, but ambiguity surrounding the nature and practice of programme management remains.

## 2.7 Conclusion

In this chapter the multi-project management and its possible applications were considered by reviewing it from different perspectives, together with the definitions of the multi-project and highlighting its importance not only in the engineering, construction fields, or manufacturing fields, but in several areas, even its application to personal life.

Based on the literature review, it is clear that there were some shortages and gaps in researching the multi-project in an integrated fashion with all the three aspects: priority selection, resources allocation, and risk management. A number of research publications have touched upon these aspects, but not all together as an integrated framework, either one or two together whereas this research gives an integrated framework between the three aspects.

The next chapter will describe the methodology which will be pursued in this research, and elucidate why this integrated framework has been chosen.

## 3 CHAPTER THREE

### Methodology and the Proposed Integrated Framework

#### 3.1 Introduction

This chapter gives a brief description of the methodologies that have been pursued in this research as well as the proposed integrated framework. Shorter Oxford English Dictionary presents the definition of methodology as “the branch of knowledge that deals with method and its application in particular field. Also the study of empirical research or the techniques employed in it”. The following paragraph reviews the problem, which has been tackled in this research.

As mentioned earlier, this research tackles the multi-project from the owner's perspective, as there is a difference between the owner's perspective and that of the contractor's, where the owner looks at the project as a whole without going into its day to day running details; unlike the contractor for whom every stage and the day to day running of the project are important. As there are a number of projects running at the same time with a limitation of resources, there is a real urgency to finding a solution for this situation. There are two kinds of projects which will be discussed the large project and the small one. A project is considered as a large project, if it is worth more than three million Qatari Riyals (approx one million US Dollars).

The main resource is the engineer; there are five civil engineers who are responsible for supervising all projects both large and small. Usually the large project is an investment

project; therefore the senior management allocates a huge amount of time to the larger projects.

There are many projects which cannot take off the ground due to the lack of resources and capacity issues. There are normally around one hundred applications a year, with most of them being smaller and non investment projects. Of these applications there is a capacity to process around thirty projects at most per year. This issue could be solved by mathematical programming, therefore, priority selection should be taken into consideration, because of the limitation of resources and analytical hierarchy process (AHP) (Satty, 1980) proposed to tackle this problem. Moreover, its multi objectives decision, and goal programming are applied to deal with this kind of problem by optimising the solution to fit the needs within the limited resources. In addition, there is a use of risk management where simulation methodology is applied.

This research focuses on the application of three main methodologies. First, the Analytical Hierarchy Process (AHP) second, goal programming, and finally simulation are applied. The following sections give an elucidation about these methodologies.

### 3.2 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process helps the decision makers to determine a decision that suits their needs, wants and understanding of the problem. Based on mathematics and psychology, it was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then.

The analytic hierarchy process (AHP) provides a comprehensive and rational framework for structuring a problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. It is used throughout the world in a wide variety of decision making situations, in fields such as government, business, industry, healthcare, and education.

AHP allows decision makers to model a complex problem in a structure showing relationships of the goal, its objectives and alternatives. It covers uncertainties, pros and cons as well as other influencing factors that can also be included. The goal is defined as a statement of the overall objectives. Therefore, our definition of best choice is that it is the choice that best meets the set objectives.

AHP allows decision makers to pull information together for one alternative, assess the pros and cons of that alternative, weigh that alternative against others using a variety of measurement techniques, and finally communicate the decision through synthesis of the alternatives in relation to the goal.

One of AHP's strengths is that it allows for inconsistency by the decision maker that may result from clerical error, lack of information (as in this particular review), or a lack of concentration.

According to Saaty (2008) the Analytical Hierarchy Process has been widely applied in many fields, such as IBM as part of its quality improvement strategy to design its AS/400 computer. Also in 2001 it was used to determine the best site to relocate the Earthquake that devastated the Turkish city, Adapazari. British Airways used it in 1998

to choose the entertainment vendor. The process was also applied to the U.S. versus China conflict in the Intellectual Property Rights battle of 1995 over Chinese individuals copying music, video, and software tapes and CD's. There are many other applications which make the Analytical Hierarchy Process a very useful tool to be used in a wide variety of applications such as strategic planning, resource allocation, business/public policy programme selection and much more.

Forman and Selly (2001) covered the Analytic Hierarchy Process in details by defining each word of AHP, they said:

"Analytic is a form of the word analysis, which means the separating of any material or abstract entity into its constituent elements. Analysis is the opposite of synthesis, which involves putting together or combining parts into a whole."

"Hierarchy, how can Humans best deal with complexity?"

"Process, a process is a series of actions, changes, or functions that bring about an end or result".

Vaidya and Kumar (2006) classified the Analytical Hierarchy Process as a multiple criteria decision making tool and they argued that most of decision making applications used it as a tool for priority selection, for the reason that the Analytic Hierarchy Process has such a prominent reputation.

The Analytic Hierarchy Process has been applied in different fields, such as energy, where Radcliffe and Chiederjans (2003) used it for establishing trust within groups. In

the project management fields Al-Harbi (2001) used it in contractor prequalification problem as an example. Alidi (1996) used it in industrial projects, and last but not least, Forman and Selly (2001) applied it in health care.

According to Vaidya and Kumar (2006) the Analytic Hierarchy Process is a very flexible application which can be integrated with different techniques like linear programming, Quality Function Deployment, Fuzzy Logic, and many others, which enable it to extract the benefits from all the combined methods and hence, to achieve the desired goal in a better way and this is what gives the Analytic Hierarchy Process its uniqueness.

Vaidya and Kumar (2006) analysed different applications of the Analytic Hierarchy Process and then classified them into three groups:

1. Selection
2. Evaluation
3. Applications combined with some other methodology

Table 3.1 lists some research papers which used the Analytical Hierarchy Process as a tool.

Table 3.1 References on the topic of Selection (Cited in Vaidya and Kumar (2006))

	Year	Author/s	Application areas	Other tool/s used
1	1995	Ahire S L, Rana D S	Social	
2	2001	Al Harbi K M Al-S	Personal	
3	2002	Al Khalil M I	Social	
4	2003	Bahurmoz A M A	Education	
5	1986	Brad J F	Manufacturing	
6	2001	Byun Dae Ho	Personal	
7	1994	Ceha R, Hiroshi Ohta	Political	
8	1997	Cheng C H	Social	Fuzzy theory
9	2003	Ferrari P	Political	
10	1998	Ghodsypour S H, O Brien	Personal	Linear programming
11	1986	Golden B L, Wasil E A	Engineering	
12	1990	Hegde G, Tadikamalla R	Social	
13	1999	Jung H W, Choi B	Engineering	
14	2001	Kengpol A, O Brien C	Engineering Cost benefit	statistics
15	1992	Kim C S, Yoon Y	Education	
16	1996	Korpela J, Tuominen M	Social	
17	1999	Kuo R J, Chi S C, Kao S	Political Artificial neural network	fuzzy set theory
18	2002	Lai V, Wong B K, Cheung W	Engineering	
19	1999	Lai V, Trueblood R P, Wong B K	Engineering	
20	1987	Libertore M J	Social	
21	1998	Mohanty R P, Deshmukh SG	Manufacturing	
22	1990	Murlidhar K, Shantharaman R	Engineering	
23	2003	Ngai E W T	Industry	
24	2000	Noci G, Toletti G	Industry	Fuzzy linguistic approach
25	1999	Raju K S, Pillai C R S	Government	
26	1991	Schniederjans M J, Wilson R L	Engineering	Goal programming
27	1997	Schniederjans M J, Garvin T	Personal	Multi-objective programming methodology
28	1995	Shang J et al.	Manufacturing Simulation model	accounting procedure
29	1991	Tadisna S K, Troutt M D, Bhasin V	Education	
30	2001	Tam M C Y, Tummala VMR	Personal	
31	2003	Vaidya O S, Kumar S	Engineering	Graph theory
32	1995	Yurimoto S, Masui T	Social	

Table 3.2. References on the topic of Evaluation (Cited in Vaidya and Kumar (2006))

no	Year	Author/s	Application areas	Other tool/s used
1	2001	Akarte M M et al.	Engineering	
2	1986	Brad J.F	Manufacturing	
3	1997	Bryson N, Mololurin A	Education	
4	2001	Cagno E, Caron F, Perego A	Personal	
5	1999	Cheng C H et al.	Government	Linguistic variable weight
6	2001	Fogliatto F S, Albin S L	Industry	
7	2002	Forgionne et al.	Education	
8	2001	Forgionne G A, Kohli R	Education	
9	2002	Handfielda et al.	Personal	
10	1990	Klendorfer P R, Partovi F Y	Manufacturing	
11	1999	Korpela J, Lehmusvara A	Social	Mixed integer linear programming
12	1998	Korpela J, Tuominen M, Valoho M	Social	
13	1998	Lam K Education	QFD	
14	2003	Li Q, Serali H D	Government	
15	1994	Liberatore M J, Stylianou A C	Management	Scaling models logic tables
16	2001	Murlidharan C et al.	Personal	
17	1999	Ossadnik W, Lange O	Engineering	
18	1999	Poh K L, Ang B W	Government	
19	1999	Sarkis J	Social	ANP data envelopment analysis
20	1992	Suresh N C, Kaparathi S	Manufacturing	Goal programming
21	2003	Takamura Y, Tone K	Government	
22	2003	Tavana M	Government	Probability, MAH
23	1997	Weck M et al.	Manufacturing	
24	1994	Weiwu W, Jun K	Social	Statistics
25	1990	Zahedi F	Management	
26	1991	Zanakis S H et al.	Engineering	

Table 3.3. References on the topic of Benefit–cost analysis (Cited in Vaidya and Kumar (2006))

No	Year	Author/s	Application areas	Other
1	1996	Angels D I, Lee C Y	Manufacturing	
2	1990	Azis I J	Social	
3	1999	Chin K S, Chiu S, Tammala V M Rao	Management	
4	2001	Saaty T L, Chob Y	Government	
5	1983	Saaty T L	Political	
6	1997	Tummala V M Rao, Chin K S, Ho S H	Manufacturing	
7	2001	Wedley W C, Choo E U, Schoner B	Industry	

Table 3.4 References on the topic of Allocations (Cited in Vaidya and Kumar (2006))

No	Year	Author/s	Application areas	Other tool/s used
1	1998	Andijani A A	Manufacturing	
2	1997	Bitici U S, Suwignjo P, Carrie A S	Manufacturing	
3	1994	Greenberg R R, Nunamaker T R	Government	
4	2002	Korpela J et al.	Personal	Mixed integer programming
5	1998	Kwak N K, Changwon L	Education	Goal programming
6	1996	Ossadnik W	Political	
7	1995	Ramanathan R, Ganesh L S	Engineering	Linear programming
8	2003	Saaty T L et al. Gen.	Management	Linear programming

Table 3.5. References on the topic of Planning and Development (Cited in Vaidya and Kumar (2006))

No	Year	Author/s	Application areas	Other tool/s used
1	1990	Arbel A, Orger Y E	Banking	
2	1992	Benjamin C O, Ehie I C, Omurtag Y	Education	Linear goal programming
3	2003	Chen S J, Lin L	Industry	
4	2002	Crary M et al.	Government	Mixed integer programming
5	1990	Ehie I C et al.	Banking	
6	1993	Ehie I C, Benjamin C O	Social	Linear goal programming
7	1998	Kim J	Engineering	
8	1994	Ko S K, Fontane D G, Margeta J	Social	Linear programming
9	2001	Korpela J, Lehmusvaara A, Tuominen M	Engineering	
10	1999	Lee M et al.	Industry	
11	1999	Lee C W, Kwak N K	Social	Goal programming
12	1999	Momoh J A, Zhu J	Engineering	
13	2003	Su J C Y et al.	Engineering	
14	1999	Weistroffer H R, Wooldridge B E, Singh R	Government	
15	1991	Wu J A, Wu N L	Personal	
16	2003	Yang T, Kuo C	Industry	
17	1997	Zulch G et al.	Engineering	

Table 3.6 References on the topic of Priority and Ranking (Cited in Vaidya and Kumar (2006))

No	Year	Author/s	Application areas	Other tool/s
1	1996	Alidi A S	Industry	
2	1993	Arbel A, Vargas L.G	Personal	
3	1998	Babic Z, Plazibat N	Industry	
4	2001	Badri M A	Industry	Goal programming
5	2000	Bodin L, Epstein E	Sports	
6	2001	Bolloju N	Personal	
7	2000	Braglia M	Manufacturing	Failure
8	1999	Bryson N, Joseph A	Personal	Goal programming
9	2001	Chwolka A, Raith M G	Social	
10	1999	Dweiri F	Engineering	Fuzzy set theory
11	2000	Easlav R F et al.	Personal	
12	1998	Forman E, Peniwati K	Personal	
13	1999	Frei F X, Harker P T	Industry	Tournament ranking

Table 3.7 References of Decision Making (Cited in Vaidya and Kumar (2006))

No	Year	Author/s	Application areas	Other tool/s
1	1986	Arbel A, Seidmann A	Manufacturing	
2	1993	Baidru A B, Pulat P S, Kang M	Management	
3	2002	Beynon M	Engineering	Shafer theory
4	2003	Condon E et al.	Personal	
5	1998	Crow T J	Industry	
6	1994	Davis M A P	Personal	
7	1990	Dobias A P	Personal	
8	1992	Dyer R F, Forman E H	Personal	
9	1994	Choi H A, Suh E H, Suh C	Personal	
10	1990	Hamalainen R P	Government	
11	1996	Hauser D, Tadikamalla P	Personal	
12	1996	Jain B A, Nag B N	Engineering	
13	1999	Leavary R R, Wan K	Industry	Simulation approach
14	1995	Miyaji I, Nakagawa Y, Ohno K	Education	Branch and bound theory
15	2003	Abdi R M	Engineering	
16	1994	Riggs J L et al.	Management	
17	1993	Weber S F	Manufacturing	
18	1990	Weiss E N	Social	Dynamic programming
19	2003	Xu S	Industry	
20	2002	J Yu C S	Personal	
21	1997	Zahedi F M	Engineering	

Table 3.8. References on the topic of Forecasting (Cited in Vaidya and Kumar (2006))

No	Year	Author/s	Application areas	Other tool/s
1	2002	Blair A R et al.	Government	
2	1993	Kim S B, Whang K S	Engineering	
3	1997	Korpela J, Tuominen	Management	
4	1994	Ulengin F, Ulengin B	Commerce	

Table 3.9 References on the topic of Medicine and related fields (Cited in Vaidya and Kumar (2006))

No	Year	Author/s	Application areas	Other tool/s
1	1990	Cook D R et al.	Social	
2	2003	Libertore M J et al.	Social	
3	2001	Rossetti M D, Selandari F	Social	
4	1999	Singpurwalla et al.	Social	
5	2003	Sloane E B et al.	Social	

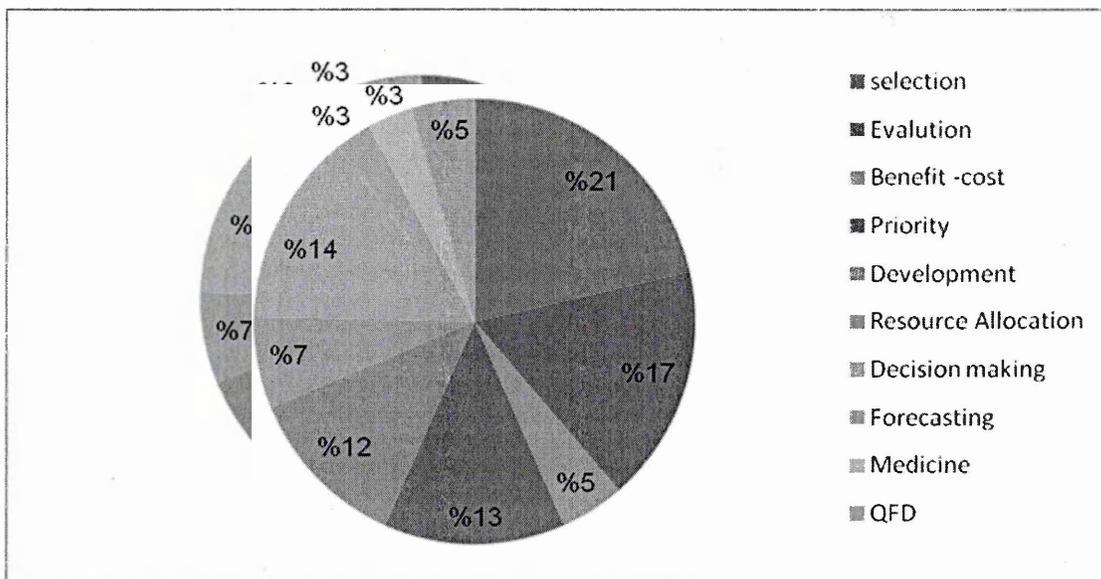


Figure 3.1. Theme specific distribution of reviewed papers (Cited in Vaidya and Kumar (2006))

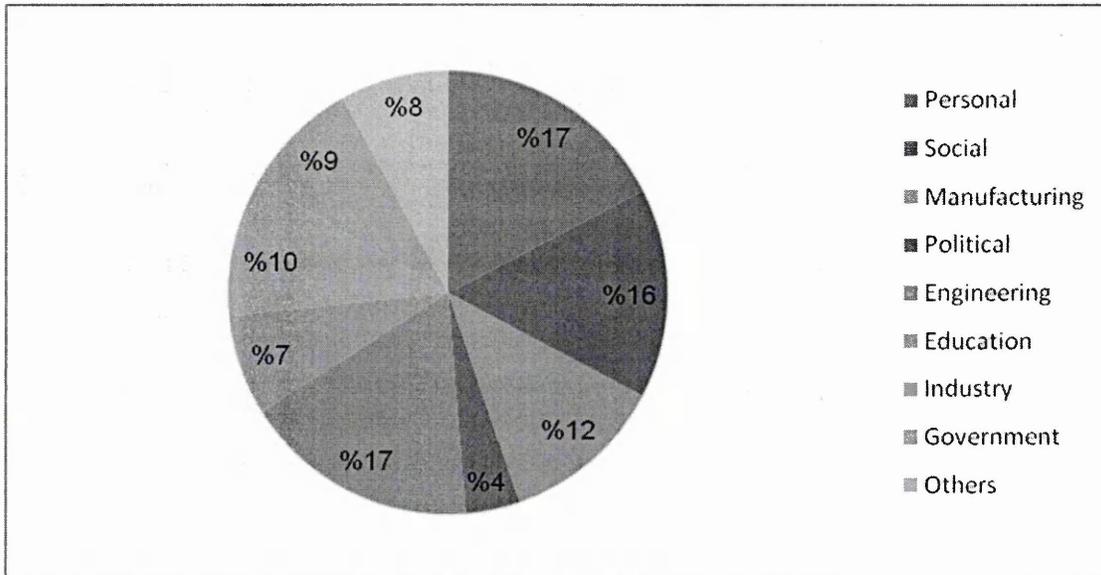


Figure 3.2. Application area specific distribution of reviewed papers (Cited in Vaidya and Kumar (2006))

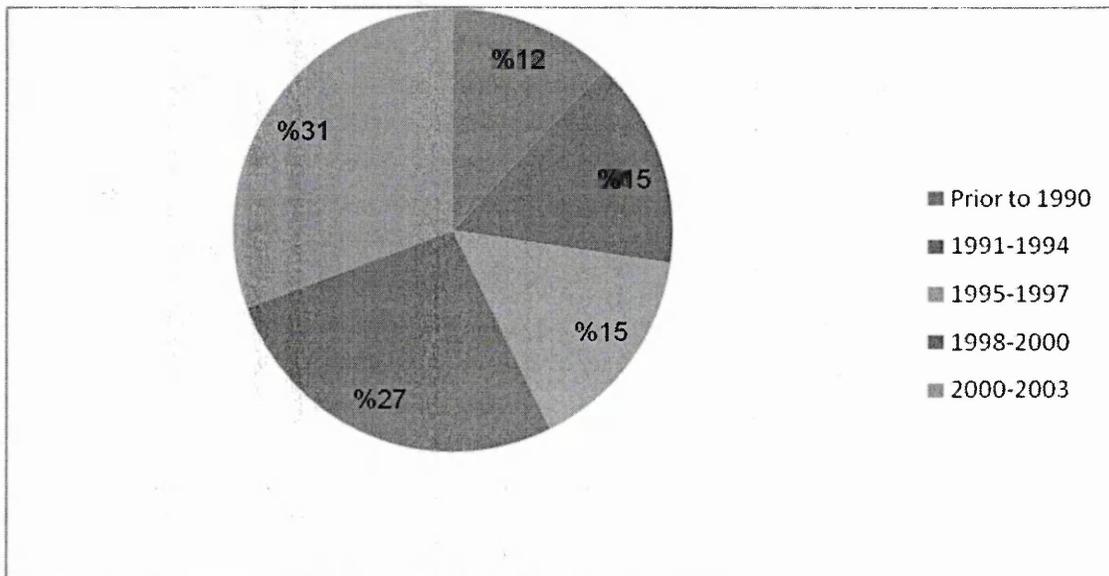


Figure 3.3. Distribution of reviewed papers over the years (Cited in Vaidya and Kumar (2006)).

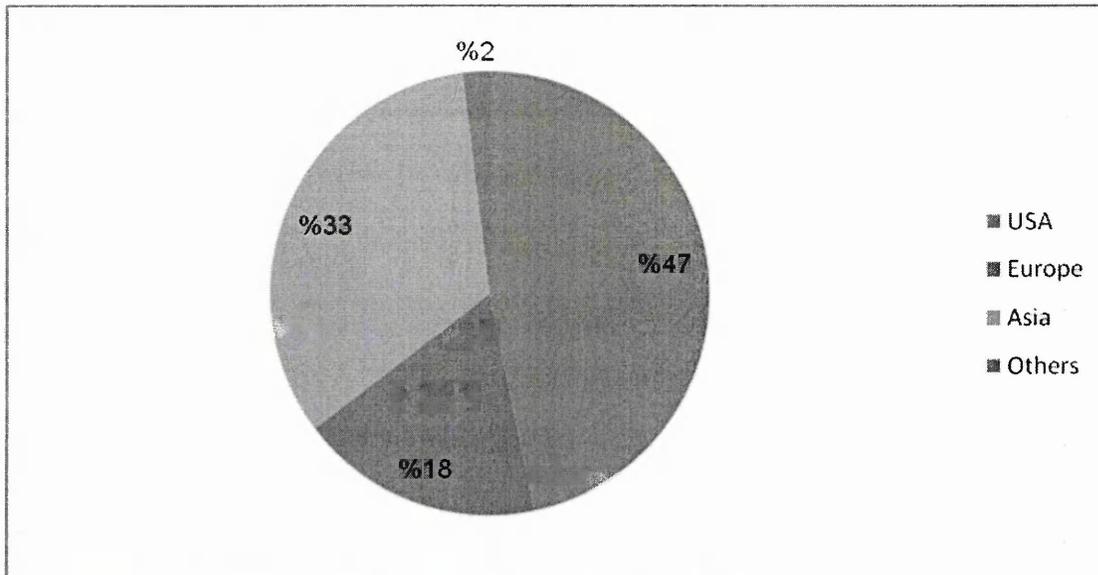


Figure 3.4. Region wise applications of Analytic Hierarchy Process (Cited in Vaidya and Kumar (2006)).

In Kovacs et al. (2004) a study included 22 interviews which were conducted in four villages on the Mexican Pacific. Fishermen were asked to assess the impact of a hurricane on mangrove trees based on three criteria: main stem, condition, diameter and species. Results showed consistency amongst fishermen and with previous scientific studies, with a few exceptions. Large diameter trees were seen as most susceptible to hurricanes and that the black mangrove species and intact main stem were most resistant. AHP allows easy interpretation for ecologists and easier comparison between different geographical regions.

Surendra et al. (2001) used AHP in order to identify suitable suppliers for the automobile casting sector. 18 main criteria were used, divided into four, product development capability, manufacturing capability, quality capability, and cost. The approach has been incorporated into a web based programme, providing consistency in decision making when it comes to both tangible and intangible criteria.

Golden and Wasil (1987) applied AHP to rank three types of sporting record: season, career, multiple years and daily single game. Appropriate Pair wise comparison matrices were used for the hierarchies. Human hierarchies: duration of record- split into years of record has stood and years of record is expected to stand, incremental improvement split into 'better than previous record', other record statistics split into 'glamour' 'and purity'

Yahya and Kingsman (1999) found contemporary ways of rating vendors in Malaysia for a government sponsored entrepreneur development programme inadequate. Therefore they developed an AHP method and in their conclusion they found it a much more systematic way of judging vendors.

Mehrez et al. (1996) employed AHP to help a public committee decide whether a hospital should be built for an expected wave of immigrants in north eastern Israel. A number of stages involving identifying a set of candidate sites, then 'quantitative location models assigned', then a subjective multi-criteria model were used to get the location. They used a computer program called 'exact choice' as an alternative to 'expert choice'. Categories were minimal, availability of remote settlement, improving employment situation, population dispersal and exhausting infrastructure. "One of the most interesting lessons from the information supplied by the experts pertains to views and attributes of the problem which were not taken into account at the beginning of the evaluation process".

Nuijten and Kosa (2004) utilized AHP to identify a better way of pricing and reimbursing new pharmaceuticals as opposed to the traditional method of assessment based on clinical trial outcomes (efficacy, quality and safety). Now additional requirements can be factored in such ways as effectiveness, cost-effectiveness and budgetary impact. This Method was used to develop a more comprehensive pricing strategy.

Lowe and Sharp (1990) applied AHP to reach a decision on what computer operating system should be used, a good case study for identifying the problems because it was shown to prove that it was difficult to interpret final scores because the method does not identify statistical significance. Also, the importance of tangible to intangible factors were not easily measured.

Alho et al. (1996) found AHP to factor in the need for forest plans to not only include economic yield but landscape and recreation, however it fails to provide a statistical assessment for uncertainty of results. Therefore, variance component modelling is used and the methods are compared by applying it to a case study using several experts who were asked to predict how forest plans influence the forest as a habitat of black grouse. There was considerable variance in the expert's opinions despite use of computer modelling, therefore the expert's opinions must be used with caution.

Dyer et al. (1992) addressed the media selection problem in which two forms of AHP were used, first utilizing AHP in conjunction with integer programming; second goal programming in conjunction with AHP. One of the best examples of complex multi

faceted decisions 'using the AHP/IP approach, the media planner can bring judgment to bear on the quality of the plan as a whole as well as on its parts. Therefore, computerised support is essential to the decision making process especially to generate new plans.

Mawapanga and Debertin (1996) in their research used AHP to help the decision making problem for farmers in order to complement knowledge and experience. AHP helps to blend these intangibles. Categories are, profit, health, environment, and sustainability.

Arrington et al. (1984) claimed that many accounting and auditing decisions were not adequately served by input, output models e.g. the relative importance of liquidity to insolvency. The AHP is stacked up against the analytical procedures of experts judged usually on "effectiveness". AHP is especially useful in aiding qualitative nonnumeric decisions.

Cook et al. (1984) addressed the external information for household population forecasts combined with time series and AHP to produce urban allocation forecasts: AHP methodology was compared with a transfer function noise model. The resulting forecasts differed very little in population estimates, but in terms of methodology: the non AHP method entails direct adjustment directly related to the standard errors while AHP used these constraints within a hierarchical model.

Benjamin et al. (1992) exploited AHP to design a computer integrated manufacturing laboratory. The (often conflicting) goals of teaching, research and extension service had to be prioritised. Questionnaire responses revealed inconsistencies in 'subjective pair wise comparisons of attributes'. Greater consistency was achieved when opportunity was given to revise responses.

Brice and Wegner (1989) used AHP to translate subjective values such as objectives and perceptions involved in programme creating into quantitative measurements. Therefore: goal - CSR Programme formulation; primary criteria - general business principles, needs identification process and political issues then divided into further criteria such as defensibility, responsibility to South African society and non offensiveness to government. This has resulted in two alternatives, economic advancement and education and training. Respondents were generally positive about the methodology.

The above has been explored to prove that the Analytic Hierarchy Process is widely used in many fields and it is acceptable to say that the analytical hierarchy process can be accommodated within most fields; not only to set priorities, but it could be combined with other methodologies to come up with precise analysis and outcome.

According to Vaidya and Kumar (2006) the other tools that are mostly used with the analytical hierarchy process are mathematical methodologies such as fuzzy theory, linear programming and goal programming. In this research goal programming and simulation were applied. As it is mentioned in the introduction, there are many research

studies in this field, but there are few where all three tools are used together. Most of the research studies tackle problems in isolation or individually, but an attempt has been made through this thesis to tackle the problem from the owner's perspective rather than that of the contractor's, where other researchers concentrate on the contractor's perspective as the business sector, not the government side as it is always the owner's perspective. In order to have a tracking system for the owner to help predict the future for better outcome, this research tackles the problem from different angles.

In conclusion this methodology is a powerful tool for priority selection. Therefore, it is an essential means to be included in the proposed integrated framework. Since there are multi-projects, the priority selection plays a very important role due to the large numbers of projects which are put forward for consideration as well as the resource limitation. This will be described in more detail in chapter four where the implementation of the proposed AHP is considered in the case study. Figure 3.5 illustrates the decision hierarchy for a model as an example.

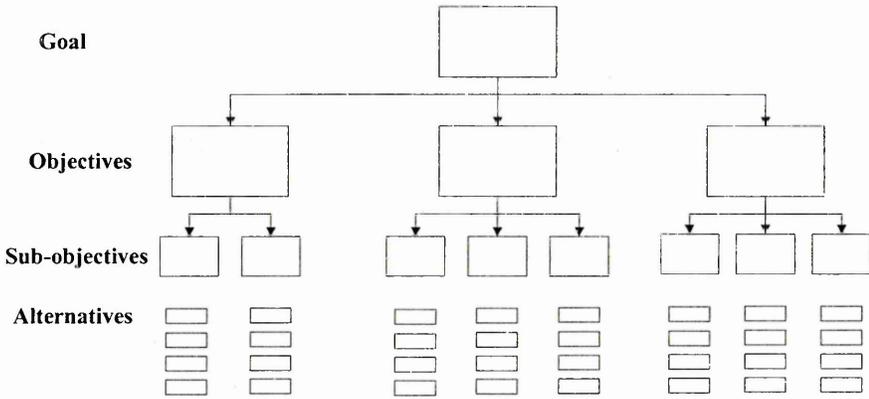


Figure 3.5 . Decision Hierarchy (Forman and Selly (2001))

### 3.3 Mathematical Modelling

Mathematical modelling is another method used to solve complex problems; there are several mathematical models such as, non linear model, linear model, goal programming, integer programming, etc. In our case the problem is a multi-objective problem, thus, the best model that could be used is goal programming, where the multi-objective problems could be tackled. It is an incredibly dominant quantitative model developed by Cooper (1961). Goal programming is an extension of linear programming, and it is a method for optimisation.

Rifai (1996) mentioned three important steps for solving the goal programming model: first, to identify the problem, and this step needs to be described extremely cautiously; the second step is to describe the problem in a quantitative manner in order to solve it and finally, to proceed to solve the problem.

In other words, mathematical programming, goal programming or optimization is a mathematical procedure to achieve an optimal solution in spite of the limitation of resources, and where the decision maker can obtain the best results from available resources. Therefore the reader should differentiate between computer programming and mathematical programming. However, the computer programme LINGO has been applied to implement the mathematical programming in this research.

Li and Hu (2009) claimed that in an actual decision making situation most problems involve multiple criteria (attributes or objectives). They figured out that multiple objectives decision making has become a promising field in the recent years and has

attracted more researchers. They believe “however, in real-world, synchronous optimization of multiple objectives is an iterative, trial-and-error process for being conflicting, incommensurable and imprecise or fuzzy in nature. This often leads to that the ultimate goal in Multiple Objective Decision Making (MODM) is to seek a most preferred compromise solution rather than optimal one. During the last three decades, different methods have been employed to solve Multiple Objective Decision Making (MODM) problem (Chanking and Haimes, 1983; Lai and Hwang, 1994).”

Li and Hu (2009) in their literature review covered the fuzzy methods and the result is that the additional constrains may be too strict for the optimization model to reach decision making satisfaction, because it always requires a higher desirable achievement. The determination of distinct desirable satisfying degrees may not be possible when handling the real life problem. They pointed out that goal programming is the most promising methodology for the decision maker, because of the ability of this method to utilize real-world decision making problems.

It is used to consider all objectives with different attainment relations in finding an acceptable solution through minimizing the deviation from the expected values.

### 3.4 Simulation

Simulation is one of the useful tools that help to predict the future; accordingly the high level management could make the right decision where it could clear the picture for them.

Law (2007) introduced the basic simulation modelling in his book and stated that “the facility or process of interest is usually called a system, and in order to study it scientifically we often have to make a set of assumptions about how it works. These assumptions, which usually take the form of mathematical or logical relationship, constitute a model that is used to try to gain some understanding of how the corresponding system behaves” and this has been applied to develop a tracking system which enables the senior management to make the right decision at the right time. Law (2007) mentioned the following areas for the application of the simulation:

- Design and analysis manufacturing system
- Evaluating military weapons systems or their logistics requirements
- Determining hardware requirement for a computer system
- Design and operating transportation systems such as airports, freeways, ports, and subways
- Evaluating design for service organisation such as contact, fast-food restaurants, hospitals and post offices
- Re-engineering ordering policies for an inventory system
- Analysing mining operations

Law (2007) maintained that the simulation is one of the most widely used operations-research and management science techniques, if not the most widely used. Law gives examples of some researchers who use the simulation in their research such as Lane, Mansour, Harpell (1993) and Gupta (1997).

Kelton et al. (2007) argued that simulation looks like most analysis methods, it involves system and models. The system is a facility or a process either actual or planned and they gave a long list of examples from which I have selected a few cases as highlighted below:

- A manufacturing plant with machine, people, transport devices, conveyor belts, and storage space.
- A bank with different kinds of customer services and facilities like teller windows, automated teller machines (ATM), loan desks and safety deposit boxes.
- A distribution network of plants, warehouse and transportation links.
- An emergency facility in a hospital, including personnel, rooms, equipment, supplies and patient transport.
- A field-service operation for appliances or office equipment, with potential customers scattered across a geographic area, service technicians with different qualifications, trucks with different parts and tools, and a central depot and dispatch centre.

As highlighted above, some examples show the reader where simulation could be used. Kelton et al. (2007) pointed out that researchers often study a system to measure its performance, improve its operation, or design it if it does not exist.

There are many reports concerning the application of simulation, either the numerical or computer types, both are widely used. Moreover, there are many examples such as

Hong Kong Airport's transfer system, which was simulated in connection to the airport project to evaluate system features before the final design and construction. Both the function and operation of the system were evaluated under conditions of operation in an interval time of ten years ahead.

Currently 3D-modeling is the trend in simulation even if it is a very complex process and it is time consuming, but still in some cases it is very useful and it is worth implementing.

All those who wrote about simulation, considered it as a very useful tool, where it helps the decision maker to make the right decision by predicting the future scenario.

Xinzheng et al. (2004) quoted that "computer simulation has become an important tool in the structure analysis and design. Especially when the structures are under disaster load such as blast, penetration, impact of collapse or typhoon, it is difficult to analyse with test method, while the advantages of computer simulation method such as safe, efficient and cheap, are shown obviously in these problems". They argued that the computer has become an important analysis tool since the finite element methods were developed in the 1960s. With the development of computers we are given an opportunity for computer simulation to replace experimental research in some aspects as well as reducing the experimental workload. This is especially so in the case of experiments that could be carried out in real time such as blast, penetration or collapse. All of them are difficult to study in the laboratory, while the advantages of computer simulation can ensure safety, efficiency and cost effectiveness.

Table 3.10 shows some commercially available simulation for different purposes see appendix 5 for a snap shot from the web site.

Table 3.10 some commercially available general-purpose simulation

<b>Software Name</b>	<b>Company name</b>	<b>Web Site Address</b>
<i><b>Arena</b></i>	Rockwell Software	www.arenasimulation.com
<i><b>Promodel</b></i>	Promodel Corp	www.promodel.com
<i><b>ARCA SIM Racing</b></i>	Sim Factory	www.thesimfactory.com
<b>GPSS</b>	Minuteman	www.minutemansoftware.com
<b>Witness</b>	Lanner	www.lanner.com/en/witness.cfm

Arena has been used in this research. Arena Basic Edition is available for educational purposes and it is a powerful tool to improve business processes. The simulation software is powerful enough to create a scenario which both understands and analyses the problem. Arena Basic Edition is the effective software when analysing business, service, or simple (non-material-handling intensive) manufacturing processes or flows.

Typical scenarios include:

- Documenting, visualizing and demonstrating the dynamics of a process with animation.

- Predicting system performance based on key metrics such as costs, throughout cycle times, and utilizations.
- Identifying process bottlenecks such as queue build ups and over-utilization of resources.
- Planning staff, equipment, or material requirements.

In addition to the Arena Basic Edition, Rockwell Software offers a full suite of products to provide enterprise-wide simulation, optimization and 3D model animation.

As mentioned in the Arena Basic Edition in its 2004 guide “while you may not realize it quite yet, you now have the power to transform your business. Whenever you and others in your organisation are wondering “what if...?” you can look into the future to find the answer.”

“Arena has ability to.

- Model processes can be defined, document and communicate.
- Simulate the future performance of the system to understand complex relationships and identify opportunities for improvement.
- Visualize the operations with dynamic animation graphics.
- Analyse how the system will perform in its “as-is” configuration and under a myriad of possible “to-be” alternatives so that you can confidently choose the best way to run your business.”

There are many modules, but this research will use only a few of them to help the reader understand how it works. The following description of The Basic Process Panel that has been used in the simulation model in this research is provided hereafter.

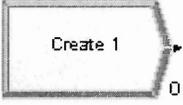
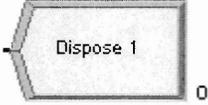
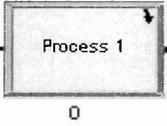
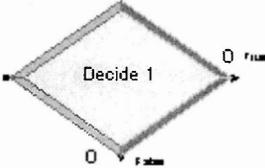
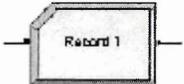
### 3.4.1 The Basic Process Panel

Table 3.11 provides a brief description of the basic process panel that has been used in the simulation module, according to (Kelton et al. 2007).

One of the most important aspects of simulation is the ability to find the best fit for the data which can be determined from previous information. In addition to all of the distributions supported by Arena, the Fit drop-down menu includes a Fit All option. Choosing this option causes all of the applicable distribution functions to be fitted to the data. The distributions are then sorted, from best to worst, based upon the values of the respective square errors. The function resulting in the best fit will then be displayed on the screen, superimposed over the histogram of the data. A brief time delay may be experienced if this option is selected, particularly if the data file is relatively large.

This function helps the researcher to get the best fit of the input data for all projects according to experience from projects dealt with in previous years.

Table 3.11 The Basic Process Panel

Name	Description	Typical Uses
<p>Create module</p> 	<p>This module is intended as the starting point for entities in a simulation model. Entities are created using a schedule or based on a time between arrivals. Entities then leave the module to begin processing through the system. The entity type is specified in this module.</p>	<ul style="list-style-type: none"> <li>• The start of a part's production in a manufacturing line</li> <li>• A document's arrival</li> <li>• A customer's arrival at a service process</li> </ul>
<p>Dispose module</p> 	<p>This module is intended as the ending point for entities in a simulation model. Entity statistics may be recorded before the entity is disposed.</p>	<ul style="list-style-type: none"> <li>• Parts leaving the modelled facility</li> <li>• The termination of a business process</li> <li>• Customers departing the store</li> </ul>
<p>Process module</p> 	<p>This module is intended as the main processing method in the simulation. Options for seizing and releasing resource constraints are available. Additionally, there is the option to use a "sub model" and specify hierarchical user-defined logic. The process time is allocated to the entity and may be considered to be value added, non-value added, transfer, wait, or other. The associated cost will be added to the appropriate category.</p>	<ul style="list-style-type: none"> <li>• Machining a part</li> <li>• Reviewing a document for completeness</li> <li>• Fulfilling orders</li> <li>• Serving a customer</li> </ul>
<p>Decide module</p> 	<p>This module allows for decision-making processes in the system. It includes options to make decisions based on one or more conditions. There are two exit points out of the Decide module when its specified type is either 2-way by Chance or 2-way by Condition. There is one exit point for "true" entities and one for "false" entities. When the N-way by Chance or by Condition type is specified, multiple exit points are shown for each condition or probability and a single "else" exit. The number of entities that exit from each type (true/false) is displayed for 2-way by Chance or by Condition modules only.</p>	<ul style="list-style-type: none"> <li>• Dispatching a faulty part for rework</li> <li>• Branching accepted vs. rejected checks</li> <li>• Sending priority customers to a dedicated process</li> </ul>
<p>Record module</p> 	<p>This module is used to collect statistics in the simulation model. Various types of observational statistics are available, including time between exits through the module, entity statistics (time, costing, etc.), general observations, and interval statistics (from some time stamp to the current simulation time). A count type of statistic is available as well. Tally and Counter sets can also be specified.</p>	<ul style="list-style-type: none"> <li>• Collect the number of jobs completed each hour</li> <li>• Count how many orders have been late being fulfilled</li> <li>• Record the time spent by priority customers in the main check-out line</li> </ul>

Arena provides many built-in system variables to access and modify data related to a model. Most variables relate to a particular type of construct, such as resources or queues. These variables typically require a construct identifier as an argument. With the exception of attributes, and variables, the construct identifier takes the form of a construct name. However, the function NSYM may be used to translate a construct name to its corresponding construct number for use with the variables that require a number.

### 3.5 The Proposed Integrated Framework

This research aims to tackle the three mentioned problems namely; priority selection between projects, resources allocation to these multi-projects and managing the risk involved that may arise due to different types of uncertainties in an integrated environment.

Figure 3.6 provides the proposed conceptual framework to cover the above mentioned three problems and their relationships to the controlling aspects.

Each of which has an essential effect on the whole process and each of those problems has been covered in the previous chapter. As a result it is acceptable to consider that each problem (priority selection, resource allocation, and risk management) is one phase for the tracking system that the researcher tries to disclose each phase when it reaches completion where each phase depends on the previous one. These three main factors are

controlled by project evaluation criteria, which derive from four performances which are respectively quality control, cost, time, and resources

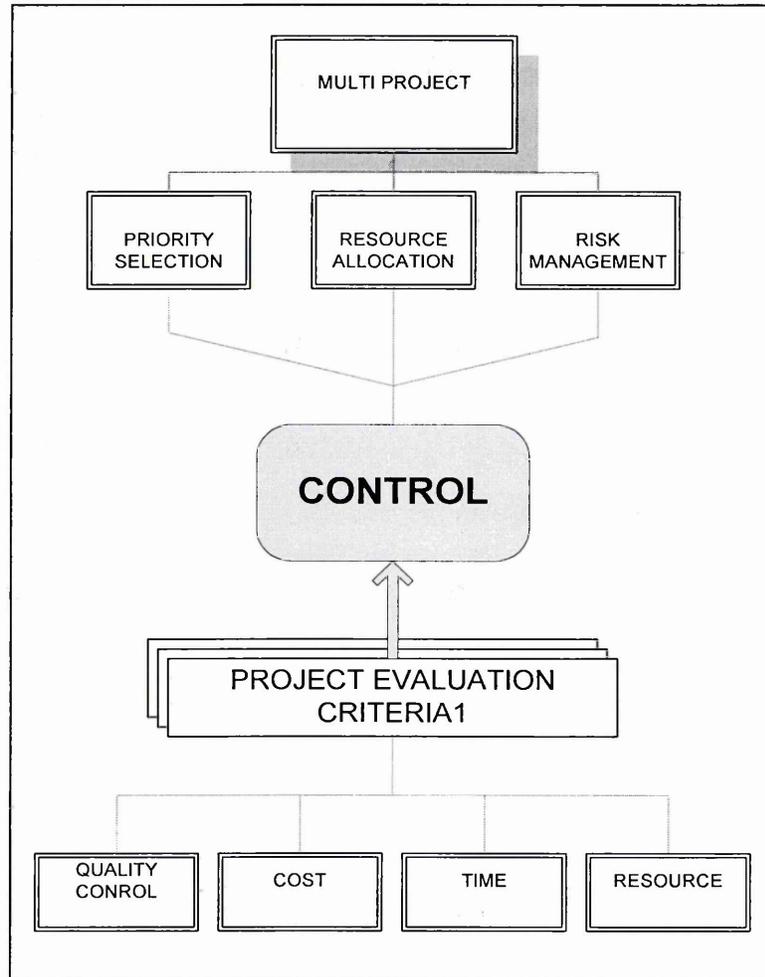


Figure 3.6 The conceptual framework in general terms

Figure 3.7 shows the proposed framework methodology used for each problem under consideration and the relationship between them in an integrated fashion.

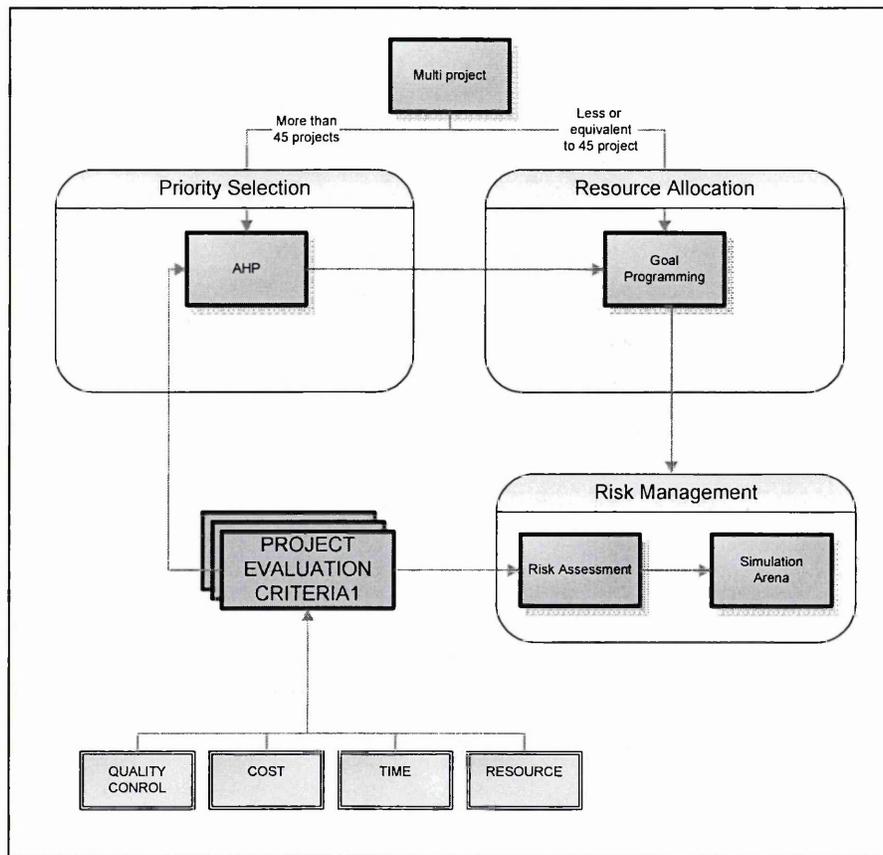


Figure 3.7 the proposed framework in detail

In real life, the number of projects could vary, however, there will be limits as it is sometimes impossible to accept all the projects or launch them at the same time. Thus some projects should be deferred to the next planning phase.

In sequence of that the senior management should make a decision to select which projects should be launched according to the importance of the projects. The analytical hierarchy was proposed to solve this problem.

In this phase many actors play a main role where the priority selection phase needs to use the intuition and experience of the Engineering Section to come up with several

criteria, where these criteria will be used to consider which projects should be launched first.

When the priority selection has been decided, then goal programming should be applied to those projects, to allocate the necessary resources. On the other hand, to validate the number of projects that could be considered, goal programming should be applied for three main goals: first, to minimise the man hours of the projects, second, to alleviate the supervision budget, and third, to be able to finish within the total budget allocated for all the projects.

Finally, risk management tool is applied using simulation to analyse the risk qualitatively and quantitatively and respond to project risk. It includes maximizing the probability and consequences of positive events and minimizing the probability and consequences of adverse events to project objectives.

### 3.6 Case study and implementation of the proposed framework

As it can be seen the proposed framework has been developed in generic terms and it can be applied in any environment in which there are multi-projects which need to be considered.

It is anticipated that implementing the framework to a real life case study will facilitate the understanding of the contents of the framework and how it can be used in real life problems.

The case study used for implementation purposes is the Awqaf (Endowments) Department in Qatar, where they run many projects for benefactors annually. The department faces the problem of dealing with these projects with limitations in resources, and the projects are characterised by different kinds of risks involved. These risks do not necessarily arise at the beginning of the project, but they could happen half way through or even towards the end of the projects. It is a challenging situation and the researcher finds that this case study is appropriate for implementation purposes of the proposed framework.

Table 3.12 shows all the projects that have been received from the department's clients and annually managed and supervised by the department, that are either endowment projects or worship places construction projects with an estimated total cost of QR 282,490,000. Analysing the figures in Table 3.12, it can be noticed that the investment type of projects does not represent more than twenty percent of all projects. On the other hand the investment projects are very important and are considered to be a source of income as well as they form a large overhead to the department. (See appendix 4 for a sample of the projects)

Table 3.12 the estimated cost for All Projects

Serial	Name	Location	Cost QR
1	Awqaf (Endowments) Tower	New District	150,000,000
2	Mosque For 750 Worshipers		900000
3	Kassem Darwish Fakhroo Center	Doha	41,000,000
4	Mosque For 250 Worshipers	Duhail	800000
5	Multi-Story Building	Bin Mahmmmod	8500000
6	M116 And Imam House	Abonakhla	1600000
7	M117 And Imam House	Alazizya	3850000
8	Four Imam Houses	Alrayan Algidid	850000
9	Imam House Model A	Abohamor	200000

10	Two DM8 With Two Imam Houses MA	Absedra	1765000
11	Daily Mosque Private Model	Almuraikh	350000
12	DM8 & Imam House	Alwaab	1290000
13	Daily Mosque With Imam House	Alseelya	1080000
14	Daily Mosque With Imam House	Alkhiasa	1040000
15	Mosque M112a	Alwakra	1500000
16	DM 10 With Imam House	Alnaja	850000
17	Mosque M94a With Imam House	Modern Doha	850000
18	DM4 With Imam House	Old Airport	1500000
19	DM 10 With Imam House	Aldafna	1500000
20	DM8 With Imam House	University West	800000
21	DM94a	Alwakra	800000
22	DM8 With Imam House	Almamora	750000
23	DM & Imam House	Almurkhiya	1150000
24	DM5 With Imam House	Modern Doha	1500000
25	DM1 & Imam House	Alkhor	1700000
26	Rebuild Mn 536	Althekhira	2000000
27	Rebuild Mn 303	Alhetmee	3300000
28	M116	Alkhor	1200000
29	DM 8	Alkeratyat	615000
30	DM2 & Imam House	Alkhor	950000
31	M112a	Akoeratyat	1200000
32	Rebuild Mn 937	Umslal Mohd	720000
33	Friday Mosque	Azqawa	770000
34	DM8 & Imam House	Aalkkhor	1100000
35	DM5 At Alkhor Hospital	Alkhor	1300000
36	DM5, Imam House And Moathen House	Alkhuratyat	2200000
37	Imam House Privet Mpdel	Alkhoraytat	200000
38	DM5 And Imam House	Alwesail	12800000
39	DM8a And Imam House	Tembik	920000
40	DM5, Imam House And Moathen House	Um Alafae	2200000
41	5imam Houses	3 Bhajer 2 rayan	1000000
42	DM & Imam House	North Moather	890000
43	M116 & Imam House	Alnaserya	1500000
44	DM8 & Imam House	Alduhail	1000000
45	Multi-Story Building	Musheerb	14000000
46	8 Villas	Oldairport	4000000
47	Multi Story Building	Umgwelina	2500000
Total in Qatari Riyals			282,490,000

The case study could be described as follows, there are several projects running at the same time and they are a mix of investment and non-investment projects, some of them are small and others are large, the small project usually has a budget of less than three

million Qatari Riyals (approximately one million US Dollars) while the budget of the large project is more than three million Qatari Riyals. Small projects are fully supervised by the department's engineers and most of the large projects are out sourced to a consultant office for supervision in addition to the project management team from the Awqaf (Endowments) Department.

The annual cost for supervision is nine hundred thousand Qatari Riyals (QR 900,000) these are the salaries of the civil engineers who are in charge of supervising projects. There are five civil engineers and in addition there is a number of back up office engineers, consisting of three architects, two graphic designers, two electrical engineers, and two engineers in charge of costing, an accountant, and other clerks. But the engineers in charge of supervising projects are civil engineers and the department has to achieve the following three main goals:

- Minimising the man hours
- Minimising (optimising) the budget
- Not to exceed the total budget

The problem will be initiated in the following paragraph. The construction section is one of the Awqaf (Endowments) Department's sections and the Engineers Section is in charge of supervising all the projects. It provides data about a number of engineers by each type of project and the cost (man hours and total cost) and labour requirements see Table 3.13.

Table 3.13 Data per project

	Data / project	
	Large	Small
Man hours	2	1
Cost of man hours (in Qatari Riyals)	4.950	2.600
Cost of the project (in Million Qatari Riyals)	12	0.8

For the large projects there is a need to have two scales for man hours, on the other hand, for small projects, only one scale is needed for man hours. In terms of cost for man hours, the annual cost per large project is 4.950 Qatari Riyals, whereas for small projects it amounts to 2.600 Qatari Riyals. In addition, there is an annual budget for all the projects which is calculated at around 80 million Qatari Riyals, around 65% are allocated for the large projects and the rest for the small projects i.e. 35%.

### 3.7 Conclusion

In this chapter a brief description about the methodologies that have been used in this research was presented as well as the proposed framework where the case study was used for implementation purposes to facilitate the understanding of the contents of the framework.

Three main methodologies are discussed including Analytic Hierarchy Process (AHP), goal programming, simulation and their strength and advantages were emphasise in order to demonstrate how they can be applied to help in problem solving.

The case study is discussed in details which is the base for the next chapter where the implementation of the methodologies will be applied starting with the Analytic Hierarchy Process (AHP) as the first methodology where priority selection modelling and analysis are used.

## 4 CHAPTER FOUR

### Priority Selection Modelling and Analysis

#### 4.1 Introduction

In the case study the priority selection means that we have to select the number of projects according to the organisation's capability. These projects should be studied carefully in order to make the appropriate choice and produce an acceptable schedule for the implementation of the received projects.

As it is mentioned in the case study, the department's capacity has been calculated to cover forty projects, due to the limitations in resources (this will be verified another time when the goal programming is applied on the project; accordingly to provide the decision maker with a relatively accurate figure of the number of projects to be run as well as the amount of needed resources).

It is accepted to say that each project has its own defined characteristics; this helps the management to set up the criteria for each of those projects where the experts can contribute and evaluate the projects under investigation and their criteria. Therefore, these criteria should be discussed very carefully so that fairness will prevail during the selection stage.

It is clear from the case study what the requirements are and it could be said that there are several projects that are applied from the department to supervise, but there is a

limitation in department capacity to deal with all projects at a time. Therefore, only some of them can be launched, hence criteria are needed to choose from those several projects to start with projects within the capacity of the department.

There are different approaches to apply priority selection the following are some of methodologies that could help to prioritise the projects. Lee et al. (2009) studied an electronic component manufacturing industry in Taiwan and studied a famous hard disk component company, which is considering building a relationship with its core-technology component supplier. They proposed an analytic network process (ANP) as an analytical approach to evaluate the forms of buyer–supplier relationship between the manufacturer and its supplier. The benefits, opportunities, costs and risks (BOCR) concept is constructed to consider various aspects of buyer–supplier relationships. The results shall provide guidance to select the most appropriate form of relationship between the manufacturer and its supplier.

They used ANP approach to identify strategic management concepts (SMCs), including mission, vision, values and competences, for an organisation with the consideration of the qualitative relationships among the concepts. The AHP was introduced by Saaty in 1980 as a multi-criteria decision support methodology and it has been widely used in practical decision-making problems in a variety of fields.

Soota et al. (2008) utilized combination of analytical hierarchy process (AHP) with quality function deployment (QFD) to evaluate the most satisfying design for the customer, establishing priorities of engineering characteristics (ECs) or design

requirements to satisfy the customer's needs. They proposed a model as an aid to produce development managers and customers arriving at a prudent decision for concept evaluation when the complexities of decision variables and multi-criteria decision environment make their decision task quite complicated.

AHP was proposed for this research as priority selection methodology where multi-criteria was involved as well as deference expert opinion, where, needed to contribute. There are number of software in priority selection. Table 4.1 lists some of them.

Table 4.1 Software in priority selection

Vendor	Product	Address
VIP Quality Software	VIP Task Manager	www.vip-qualitysoft.com
Lee Merkhofer Consulting	Priority system software	www.prioritysystem.com
Folio Technologies LLC	Folio Priority System	www.foliotechnologies.com
GENIUS INSIDE Inc.	Genius Project	www.geniusinside.com
Expert Choice	Expert choice 2000	www.expertchoice.com

Expert choice 2000 software is applied to develop the AHP model because it is based on the analytical hierarchy process and helps in analysing the different scenarios. Al-Harbi (2001) cited “‘Expert Choice’ professional software that is available commercially and designed for implementing AHP. It is hoped that this will encourage the application of the AHP by project management professionals” and he add that “an interesting aspect of using Expert Choice is that it minimizes the difficult problem of ‘group-think’ or dominance by a strong member of the group. This occurs because attention is focused on a specific aspect of the problem as judgments are being made, eliminating drift from topic to topic as so often happens in group discussions.”

Expert Choice also gives the opportunity to hesitant people involved in group discussion to give their opinion and speak up when the discussion drifts from topic to topic; on the other hand Expert Choice reduces the influences of group thinking and dominance.

Al-Harbi (2001) claimed that expert choice is an ideal tool for generating group decision through a cohesive and rigorous process. In addition, Expert Choice does provide facilities for performing sensitivity analysis, where the decision-maker can check the sensitivity of his/her judgement on the overall priorities of contractors by trying different values for his/her comparison judgement.

Sloane et al. (2003) determined many features of Expert Choice 2000 implementation of AHP, it provides a mixture of graphic tools that supplement the numerical computations and another advantage is the graphical user interface for model development. This allows easy revision of the model's structure during discussions, so that the participants can actually see the impact of their comments. Easy model revisions also inspires 'what if' brainstorming efforts, because the model can be restored to a prior version if the new model proves undesirable. Also it includes integrated sensitivity analysis tools to help interpret the significance of complicated option, price and feature concessions that happen during final vendor negotiations. In their conclusion they found that the Expert Choice implementation of AHP allowed a diverse set of decision factors to be assessed before proceeding to a product evaluation.

## 4.2 The proposed priority selection model

Figure 4.1 illustrates the structure of the proposed priority selection model which consists of the overall goal, criteria, sub criteria and its alternatives. There are eight criteria, each one of them has three or two sub criteria, to make priority selection from the projects, which exceeds the capacity of the organisation's resources and these criteria are the following:

- Building permission
- Budget availability
- Location
- Application
- Need High Skills Engineering
- Type of contractor
- Supervision
- Public Needs

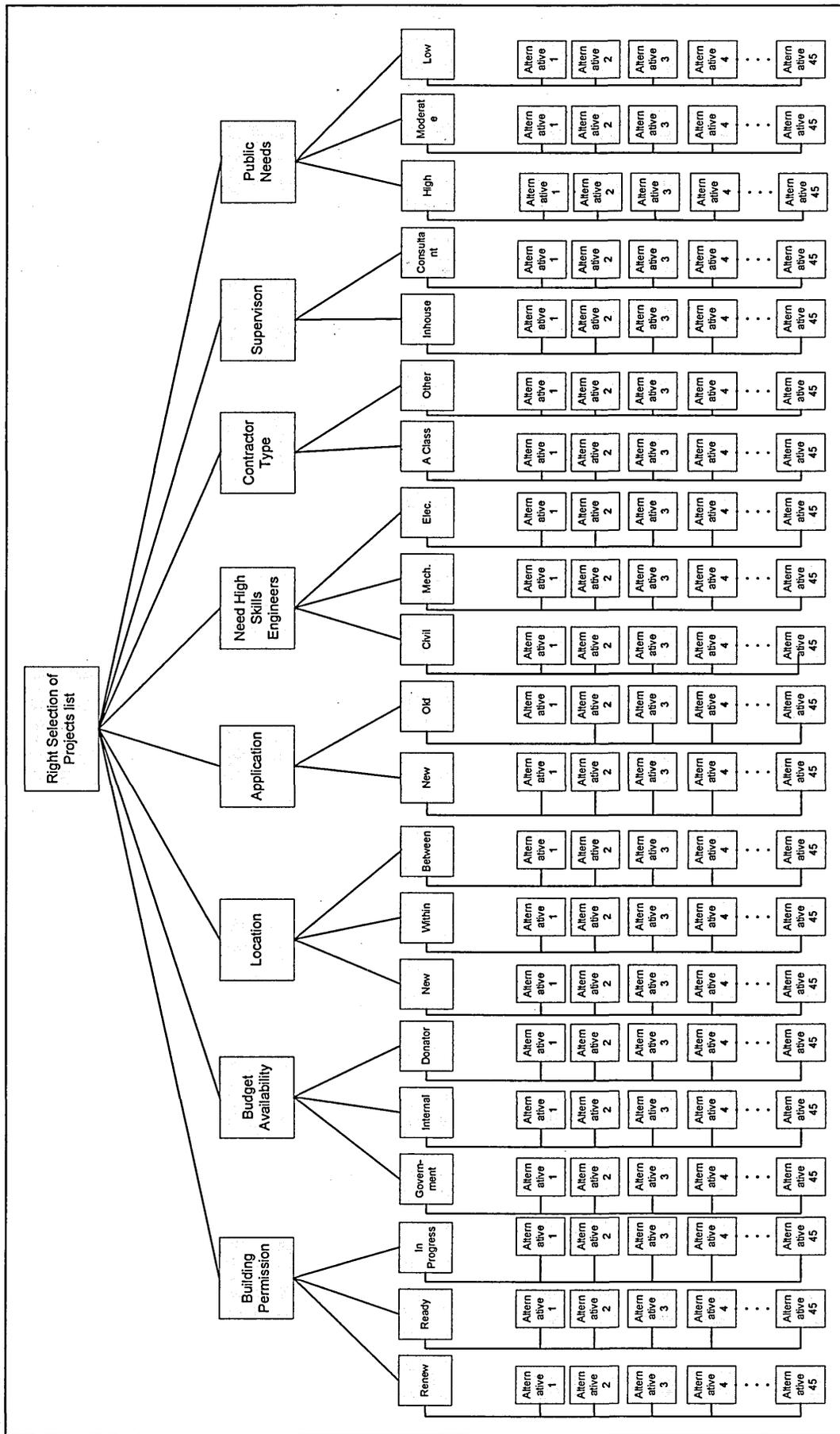


Figure 4.1 The proposed priority selection model

These are the main criteria that could affect the decision making process, which were derived from work experience at the Awqaf (Endowments) Department. These criteria will be ranked in descending orders according to their score and then the senior management will be able to choose the highest score, that fits their budget to start with first, and the rest could be scheduled for future consideration.

#### 4.2.1 Building Permission

According to the case study there are several projects received by Construction Section. These projects are applied by the senior management of the organisation; either the minister's office, the director's or the investment section (mainly investment project). Other applications that come from the public are mainly charity buildings such as Mosques (worship places), Imam's House (Imam is the person who leads the prayer) or sometimes Quranic centres.

When the application is placed at the Construction Section (the section responsible for all construction projects), the next step is to apply for building permission from the municipal department once the processing of the application is completed. Some of the projects are easy to get permission for them, some of them face problems, such as electric planning problems (for example if there is an electric cable underlie in the land; so no building permission will be granted until the electric company takes it off), drainage problems, design problems, etc.

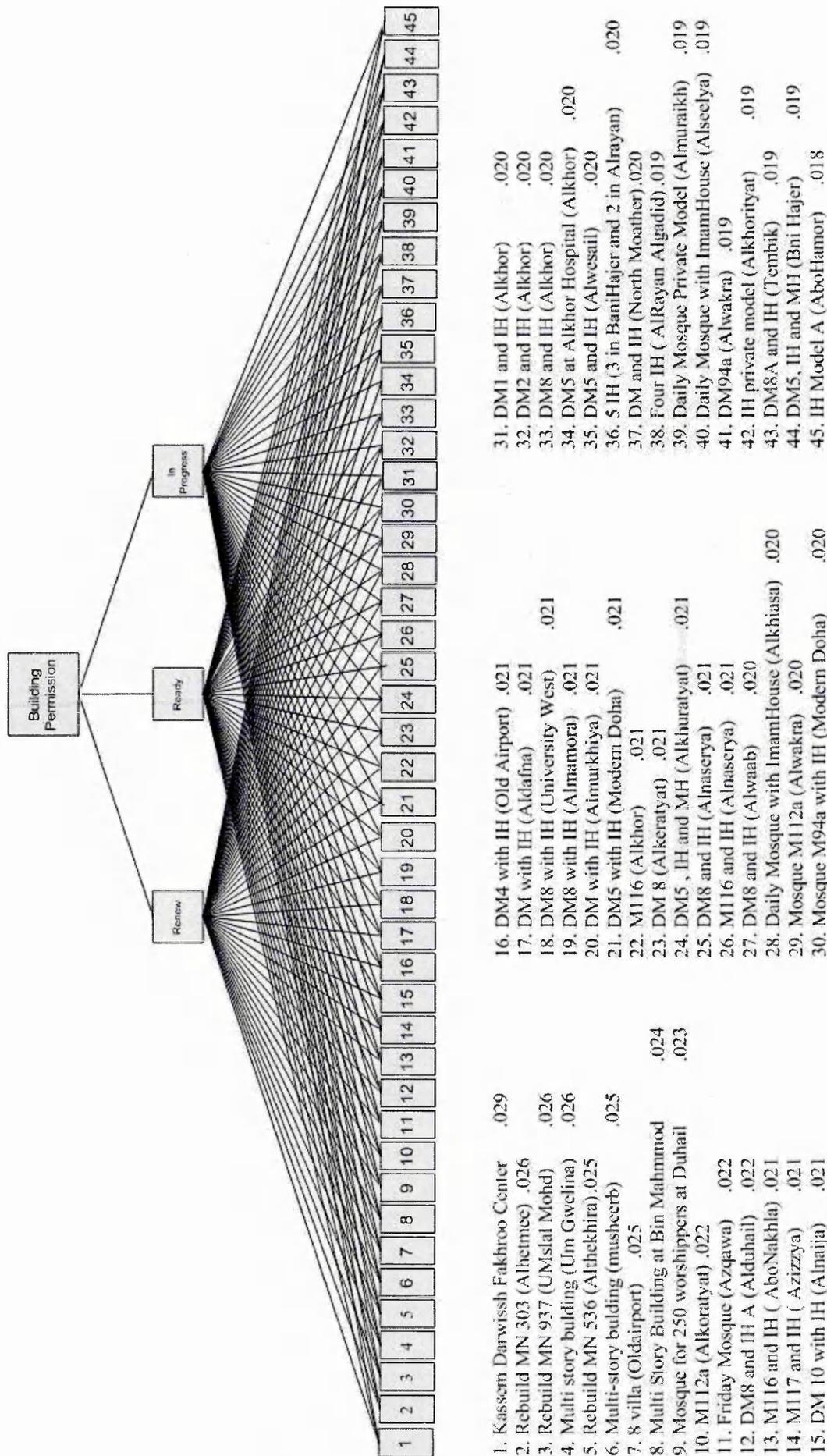


Figure 4.2. Building permission

Consequently some projects are delayed, but the building permission is in progress, by the time some projects get ready, other ones are in progress. On the other hand, there are some projects for which building permission is ready, but there is no budget available for it, therefore when its building permission expires, then it needs to be renewed. Figure 4.2 shows the building permission and its sub objectives.

#### 4.2.2 Budget Availability

In the case study under investigation, its budget comes from three main sources, the first budget is allocated by the government, and it is mainly for public buildings such as Mosques and Imam Houses as well as Quranic Centres. Then there is an internal budget which is generated from previous investments in projects, this income will either be designated for charity projects or for investment projects. Finally, the donors' budget comes from donors for building mosques and charity buildings.

These three sources of the budget are represented in the proposed model as the second criteria as shown in Figure 4.3.

#### 4.2.3 Location

Location is one of the organisation criteria to judge the priority selection for the multi project. The location here is the geographic location of the new building that should be built, whereas the projects are not all in the same area, each project is in a different area. Therefore, these projects are distributed among the department's engineers, where every engineer has to supervise his own allocated projects.

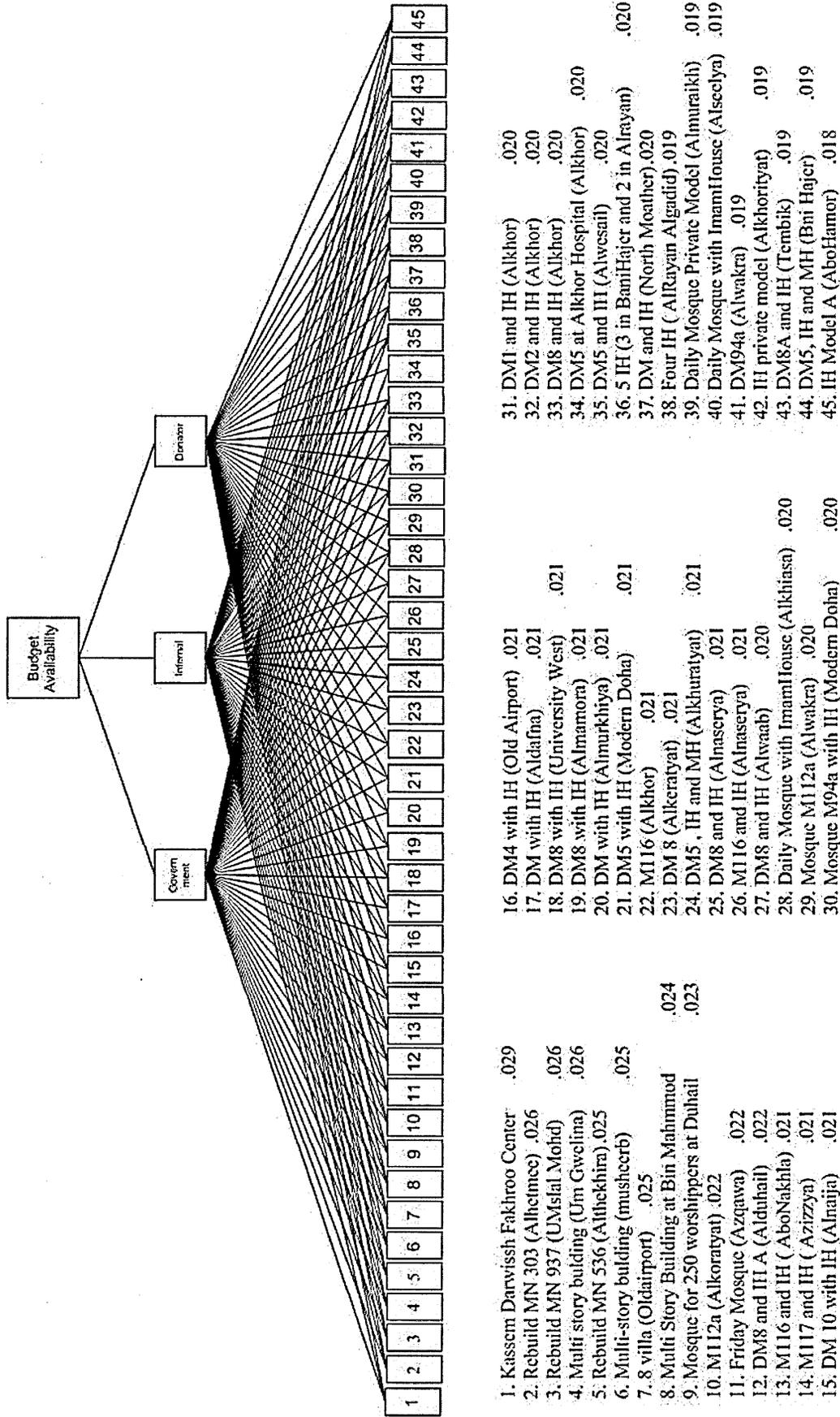


Figure 4.3. Budget Availability

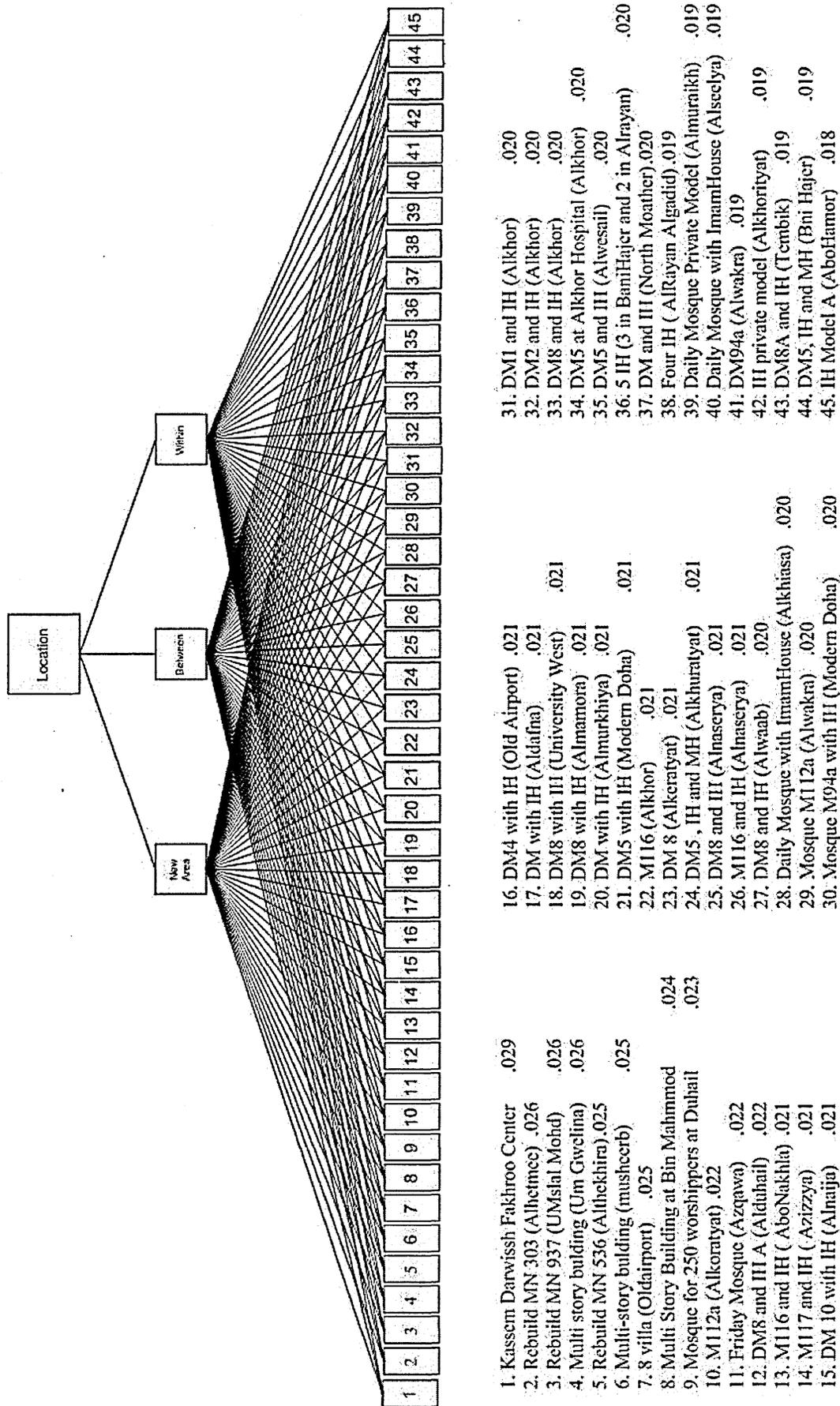


Figure 4.4. Location

Hence projects are spread all over the country, for this reason the Awqaf (Endowments) Department has divided the country into several areas, each of which comes under the responsibility of one of the department's engineers responsible for a specific area as well as specific projects.

Sometimes projects are allocated to certain areas if the project is placed under an engineer's responsibility area, it takes a higher ranking than others, but if the project does not come under the area of responsibility of an engineer; then it takes a low ranking until it is allocated to one of the department's engineers to supervise it. In case a project is situated between two areas, then it will be moderated (see Figure 4.4).

#### 4.2.4 Projects Applications

Every year the Awqaf (Endowments) Department receives a good number of applications for projects, sometimes approaching around fifty project applications a year which by far exceeds the department's capacity. Therefore, these applications build up in the department and remain as such for the lack of the necessary budget to launch these projects.

But even though there is no budget available for these projects, the department usually carries out the administrative procedures to get the building permit from the related services department such as the municipality, Qatar telecommunication company, the civil defence department (for fire regulations and safety) and the electricity department. As a rule, the department proceeds this way in order to get the necessary permissions for the projects that have been approved by the senior management and to be ready when the budget becomes available.

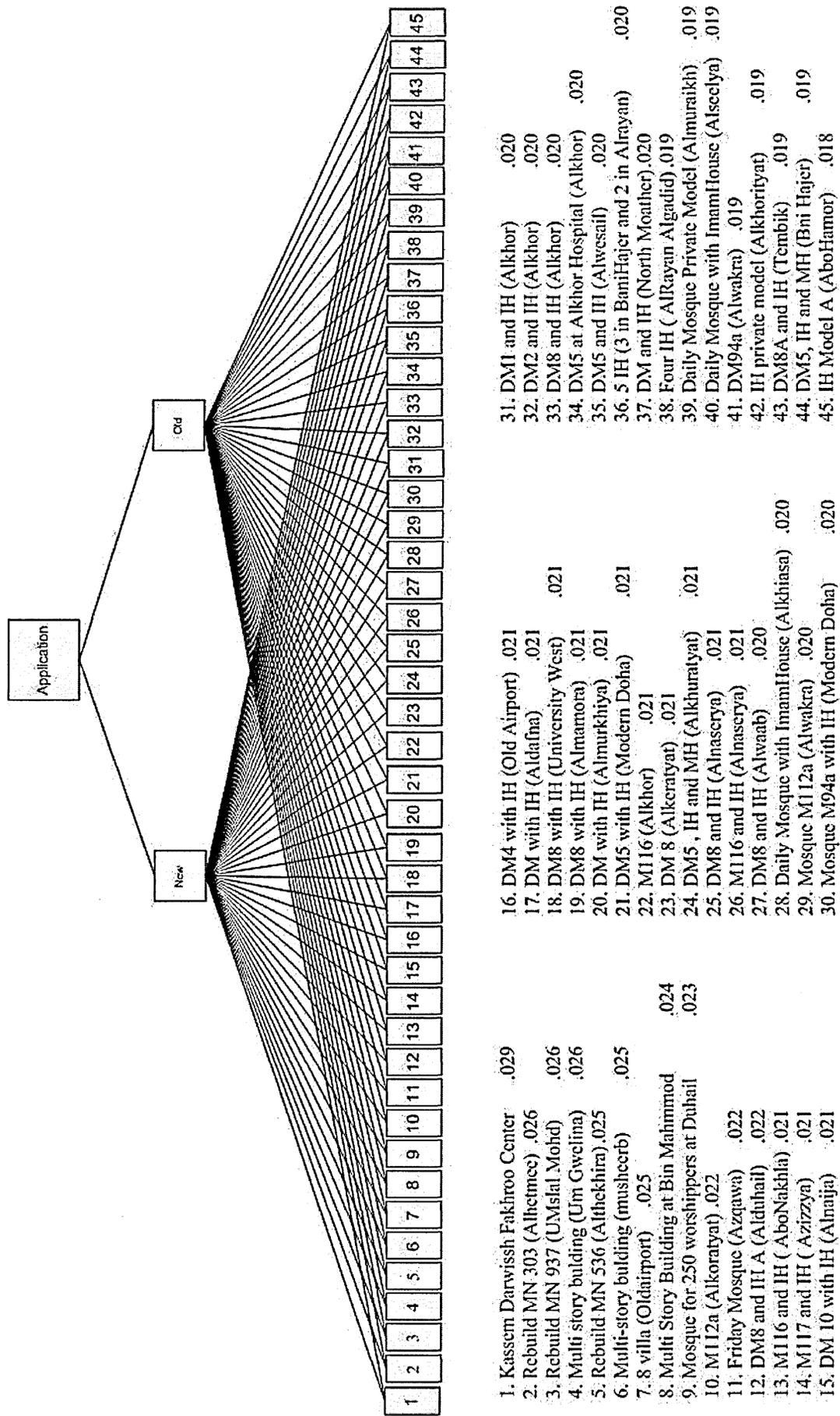


Figure 4.5. Project applications

As a result of that, some project applications remain dormant because of the lack of budget for their implementation. So there is a need to set up a criterion for the proper running of these projects applications. There are only two criteria namely old projects applications and new projects applications and it is obvious the old projects applications are high ranking than the new projects applications. Figure 4.5 shows the goal of projects applications and the two criteria which old and new and then the alternative that needs to prioritise among them.

#### 4.2.5 Need for high skills Engineer

Since the projects vary from small to large, consequently some of them need highly skilled engineers, but others do not. The types of engineers who are needed most for these projects are civil engineers, mechanical engineers, then electrical engineers respectively. So because of the limitations of resources, civil engineers become the most needed for their skills to handle all types of projects although there is a need for mechanical engineers in the case of some large projects together with electrical engineers.

Moreover, the civil engineer's skills that are needed for the projects vary from the small project, where there is no need for highly skilled engineers, to large projects where high skills are needed and sometimes different specialization are needed such as electrical engineering or mechanical engineering. Usually, if these skills are not available in the department then the only solution is to resort to outsourcing which will have an impact on the budget. (See Figure 4.6).

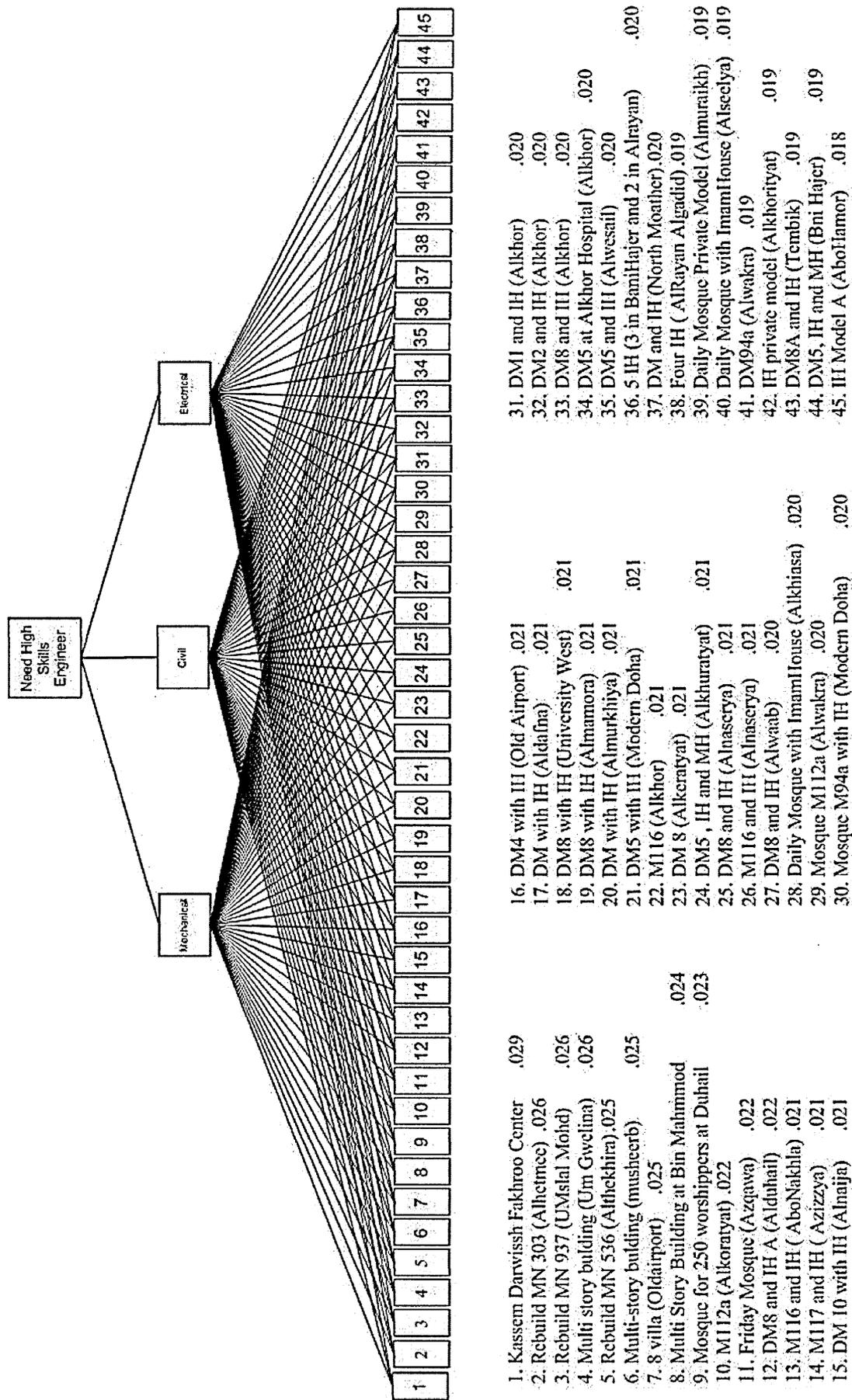


Figure 4.6. Needs High Skills Engineers

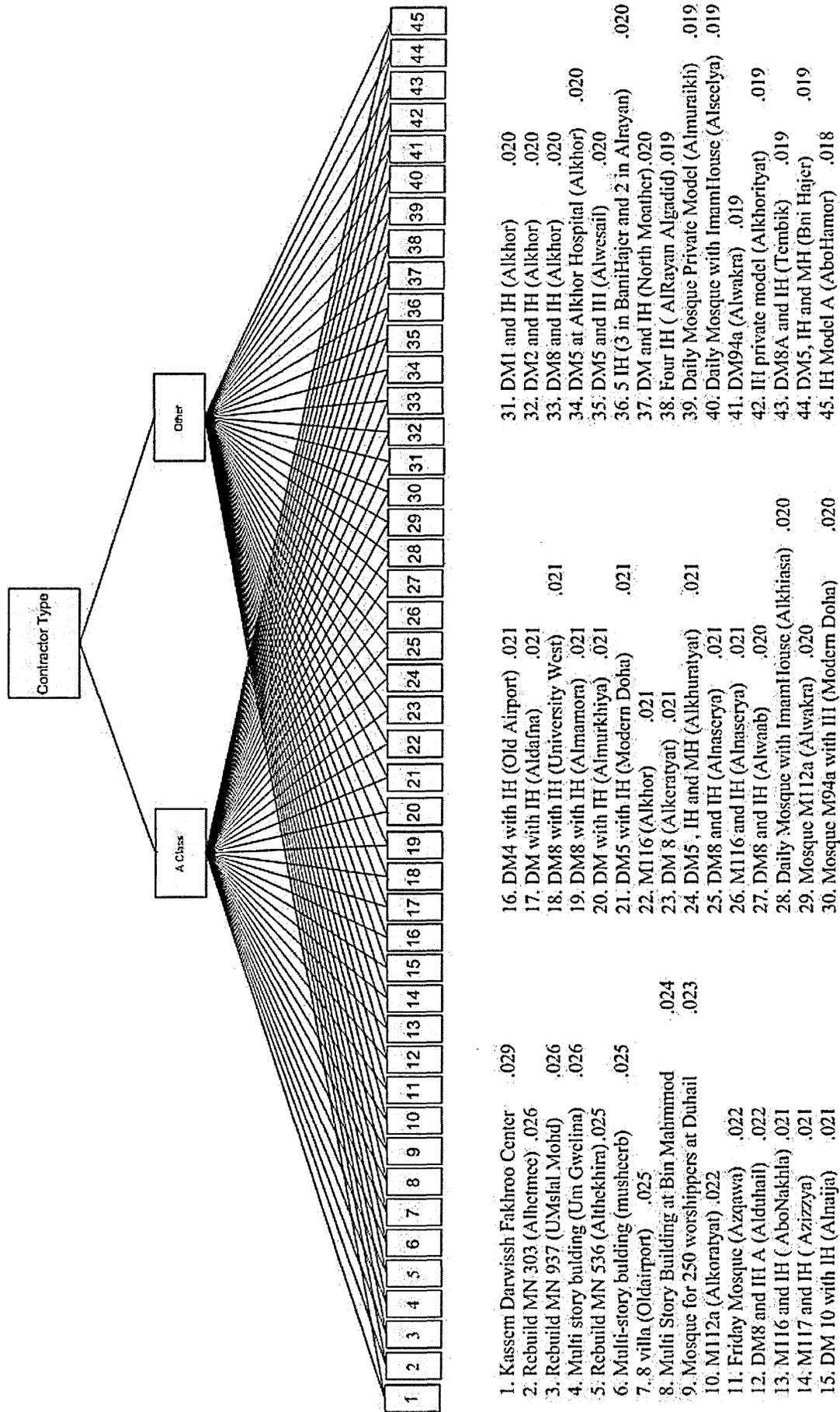


Figure 4.7. Contractor's Class Type

#### 4.2.6 Contractor Class Type

This criterion is set up to differentiate between the large and small projects, as well as to evaluate the project according to its importance. There are different contractor classes, A class and others (B, C, and D) mainly for small projects and maintenance, most of the department's contracts are signed with B or C type of contractors if it is not A type.

Moreover, this will affect the nature of the price and the quality of the service needed for the project as well as its importance. It is not a general rule that only large projects which are entrusted to first class contractors. On some occasions the donator himself / herself requests to have a first class contractor or he / she delegates the section to select the contractor. In general tendering is closely monitored within the department. (See Figure 4.7).

#### 4.2.7 Supervision

The department employs five civil engineers who are in charge of supervising all the projects, but the department usually assigns a consultant for the large projects. Only the project management is taken by the department's engineers. Occasionally, some projects are supervised by a consultant otherwise; the department's engineers supervise the rest of the projects.

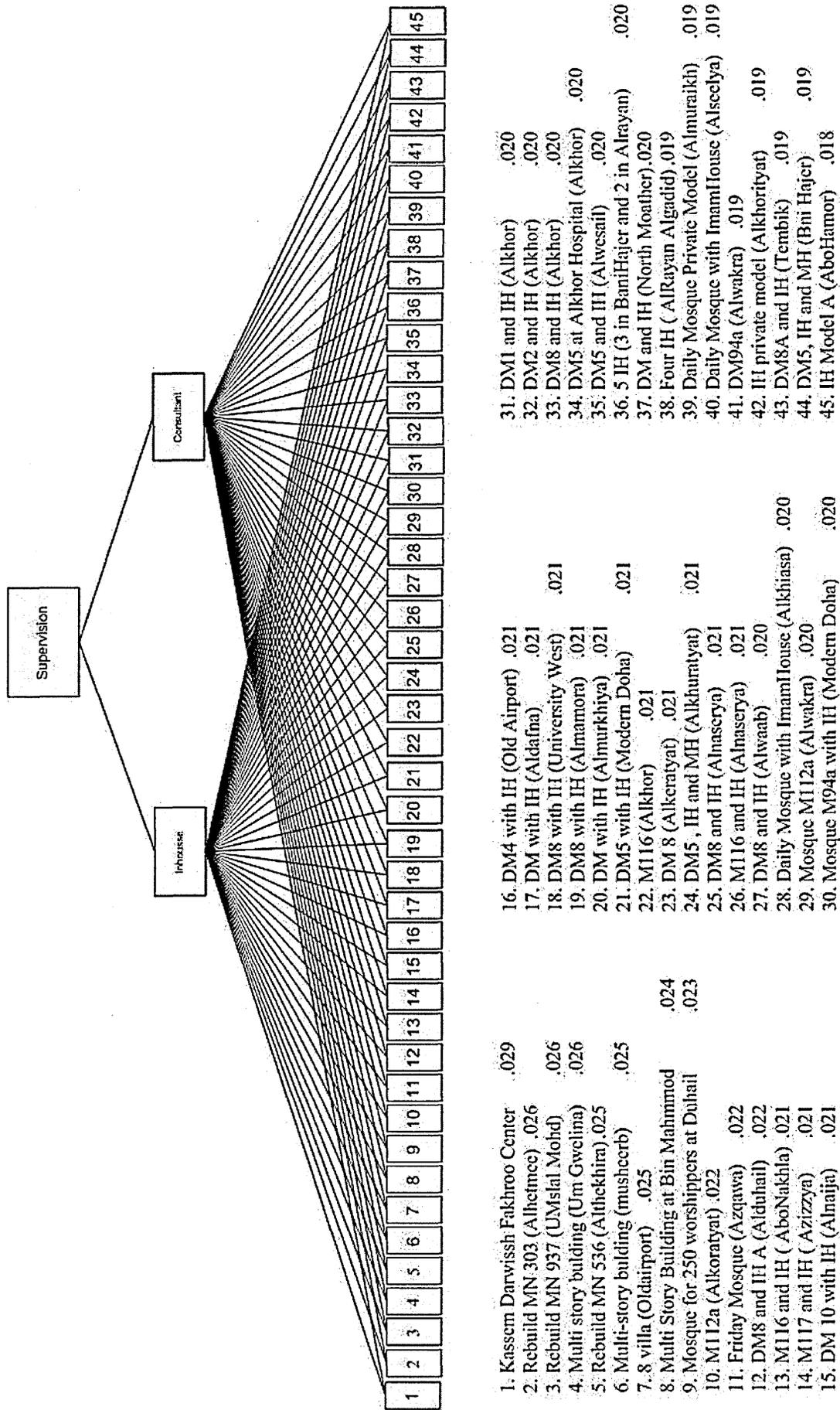


Figure 4.8. Supervision

On the other hand it is acceptable to say that all the projects are supervised by the sections' engineers because even the large projects where the direct supervision is carried out by the consultant's office for outsourcing reasons. The project management and the following up are managed by the relevant sections' engineer which means that there is a sharing of resources.

Therefore, the supervision criterion is a crucial one, where a highly skilled engineer is needed. It is not only one specialization that is required, there is also a need for the other necessary specializations. (See Figure 4.8).

#### 4.2.8 Public needs

As mentioned in section 4.2.4 there are many project applications per year, most of these projects are for public purposes such as mosques and Quranic centres. Hence, the public's need is one of the most important criteria for evaluating the projects, consequently its ranking has been arranged as in the following:

- High demand: where there are crucial needs because of a high population density in the area, with no basic services available such as (daily mosque or Friday Sermon Mosque within one kilometre reach). In some cases, there is a port cabin mosque which is usually small and not adequate for the number of worshippers.
- Medium demand: where there are basic services but they are not considered to be adequate enough for the population of that particular area; there could be a daily mosque in that area but a few are Friday Sermon Mosques, or there is a need for a Quranic centre, and in this case it is called medium demand.

- Low demand: is in the case of an area that has all the basic services, but they need to be enhanced by adding more projects in this particular area, where the local people can use the services but they wish to have services closer to their homes.

There is a committee within the Awqaf (Endowments) Department which is responsible for providing the engineering section with all the necessary information to determine whether a project application is of high, medium, or low demand.

Figure 4.9 shows how the priority selection meets the goal of public needs when the criteria are applied to match the goal or its alternative by providing a clear connection between them.

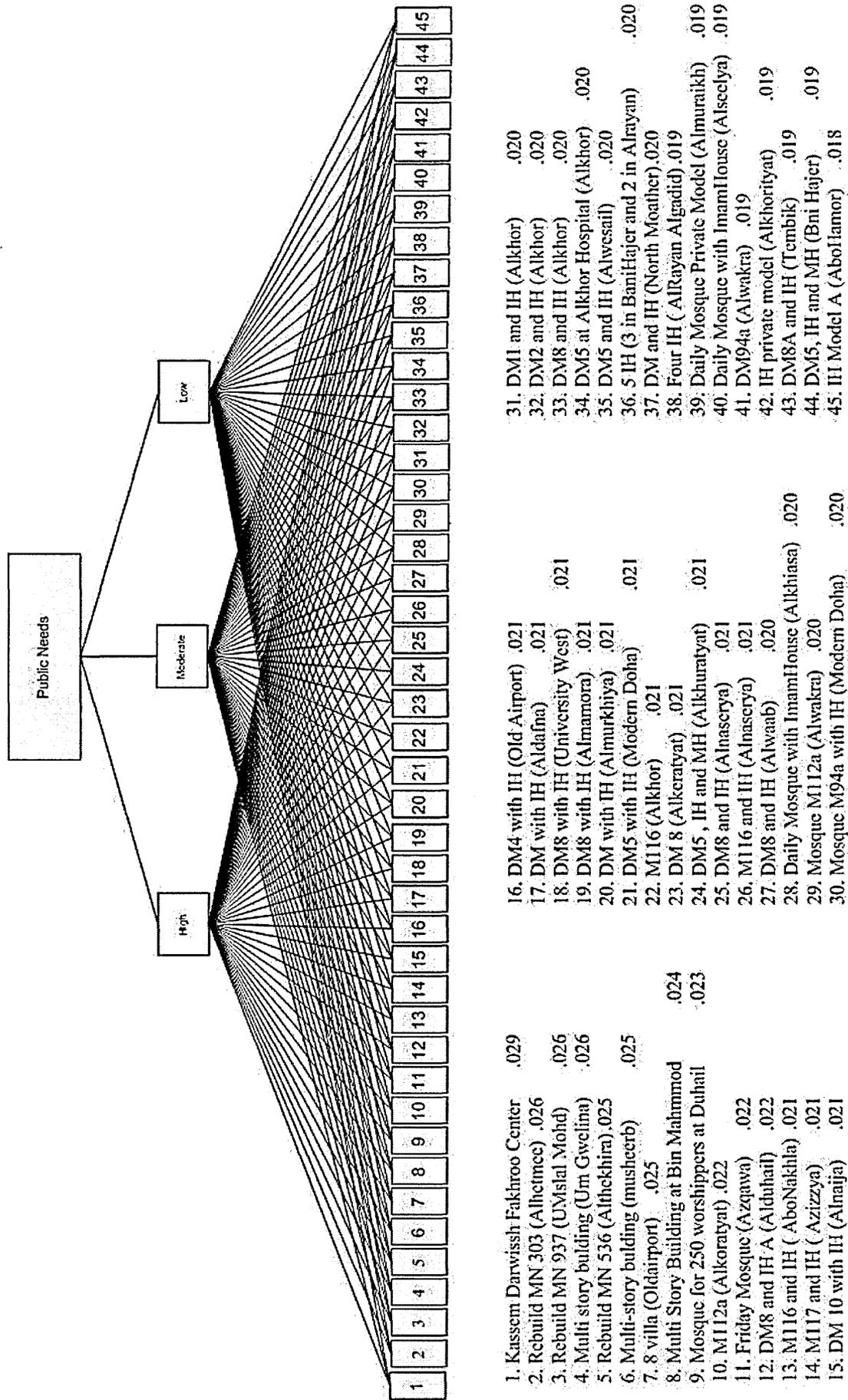


Figure 4.9. Public Needs

### 4.3 Expert Choice Decision Hierarchy

Once the criteria have been set, then the software branded Expert Choice 2000 which is based on Analytical Hierarchy Process (AHP) will be applied for priority selection; with the purpose of selecting the forty projects out of forty five projects or more, according to their importance. Figure 4.10 shows the tree view of the criteria that is applied for priority selection. Also the weight of each criterion in the model is pondered by using a pair wise comparison process that the software provides. The following sections present a briefing on how the Expert Choice 2000 was used to work out the priority selection for the projects.

#### 4.3.1 Objective

The goal is the statement of the overall objective. The objectives are what the section hopes to accomplish by meeting the goal.

The Expert Choice 2000 decision hierarchy is depicted and shows alternatives and objectives relative to the goal synthesis with respect to the selection of proper projects to be launched. See Figure 4.11. This gives the decision maker which project should be launched first, on the one hand, and on the other hand it is fair for other applicants who need to have their projects implemented first, and that makes the planning phase more straightforward.

The decision model can be constructed using two approaches, a top-down approach and then a bottom-up approach. The top-down approach focuses on identifying and organizing the objectives before evaluating the alternatives. Whereas, the bottom-up

approach focuses on evaluating each of the alternatives relative to the objectives before evaluating the importance of each objective.

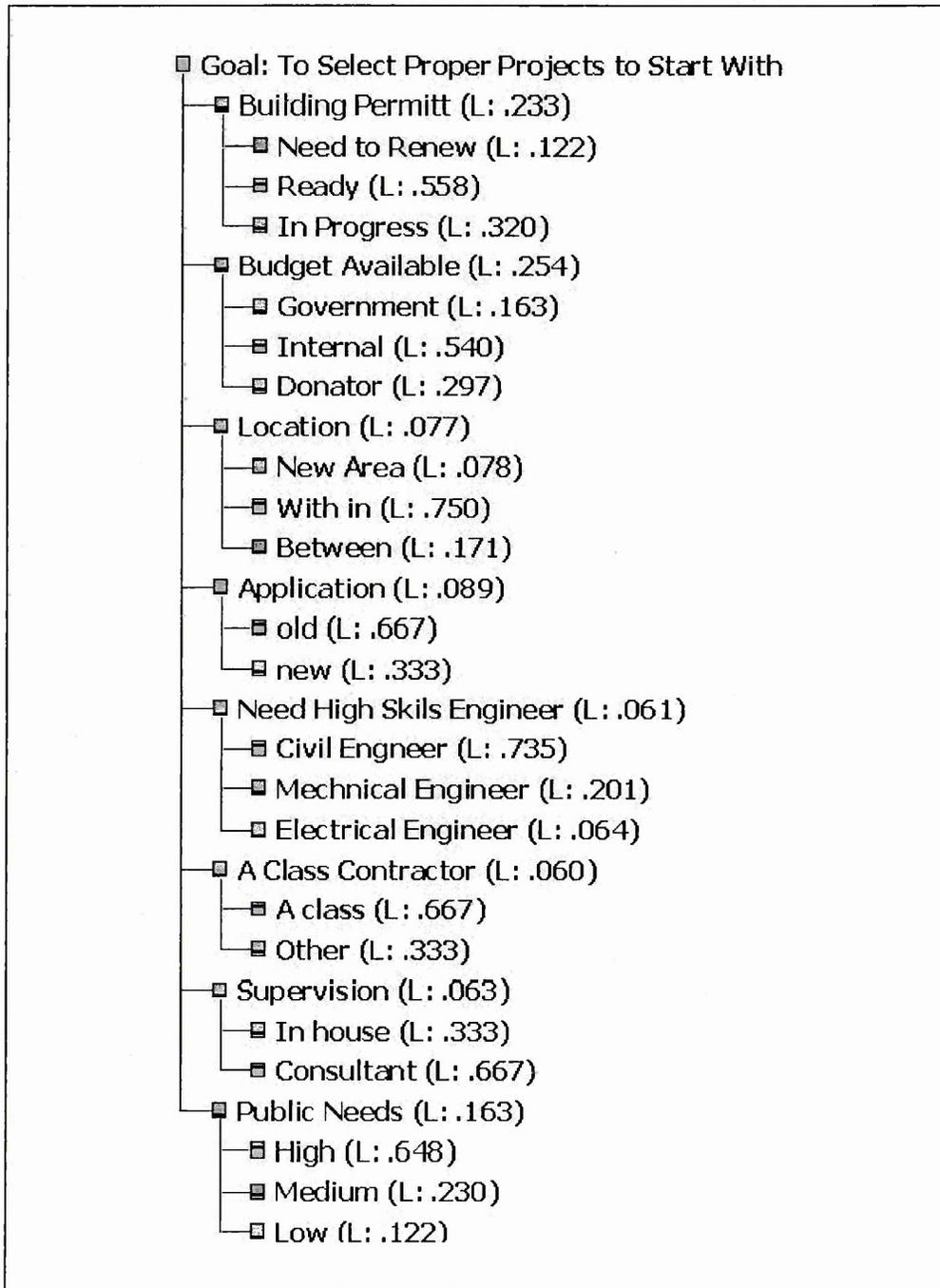


Figure 4.10. Tree View of the criteria

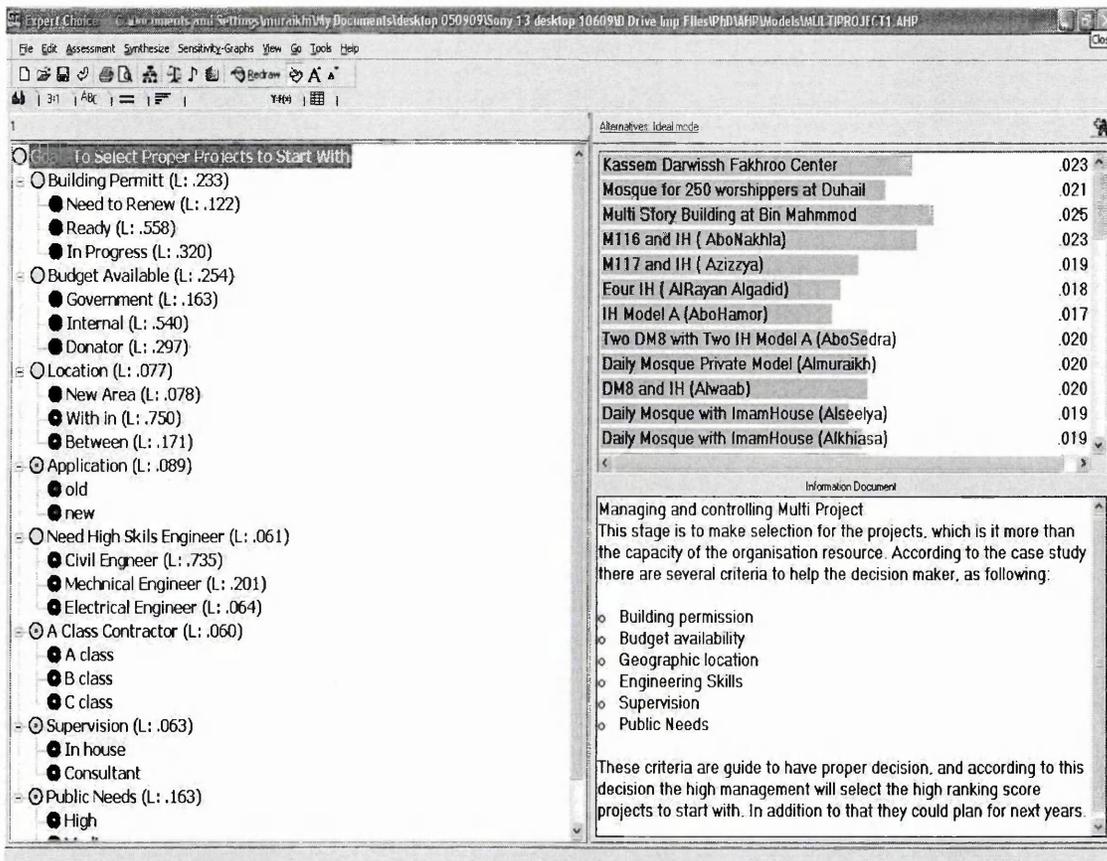


Figure 4.11. Expert Choice Decision Hierarchy

This review was a combination of the two. The review first identified objectives and then organized them according to the goal, but no weights were derived for each objective. Next, for the alternatives identified, pros and cons were developed and organized relatively to each alternative.

Because pair wise comparisons have been made primarily in the psychological context, the verbal mode was chosen. This type of comparison involves the following scale, 'equal', 'moderate', 'strong', 'very strong', and 'extreme'. Figure 4.12 is a pair wise comparison that shows management's judgments relative to two possible alternatives, namely the building permit and budget availability. The comparison shows that the



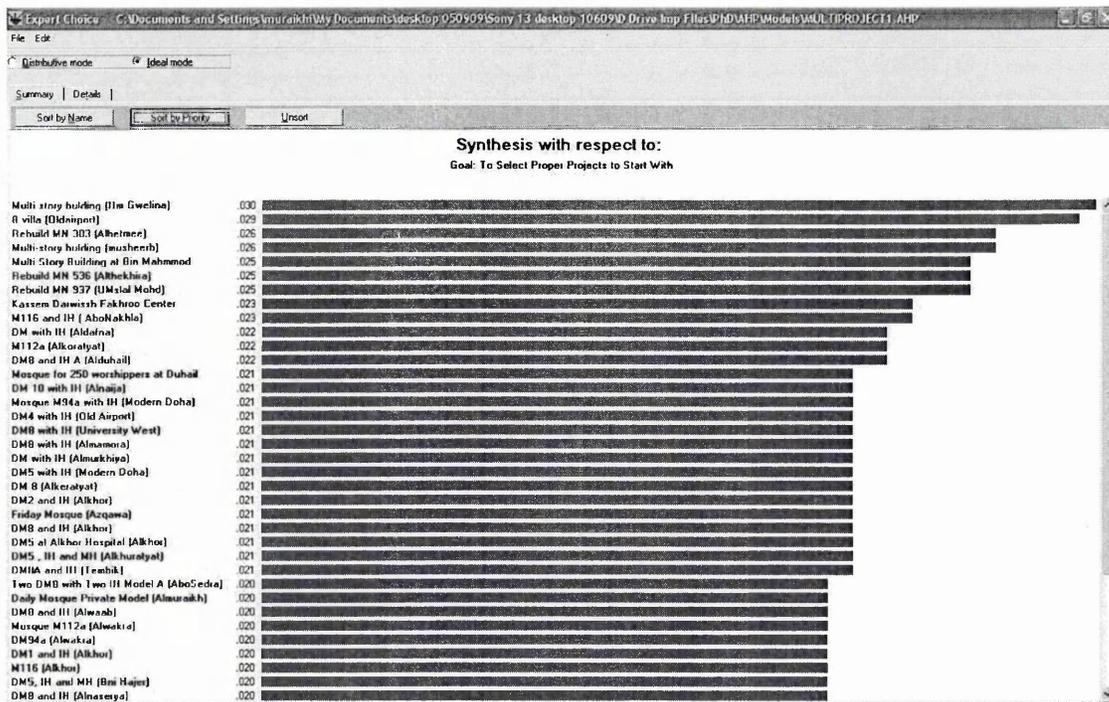


Figure 4.13. Synthesis with respect to selected proper projects to start with

Figure 4.14 shows the priority selection after applying Expert Choice to the whole projects and the reader could note that there is no big difference between the projects, which means that they are almost the same in weight for most of the criteria and it will appear also in sensitive analysis that there are no large gaps between the projects in terms of criteria.

The synthesis was conducted using the ideal mode. This mode distributes the full priority of an objective to the alternative that ranks highest under that objective. The other alternatives are given a priority in proportion to each alternative and the highest alternative. See figure 4.15 for the full synthesis.

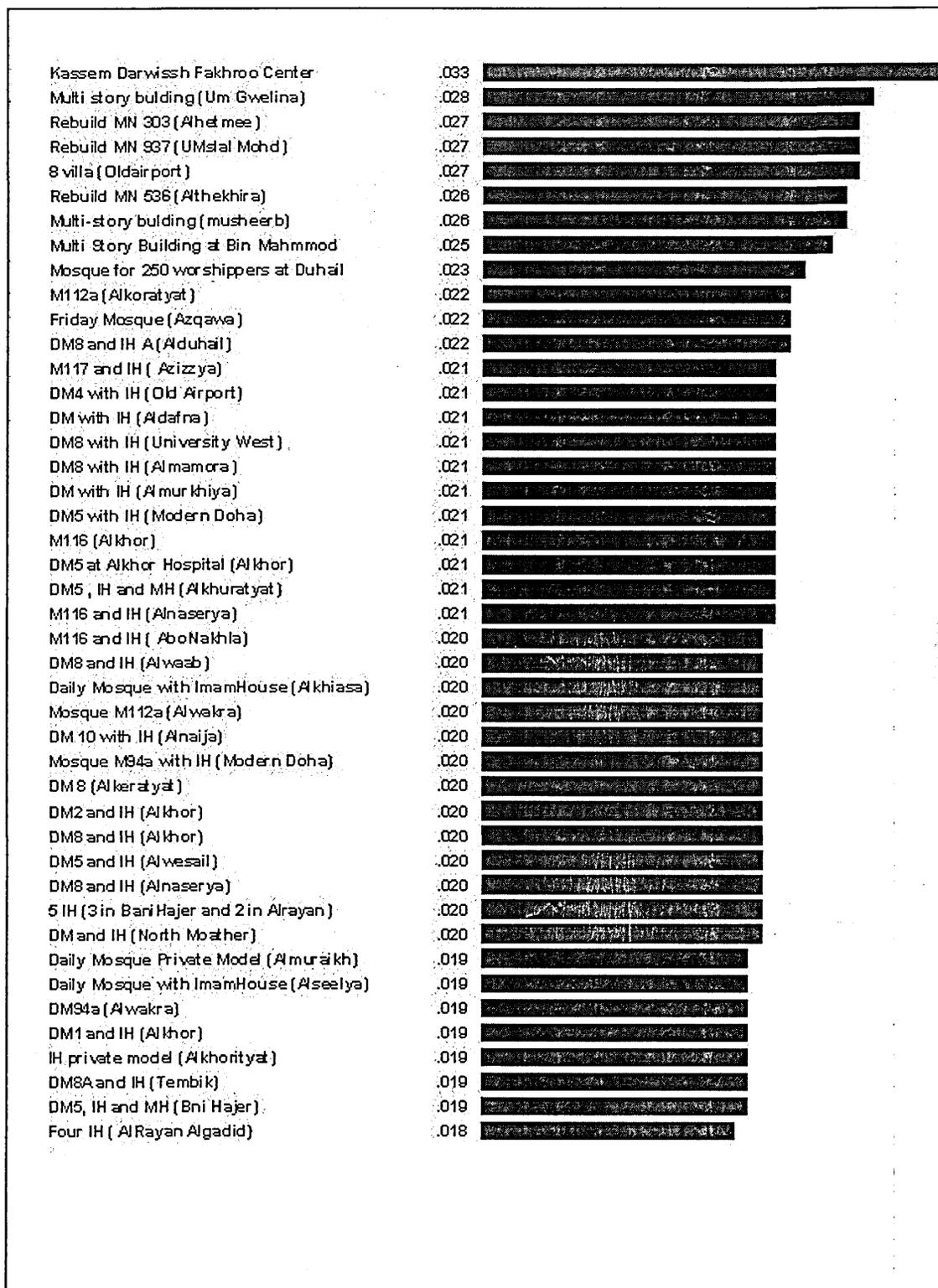


Figure 4.14. Priority selection

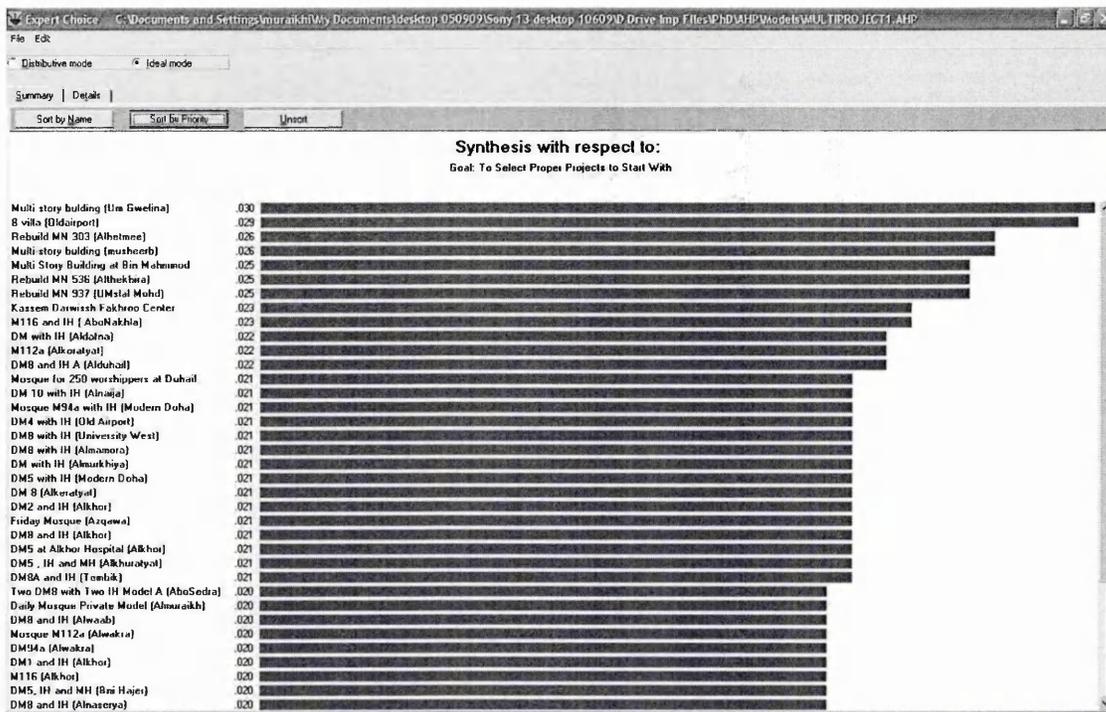


Figure 4.15. Expert Choice Synthesis (Ideal Mode)

In addition, sensitivity analysis was applied to see how the priority list will be affected when the weight allocated to each criterion is changed. Figure 4.16 and 4.17 illustrate the sensitivity, it is clear from the figures that the order of project priority has not changed even though the weight has changed.

Sensitivity Analysis is used to investigate the sensitivity of the alternatives to changes in the priorities of the objectives. There are five types of sensitivity analyses available within Expert Choice which are, Performance, Dynamic, Gradient, 2-D plot, and Head-to-Head.

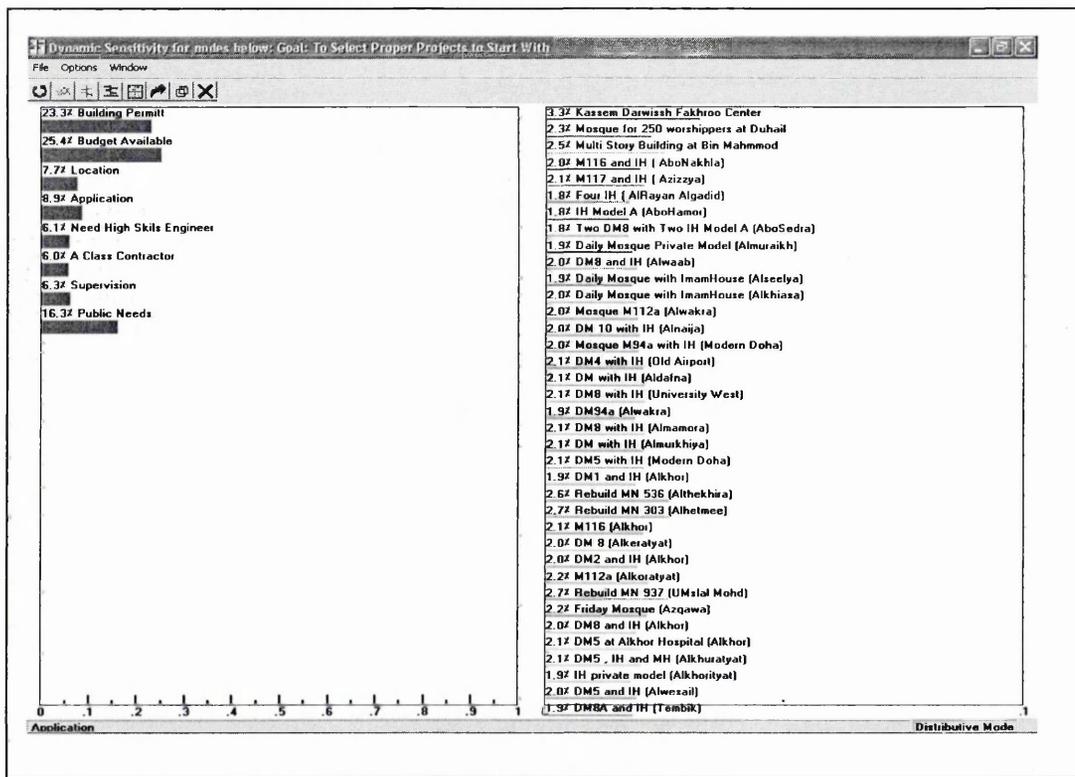


Figure 4.16. Original Sensitivity analysis

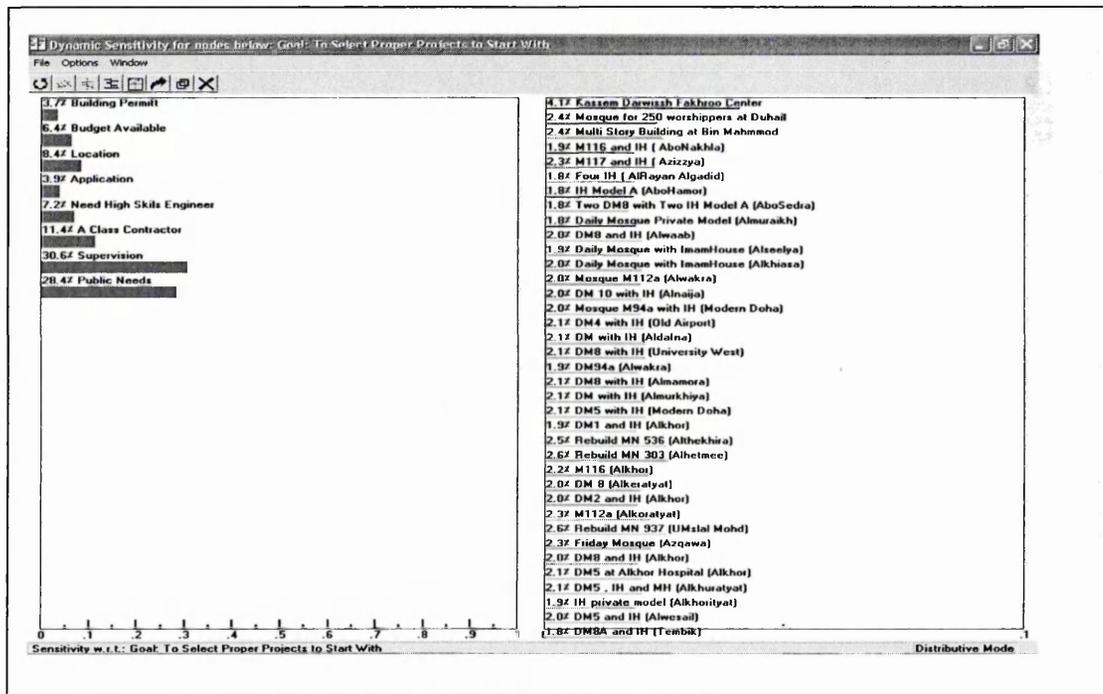


Figure 4.17. Sensitivity analysis after changing the weight of the criteria



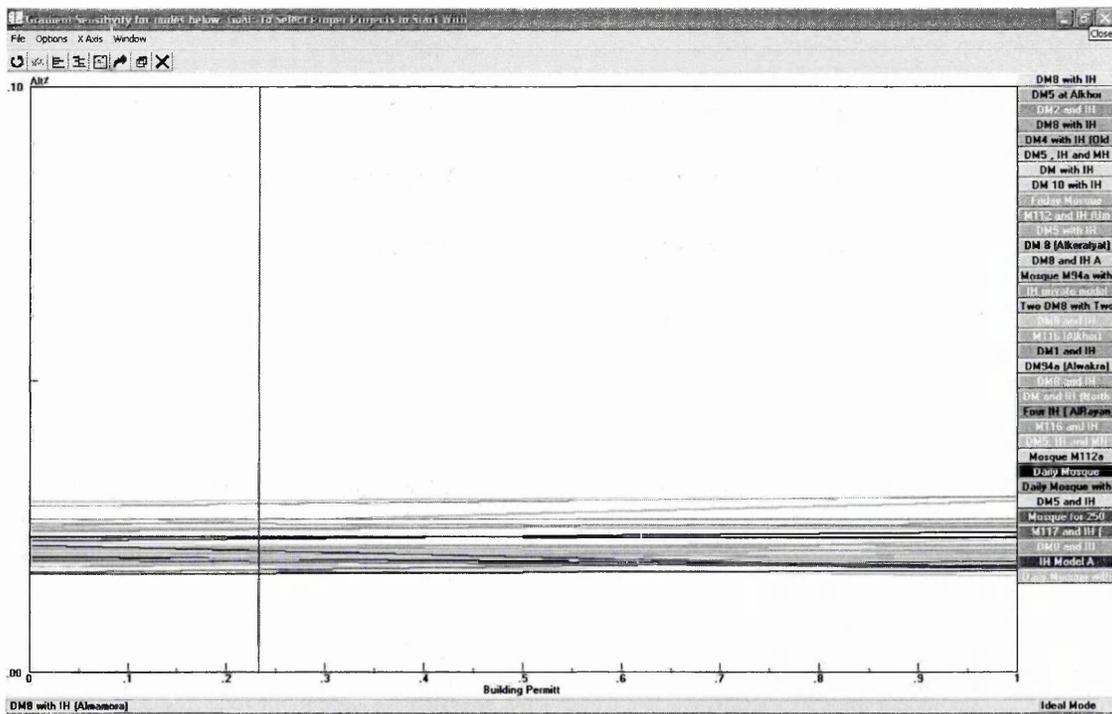


Figure 4.19. Gradient sensitivity analysis

Additional analysis may provide an even clearer picture of actions available to management.

This is the first stage to choose which project to start with, next we apply goal programming to make sure how many large and small projects the department could work with.

Figure 4.20 shows sensitivity analysis, but in a different mode it is called dynamic because Expert Choice allows the user to consider it from a different angle. There are several sensitivity analyses such as performance, dynamic, gradient, 2-D plot, and Head-to-Head.

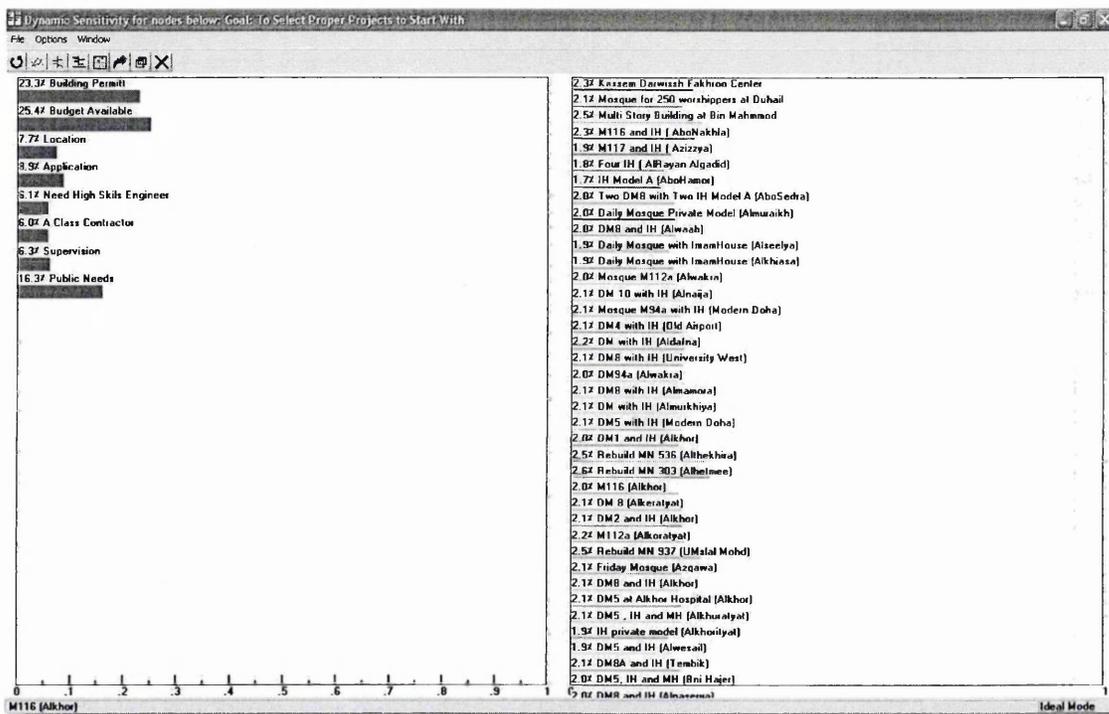


Figure 4.20. Expert Choice Sensitivity Analysis (Dynamic)

#### 4.4 Conclusion

In this chapter the first problem concerning this thesis was solved by developing the AHP model in which the criteria and objectives that affected the goal of the model to select the right projects which deserve the allocated budget. In addition, sensitivity analysis was carried out to examine the impact of changing the weight allocated to each criterion which shows that the model coped with these changes, without changing the final selection list.

The next chapter will deal with the second problem investigated in this thesis to find out the best resources allocation amongst these listed chosen projects for which goal programming will be applied.

## 5 CHAPTER FIVE

### Resources Allocation Modelling and Analysis

#### 5.1 Introduction

The previous chapter covered the first issue of the problem of how to prioritise the projects according to certain criteria. This chapter will investigate the resources allocation for the selected projects and whether the department's capacity could handle these projects or not.

Goal programming will be used to verify that the department engineers, budget, as well as the mix between them, are able to outsource supervision in case of a shortage in the number of the department's engineers.

This chapter gives a brief description about mathematical modelling and then analyses the problem where the goal programming formulation for the problem is given. Next it will show the proposed solution using LINDO/LINGO software to conclude the chapter by sensitivity analysis for the goal programming model.

#### 5.2 Mathematical Modelling

As mentioned in the literature review of this thesis, there are many mathematical models that could help the decision maker to make the right decision, one of them is the

goal programming, which is one of the popular programming techniques to tackle the multi objective goals.

Therefore, goal programming has been used to optimize three main goals namely budget, man hours, and supervision. In order to get these goals LINDO software has been utilized to approach these goals.

There are five steps that should be taken in using this type of approach,

- 1- Understanding the real problem
- 2- Formulating a model of the problem
- 3- Gathering and generating the input data for the model (e.g., per unit costs to be used, etc)
- 4- Solving or running the model
- 5- Implementing and interpreting the solution in the real world. It is clear that the first, third, and fifth approaches are the most difficult ones and most time consuming.

Integer LP models are ones whose variables are constrained to take integer values. Integer models are known by a variety of names and abbreviations, according to the generality of the restrictions on their variables. Mixed integer (MILP or MIP) problems require only some of the variables to take integer values, whereas pure integer (ILP or IP) problems require all variables to be integer. Zero-one (or 0-1 or binary) MIPs or IPs restrict their integer variables to the values zero and one.

Another solution approach known generally as constraint logic programming or constraint programming (CP) has drawn increasing interest of late. Having their roots in studies of logical inference in artificial intelligence, CP codes typically do not proceed by solving any LPs.

Since the case considered in this thesis is a two dimensional problem and associated variables are known, liner programming was proposed to solve and optimise the problem. Table 5.1 shows some of linear programming solver software and Lindo software has been chosen to solve this problem even other listed software could be used, but Lindo software was utilised due to availability and previous experience.

Table 5.1 Linear Programming Solver Software

Vendor	Product	Address
Maximal Software, Inc.	BendX Stochastic Solver	<a href="http://www.maximalsoftware.co.uk">www.maximalsoftware.co.uk</a>
Ketron Optimization	C-WHIZ	<a href="http://www.ketronms.com">www.ketronms.com</a>
Optimalon Software	GIPALS32	<a href="http://www.optimalon.com">www.optimalon.com</a>
Gurobi Optimization, Inc.	GUROBI	<a href="http://www.gurobi.com">www.gurobi.com</a>
LINDO Systems, Inc.	LINGO	<a href="http://www.lindo.com">www.lindo.com</a>

Even in this research where the case is not complicated, but the great power of LINGO software is used to solve the proposed module is in its ability to model the large system, where the set of objectives are formed to optimize them and make iteration to achieve a final solution.

As pointed out earlier the main problem of multi-project is uncertainty where it is difficult to predict the future, therefore, to achieve outstanding planning would not be

easy, because of uncertainty of the multi-projects and there are many changes that are needed in the application.

LINDO Systems, Inc. (2006) pointed out that mathematical programming or in other words optimization or constrained optimization is a mathematical procedure for determining optimal allocation of scarce resources. Optimization and its most popular special form, Linear Programming (LP), have found practical application in almost all facets of business, from advertising to production planning. Transportation and aggregate production planning problems are the most typical objects of LP analysis.

LINDO Systems, Inc. (2006) claimed that for most optimization problems, one can think of their being two important classes of objects. The first of these is limited resources, such as land, plant capacity, and sales force size. The second is activities, such as 'produce low carbon steel', 'produce stainless steel', and 'produce high carbon steel'. Each activity consumes or possibly contributes additional amounts of the resources. The problem is to determine the best combination of activity levels that does not use more resources than are actually available.

In this case study the mix product problem approach is used where there are two kinds of projects for example small and large in the presence of a shortage of resources. According to LINDO Systems, Inc. (2006), "The features of a product mix problems are that there is a collection of products competing for a finite set of resources. If there are " $m$ " resources and " $n$ " products, then the so-called "technology" is characterized by a table with " $m$ " rows and  $n$  columns of technologic coefficients. The coefficient in row

“ $i$ ”, column “ $j$ ”, is the number of units of resource “” used by each unit of product “ $j$ ”. The numbers in a row of the table are simply the coefficients of a constraint in the LP. In simple product mix problems, these coefficients are non negative. In addition, the profit or loss per unit associated with each product is presented as well the cost associated with each resource is included. These may take a form of one equation or more which are called objective functions.

The objective is to find out how much do we need to turn out of each product (i.e., the mix) to maximize profits, with the purpose of not exceeding each resource that is available”. Therefore, it is acceptable to say that the case study in this research is related to this area of the mix of products, where result leads to the optimization of the available resources; consequently this will help the decision makers to formulate the right decision.

LINDO System, Inc. (2006) proved that there are two main approaches to form the models. The first one is the framework structural (template) approach and the second one is the constructive approach, both of the approaches have its own merits, but the constructive approach is the approach that is more connected to the principle and it has main characteristics. Meanwhile the constructive approach is more suitable for the user of limited analytic skills. This could be applicable during the study of the status, that research provides for a current solution. The framework structural (template) approach develops through the following characteristics:

The Problems of the Mixture of the product; these problems are the kind to typically appear during the preliminary tests. There are a large number of marketable products, in terms of their limited viability of resources of which those products are made. It is supposed that each product achieves a percentage of profit income, as well as an amount of resources utilized. The objective here focuses on finding a mixture of products (the amount of each product will be estimated), that is able to achieve the maximum profit income, by consuming the minimum amount of resources less than the provided amount. Such problems are expressed by the theory of an amount of profit higher than less or equal percentage of pressure.

The Problems of Coverage, employment, and stopping process of supplying; such type of problems are considered to be supplementary (it means duplicate problems according to the expressions of business jargons) i.e. it is complementary to the problems of the mixture of the products, it depends on the theory of "an amount of cost less than higher or equal percentage of pressure". The variables in such cases suit the number of employees hired to different shifts during the day. The pressures constitute as a result that the outcome of the selected variables should cover the needs of the employer during each hour along the day.

The Problems of the Mixture; such category of problems is related to food, mining, industries and the industry of refining oil. The issue resulted from the process of mixing and blending a group of raw materials (e.g.: different kinds of meat, yield seeds, or the Crude oil) derivative to have ultimate product, (e.g.: sausage, dogs food, or the

gasoline). In this way, the price of conclusive product unit can be reduced against arousing some pressures in regard with the quality.

The Problem of the Planning of Multiple Stages; is the most prominent and important category among models. Such models take into consideration that the current taken resolutions can only partially define the resolution that can be taken during the future stages. The subordinate models used in each stage may appear as a result of the problem of blending, mixing, or any other kind of problems. Those models are usually related to each other according to the differences in the origin of the stockpile (e.g.: the stockpile of raw materials, the goods of the final product, the cash fund, the deferred loans) that are carried over from one term to the next one.

The Models of the net and the scope of distribution; the models of the net enjoy merits confidentially important because of two reasons (a) they are of specially simplified forms, the matter that makes it descriptive on a diagram or on the net, then (b) they include procedures to provide specified and successful solutions of their problems. Therefore, they prove that they are the easiest to be explained and the most viable to be absorbed. Such a type is resultant from problems related to the process of distributing the product. Each incorporation that is specified in producing the goods, it shall produce it in different places and then it shall distribute it to its customers everywhere and it may face a problem related to the net of distributing the product. The prominent problem in this regard should follow specified procedures to be solved. Among the simplest problems that result from the web of distribution is how to reach the shortest way initiating from one of the points on the web map to another point. According to a slight

difference in such problems, finding the longest way on the web map may constitute the most prominent elements and tools to administrate the projects (the technique of evaluating and revising the program) and (the way of the critical passage).

The models that are similar to the category of distributing the product are the models of the theory of inputs/outputs that are vertically integrated. For example the Company of General Motors assembles its engines in specified factories. Such engines are sold directly to the clients, or to the suppliers of the industrial equipment, or it uses the engines of cars and trucks from the factory of General Motors itself. Such company is said to be vertically integrated. With regards to the comprehensive model, usually, there is a kind of pressure according to each medial product. Such kind of pressure rationally imposes, the basic law of Physics that: the used amount of a medial product through different processes will not exceed the amount of the same product produced by other processes. There is usually only one variable in one resolution to be taken in each similar process.

The Problem of Planning of Multiple Stages along with existing of Random Elements; one of the basic proposals to improve the models depends on all of the input data being irrevocably known. It seems that in some cases the data are variably random. For example, whenever an oil company takes final decisions regarding fuel oil production to satisfy the needs of the next winter, the demand on such an oil product will be randomly assigned to a large extent. Moreover, if the possibility of distributing all random variables is known, this means that we are dealing with the technique of forming and creating to transfer an issue of improvable curve, in exception of the random elements,

into improvable model of definitive nature and of equivalent volume, if it is not larger. Such models are sometimes known as subtitling improvable programs.

The models of portfolios: among the prominent and important applications for improvements during the last ten years, something that is known as investment portfolio appeared. In its simplest form, it concerns defining the supposed value and the volume of incomes should be in a group of investments that involve risks, so that, in this regard, a settlement viable to combine between expected revenue and limited risk. In regard with the images of more complicated applications of the same idea, it concerns the process of investment of its meaning and searching for an index financial in itself.

The models of the theory of the game: this concerns the analysis of complete elements. It is constituted in its simplest form in a game consisting of two players, each one has a group of possible resolutions. Each player should select and set himself a special strategy in order to make the decision as he/she does not know the competitive player. Sometimes, following the process of making the decision, each player will receive material reward in harmony with the group of decisions reached. In regard with the estimating of the ideal strategy for each player, it can be formed in a written/linear program.

It is not necessary that all of the confronted problems should be applied only on the categories and models mentioned above. Most of the problems are consisted of a mixture of the above mentioned kinds. For example, in case of the planning of multiple

stages, the problems of the mixture and of the blending of the product would be resultant as subordinate problems of an individual stage

### 5.3 Problem Analysis

As mentioned in section 5.2 the most important step is that the problem should be identified and then according to that cleared identification of the problem, it could be described in a quantitative manner (mathematical). The problem under investigation can be described as; there are many projects running at the same time, and there is a limitation of the "resources" which is mainly the engineers, however, in this thesis the man hours and budget are amongst the goals that should be considered.

In the Awqaf (Endowments) Department, there are five civil engineers who are in charge of supervising those projects which have been selected after applying the priority selection, as explained in the previous chapter, by employing the Analytical Hierarchy Process using Expert Choice software. Through experience it was found that each engineer should not supervise more than fifteen small projects or five large projects at the same time. The supervision of small projects is not the same as that of large ones, for obviously, large projects need more attention from the engineers and requires more of their time than the small projects.

As mentioned above, there are two kinds of projects, the large and small projects; most of the large projects are investment projects, whereas the small ones are charities or public projects. The annual budget consists of two types, the first, is allocated to

supervision and is translated into the salary of the department's engineers, and it is estimated at around QR 900,000 (approximately US\$ 300,000). The second budget is allocated for the implementation of projects and it varies from one year to another. This is estimated at around QR 30M (approximately US\$ 10 M) for charities projects and QR 40M (approximately US\$ 15M) for investment projects.

Refer to Table 3.13 Data per project, which was mentioned in chapter three and the description of the problem, the model could be developed as in the following:

Let  $x_1$  and  $x_2$  be the number of the large and small projects. Then the goal programming formulation for the problem is given as:

$$\text{Minimise } G_1 = y_1^- \quad (\text{satisfy the man hour goal})$$

$$\text{Minimise } G_2 = y_2^+ + y_2^- \quad (\text{Satisfy total budget goal})$$

$$\text{Minimise } G_3 = y_3^- \quad (\text{Satisfy the Supervision goal})$$

$$\text{Minimise } z = G_1 + G_2 + G_3$$

*Subject to*

$$2x_1 + x_2 + y_1^+ - y_1^- = 10400 \quad (\text{Man hour limitation})$$

$$12x_1 + 0.8x_2 + y_2^+ - y_2^- = 80 \quad (\text{Total budget goal})$$

$$4.95x_1 + 2.6x_2 + y_3^+ - y_3^- = 900 \quad (\text{Man hour budget})$$

$$\left. \begin{array}{l} x_1 \leq 4 \\ x_2 \geq 36 \end{array} \right\} \text{(Project limitation)}$$

$$x_1, x_2, y_1^+, y_1^-, y_2^+, y_2^-, y_3^+, y_3^- \geq 0$$

$y_1^-$  Considered to be minimising, because it should not exceed the total budget,  $y_2^+$  and  $y_2^-$  considered as a constraint, and lastly to minimise the supervision budget  $y_3^-$  was considered.

Where  $G_1$  is to satisfy the man hour goal,  $G_2$  is to satisfy the total budget goal, and  $G_3$  is to satisfy the Supervision goal.

#### 5.4 Proposed solution

To solve this equation LINGO software was used, the following is a snap shot screen from the model software (see figure 5.1).

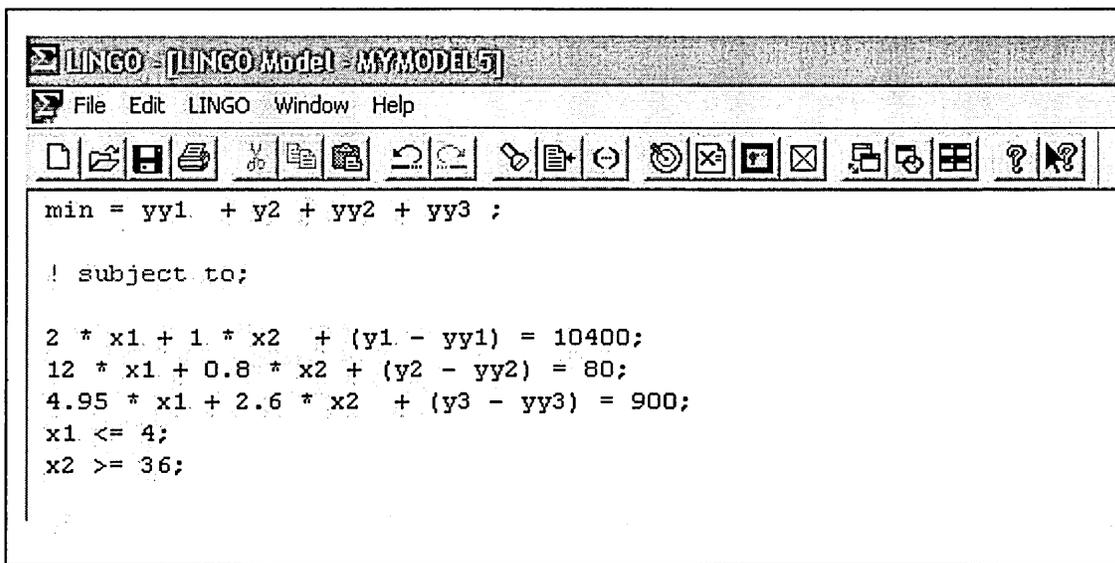


Figure 5.1. Snap shot shows the LINDO model

Figure 5.2 shows the solution report, where the global optimal solution is found as well as the total solver iterations where figure 5.3 gives the formula of the goal programming that is to minimise the man hours and figure 5.4 shows the solution report and it is clear that the goal has been satisfied by finding the objective value equal to zero. Thus, the goal has been reached, because it is a minimised case, but in the slack and surplus column there are 4 slack units, which means that it is possible to add 4 more small projects to become 40 small projects and 4 large projects.

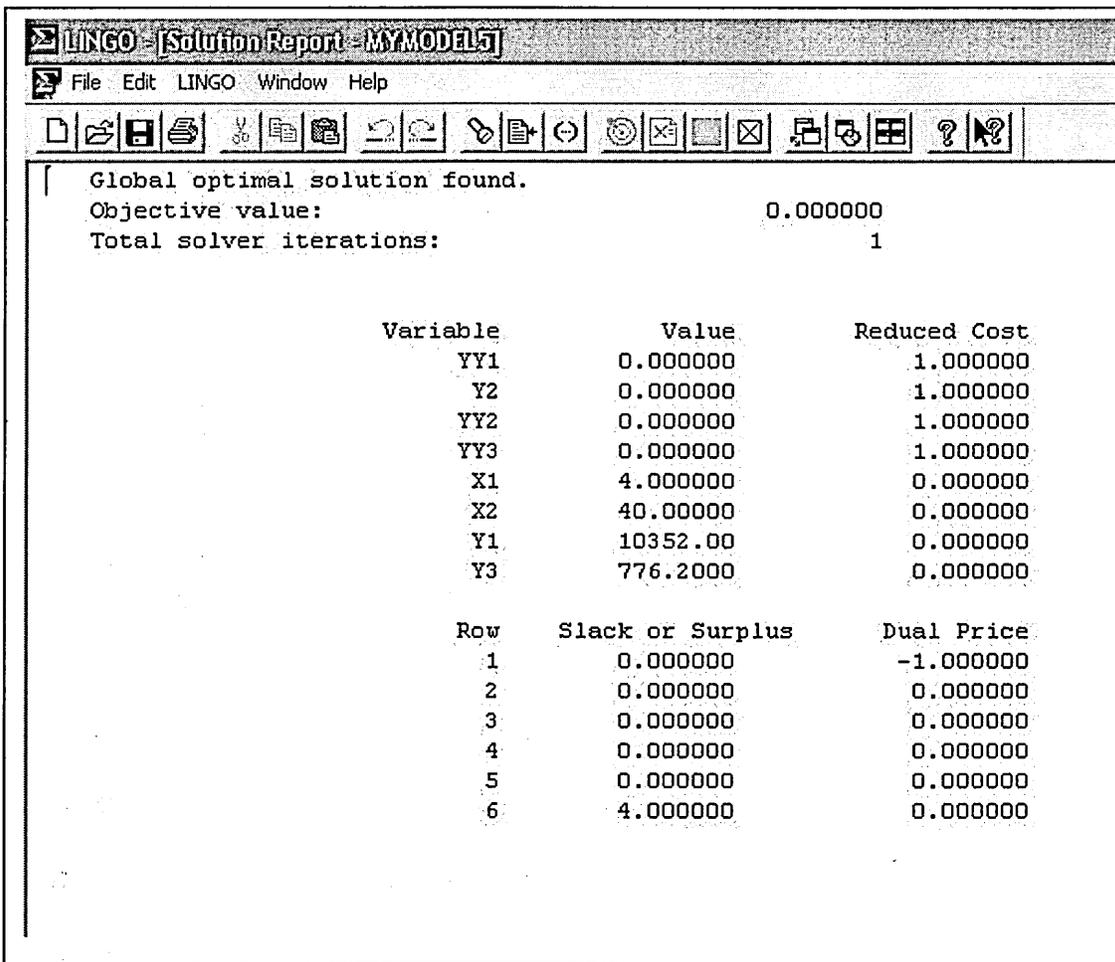


Figure 5.2 snap shot of the solution report

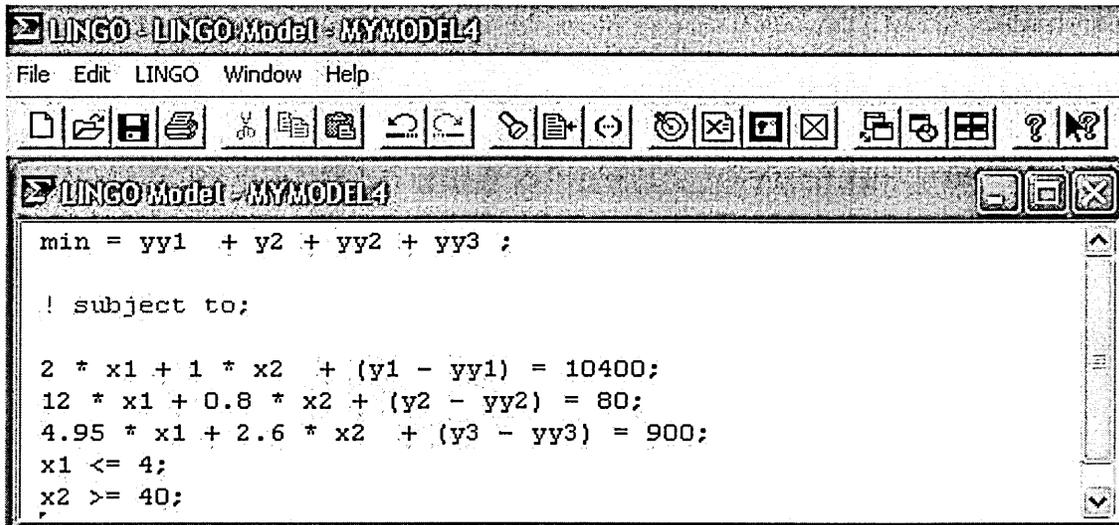


Figure 5.3 Formula after change

The following figure (see figure 4.5) illustrates the solution report after carrying out the change. Because the software did not accept the symbol, hence  $y_1^-$ ,  $y_2^+$ ,  $y_2^-$ ,  $y_3^-$  are represented at the software as yy1, y2, yy2, yy3 respectively.

After carrying out the change, where  $X_2$  became forty instead of thirty six, the solution report shows no slack, and this means that the goal has been achieved with no slack.

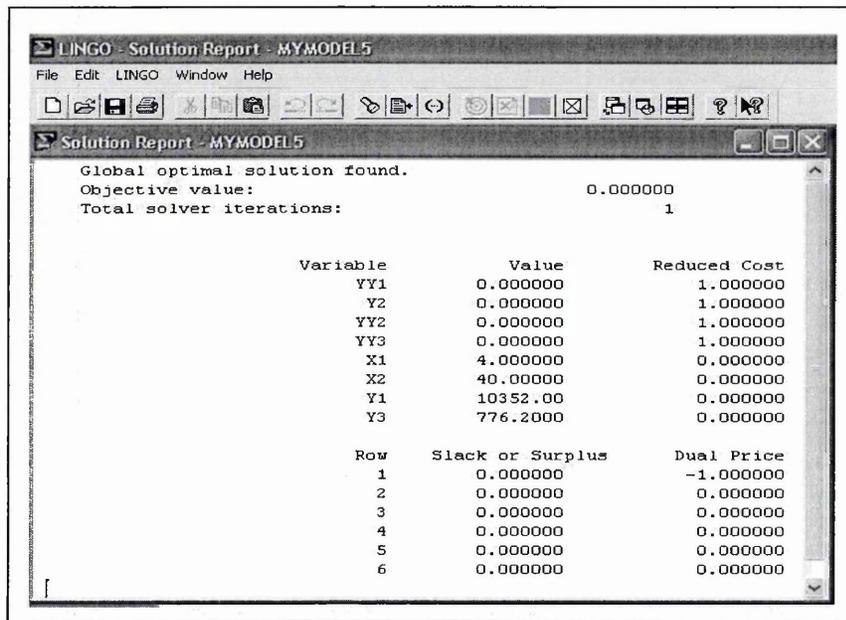


Figure 5.4 Solution Report

### 5.4.1 Sensitivity analysis for goal programming model

Sensitivity analysis has been applied to verify the solution from the previous input, and the following table shows the effect on the slack and surplus column when  $X_1$  or  $X_2$  are changed. For more details see appendix 2.

Table 5.2 illustrates the number of tries that have been carried out, each time  $X_1$  and  $X_2$  have been changed, which presented large and small projects respectively.

Table 5.2 Sensitivity analysis

No try	$X_1$	$X_2$	Slack $X_1$
1	4	36	Yes
2	4	40	No
3	4	44	Yes
4	5	0	Yes
5	0	30	Yes

From previous experience at the department, there are no more than four large projects which are submitted to the department per year. Therefore, it is less than or equal to four large projects ( $X_1$ ); on the other hand there are more than thirty six applications available for small projects ( $X_2$ ). It is also possible to know how many large projects the department could supervise for future planning.

From appendix 2, it is clear that the first try was with thirty six for  $X_2$  and four for  $X_1$ , it gives a slack with four. Then four was added to  $X_2$  to become forty, and the result was optimum where there is no slack and zero for objective value, this mean that the model is optimum. When  $X_2$  is increased again by four and became forty four instead of forty, solution report gives a value for  $X_1$  in slack or surplus column, this means that more weight could be add to  $X_1$ .

The fourth try that is provided in appendix 2 gives  $X_2$  a value of zero and five for  $X_1$ , this time the solution report also gives value in the slack and surplus column for  $X_2$  with twenty five, in this case we could add more weight to  $X_2$  by twenty five. Finally, when  $X_1$  is increased to thirty and  $X_2$  reduced to zero, the slack is presented but this time in  $X_1$  with a value of twenty three. This means that the weight of  $X_1$  could be increased to reach twenty three. See appendix 2 for the formula and their solution report. From the sensitivity analysis, it can be concluded that the best solution for this problem is  $X_1 = 4$  and  $X_2 = 40$ , in this case the department could supervise four large projects and forty small projects at a time.

## 5.5 Conclusion

In this chapter a Goal Programming Mathematical Model has been developed within which three different goals were considered to be minimised. They are man hours, total budget and supervision. The sensitivity analysis was carried out to arrive to the optimal solution and make the right decision in relation to the resources allocation. The next chapter tackles the third problem under investigation in this thesis that is the risk management.

## 6 CHAPTER SIX

### Risk Management Modelling and Analysis

#### 6.1 Introduction

After developing the goal programming mathematical model in the fifth chapter, which talked about its aspects at length, the model has yielded positive results which contribute to the study of the next link or stage concerning risk management. This will be defined by considering the different steps of risk management in three different sections where: one defines the researcher's approach to analyse it and in the second devise a scenario that will be applicable – in the third section – to the simulation as a model for risk assessment.

#### 6.2 Definition

In order to understand the risk management it is important to define risk management; according to The Project Management Institute (2004), risk management is “the systematic process of identifying, analysing and responding to project risk. It includes maximizing the probability and consequences of positive events and minimizing the probability and consequences of adverse events to project objectives”.

The Project Management Institute (2004) mentioned that there are six main processes for risk management: Risk Management Planning, Risk Identification, Qualitative Risk Analysis, Quantitative Risk Analysis, Risk Response Planning, Risk Monitoring and Control. There is an interaction between each one of them and this process should be

applied for each project. In the case study there is no need to apply all processes to all the projects, because as it was mentioned in the introduction, there are several types of projects some of them are public, others are for charities and investment projects and at the same time they are small or large projects.

Therefore, it was not necessary to go through all the processes, but it dwelled on the parts that are needed for the system; otherwise other processes are important for the life cycle of the project.

Since this research concentrated on the tracking system, the risk analysis is the essential process for it gives the best fit and that helps to know how the problem can be tackled when it occurs.

In this research the author's aim is to develop a tracking system that helps the decision maker to formulate the right decision in a multi-project environment.

The most important step is the risk identification one and risk might affect the project either in a negative or positive way. The identification process sometimes needs to have many participants from the project team, the risk management team and the subject matter experts from other parts of the organisation, such as customers, the end users, other project managers, stakeholders and outside experts.

Risk identification is an iterative process, therefore, it could pass on to most of the participants to be performed and it is here where the importance of the simulation intervenes, where it will give the decision maker a short cut to formulate their decision.

According to the Project Management Institute (2004) there are number of tools and techniques which assist in identifying project risks based on The Project Management body of knowledge (2004). Detailed reviews of key tools are explained below.

Documentation reviews: usually, the first step taken by project teams is to perform a well organized review of project plans and assumptions at overall project level and at scope levels before any other step.

Information Gathering Techniques: Conducting brainstorming, Delphi, interviewing; and strengths, weaknesses, opportunities, and threats (SWOT) analysis are among the tools used to gather information in project management environment.

Project teams use this tool to mainly identify the risks. Their key goal is to reach to a detailed list of risks which would be considered as quantitative and qualitative risk analysis processes at later stages of the project. Brainstorming as a tool requires a facilitator who could lead a multidisciplinary team of experts. The approach is based on gathering the ideas about project risks. Project teams identify risks in broader ways and then categorize by type of risk. Hence risks are clearly defined.

Another key tool is the Delphi technique. This technique allows project experts to reach an agreement through the following two steps: A project facilitator will distribute a questionnaire to seek ideas of experts about key risks of project.

The facilitator will collect the responses and then re-distribute the feedback again to the experts for further additional comments. After a few rounds, key risks are shortlisted and consensus is reached. The key value of the Delphi technique is in reducing bias in the project or information gathered and minimize due influences on outputs.

Interviewing project managers and experts helps in risk identification. Usually, appropriate individuals are identified by the person responsible for risk identification. He or she will provide a brief of the project and provides information about Work Breakdown Structure (WBS) and the list of assumptions. Every interviewee is expected to identify risks on the project and any other relevant information according to his or her experience.

Strengths, weaknesses, opportunities, and threats (SWOT) analysis provides good levels of assurances. Using this tool to assist in examining the project's Strengths, weaknesses, opportunities, and threats, will assist in better understanding of risks.

Checklists are another tool where project teams utilize historical information and knowledge that has been accumulated from previous similar projects and from other sources of information in developing risk identification checklists. Checklists have advantages and disadvantages. Checklists are simple and could be used quickly in risk identification. However, one disadvantage of checklists is that it is not possible to develop a complete and thorough checklist of risks and the user may be limited to the categories in the list. It is quite important that attention is directed to find out items that do not appear on a standard checklist if they are close in relevance to the specific

project. All categories of possible risks to the project should be itemized in the checklist. Prior to every project-closing procedure, reviewing the checklist is an important formal step to improve the list of key risks, to improve the description of risks.

Assumptions analysis is used as one tool because projects are designed and developed on the basis of a group or set of hypotheses, scenarios, or assumptions. The validity of assumptions is rigorously explored through assumption analysis. Assumption analysis identifies risks to the project from incompleteness of assumptions, inaccuracy, or inconsistency.

Diagramming techniques may include the following: cause-and-effect diagrams (also known as Ishikawa or fishbone diagrams). This technique is useful in identifying the causes of risks.

System or process flow charts demonstrate how various components of a system are interrelated and how the mechanism of causation takes place.

Influence diagrams are a graphical representation of a problem demonstrating causality of influences, sequencing of events per unit of time and other interrelationships among variables and outcomes.

Although what has been pointed out in The Project Management Institute (2004) PMBOK about how to identify risk is very important and it could be done in prior of applying the simulation, it has been considered as part of simulation to achieve what has been planned.

There are two kinds of risk analysis: qualitative and quantitative; the above discussed qualitative and the following paragraph will discuss qualitative risk analysis.

The Project Management Institute (2004) points out that qualitative risk analysis is the process of assessing the impact of identified risks and there are tools and technique to the analysis as following :

Qualitative terms such as very high, high, moderate, low and very low are used to describe risk probability and risk consequences. Risk probability in a case study like Imam House that type of a risk will occur. Project objectives are affected by risk consequences when the risk event occurs. Risk probability and risk consequences are applied to specific risk events, not to the overall project. In order to manage the risks aggressively; analysis of risks using probability and consequences is quite helpful in identifying the risks.

Impact risk could be developed to assign a specific rate such as very high, high, moderate, low and very low according to the combing process of impact scales. If conditions show a risk scale with both high impact and high probability; then there is a need for more analysis. Such analysis would include qualification and strong risk

management. Accomplishment of risk rating is done using a matrix and risk scales for each risk.

The scale of probability of risk is either zero meaning no probable risk or for certainty of risk. The difficulty of the risk probability assessment method is due to lack of historical background data and hence, expert judgement might be limited. What could be used is an ordinal scale which represents relative probability values from very unlikely to almost certain. Otherwise, a general scale (e.g., .1 / .3 / .5 / .7 / .9) with specific probabilities assigned could be used.

The severity of the risks effect on the project objective is reflected by impact scale. According to the culture of the organisation who is conducting impact analysis, the approach might be ordinal or cardinal. In the case of ordinal scales, simply values from very low, low, moderate, high, and very high are ranked in order. However in cardinal scales; values of scale for example .1 / .3 / .5 / .7 / .9 are linear. Yet, when reflecting the organisation's desire to avoid high-impact risks, the impact scale become nonlinear (e.g., .05 / .1 / .2 / .4 / .8).

Both approaches share similar intentions which are to assign a relative value to the impact on project objectives when the risk under question happens. To develop clear scales, be it ordinal or cardinal; the organisation shall use agreed definitions. Otherwise, the quality of data would not help in repeating the process. In Table 6.1 an example of evaluating risk impacts by project objective is shown. It shows using either ordinal or cardinal approach. The organisation shall prepare scaled descriptors of relative impact

before the project starts. The organisation must work in determining which combinations of probability and impact result in a risk being categorized as high risk (red condition), moderate risk (yellow condition), and low risk (green condition) for ordinal or cardinal approach. A better guide for risk response actions is reached after risks are scored.

Table 6.1 Evaluation Impact of a Risk on Major Objectives

<b>Evaluating Impact of a Risk on Major Project Objectives (ordinal scale or cardinal, non-linear scale)</b>					
<b>Project Objective</b>	Very Low .05	Low .1	Moderate .2	High .4	Very High .8
<b>Cost</b>	Insignificant Cost Increase	<5% Cost Increase	5–10% Cost Increase 5–10% Quality	10–20% Cost Increase	>20% Cost Increase
<b>Schedule</b>	Insignificant Schedule Slippage	Schedule Slippage <5%	Overall Project Slippage	Overall Project Slippage 10–20%	Overall Project Schedule Slips >20%
<b>Scope</b>	Scope Decrease Barely Noticeable	Minor Areas of Scope Are Affected	Major Areas of Scope Are Affected	Scope Reduction Unacceptable to the Client	Project End Item Is Effectively Useless
<b>Quality</b>	Quality Degradation Barely Noticeable	Only Very Demanding Applications Are Affected	Reduction Requires Client Approval	Quality Reduction Unacceptable to the Client	Project End Item Is Effectively Unusable

Project assumption testing is used to test the identified assumptions against two criteria. One is assumption stability and the second is consequences on the project if the assumption is false. Other assumptions that might be true should be identified and their consequences on the project objectives should be tested in the qualitative risk-analysis process.

Accuracy and unbiased data are crucial for qualitative risk analysis. In project management, data precision is essential. Data precision ranking is a technique to evaluate the degree to which the data about risks is useful for risk management. This technique includes examining the following:

- To what extent risk is understood.
- Availability of Data about the risk.
- Data Quality
- Data reliability and integrity

As qualitative analysis assists in identifying project risks; quantitative risk analysis is equally important as the qualitative. The quantitative risk analysis process uses numerical approaches to identify the probability of each risk and its impact on project objectives, as well as the degree of overall project risk. This process uses techniques such as simulation and decision analysis too.

Determination of how the probability of achieving a specific project objective is reached.

The quantification of the risk exposure for the project, the determination of the size of cost and schedule contingency reserves may be required.

Identification of risks which require the most attention is by quantifying their relative contribution to project risk. Also by identification of realistic and achievable cost, schedule, or scope targets of the project.

Both Qualitative and Quantitative risk analysis are important. Generally quantitative approach follows qualitative risk analysis. Simply, risks require identification before any further step. Project teams can use qualitative and quantitative risk analysis processes separately or together.

As noted before, interviewing techniques could be used to quantify the probability and consequences of risks on project objectives. The first step in quantifying risks is to conduct risk interview with project stakeholders and subject-matter experts. The type of probability distribution will depend on the information needed.

Usually in project teams' environment, a project simulation is used as a model to translate the uncertainties which are specified at a detailed level into their potential impact on project objectives, which are described at the level of the total project. There is a technique called Arena used to conduct project simulations.

### 6.3 Risk Management Modelling

This section tackles risk management using simulation as mentioned in chapter three, there are many simulation programs (see section 3.4), but in this research the researcher used Arena as developed by Rockwell Automation. .

The following section illustrates how we can benefit from Arena software and how we can apply it to our case study in order to get the required result.

### 6.3.1 Scenario

The following section covers the scenario of how Arena basic edition has been applied to the case study and how the result can be generated by the software which will help the decision makers to formulate the right decision at the right time.

In order to apply Arena, there are two main factors namely cost and time; these two main factors could affect risk management. There are two other factors which are quality and resources. Although they are important they depend on previous factors (cost and time). In other words, if time or cost is affected, also quality and resources will be affected as well.

As it was mentioned in the opening above the research tackles the problem from the owner's perspective. Therefore, change of order usually comes from the owner, either he or she needs to complete the project earlier than what has been planned or they need to change the quality of the project/s. Under these circumstances the risk analysis needs to be carried out.

In this situation, Arena has been used to carry out such analysis taking into consideration two of the evaluating factors such as cost and time. Sometimes the owner wants the project/s to be complete before the time that has been agreed upon, because they have a tenant who needs the building as soon as possible; or sometimes they do not care about the time, but they do care about quality despite the time, and this case occurs when the tenant likes the location of the project but he needs some changes either in the quality of the material or in the internal design to match his needs.

Usually these changes in the project's specification happen in investment projects and it is rarely requested in other projects such as charity or public projects; where in these projects there are standards which should be applied in all of them, but on a few occasions the donator likes to have high quality services for his project. In this case the public projects may have changes in their specifications.

In other occasions some donators do not have a sufficient budget to finish the project and the department also has not assigned any extra budget for this particular project. Therefore, one of the ways to handle such situations is reducing the quality of finishing and this could be in the form of a lesser quality air conditioning specification or sometimes cheaper electricity appliances. This shows that both quality and resources are interactive.

At the same time this situation will also affect resources in a negative or a positive way in the project. The negative effects occur when there is a change in the specifications and in this case, it will affect the project, thus causing for instance a delay in the project schedule; or on the overall project time because the quality requirements have been changed. In this way there will be an additional cost and here the direct relationship between the cost and time becomes obvious. Sometimes the extra time causes an additional cost and at other times the reduction of time could cause an additional cost.

In order to build a simulation model, the scenario has been set up to represent the risk in cost, where the cost could represent both time and financial cost. Therefore, the cost will be the core criterion to build the simulation model. Since this research is dedicated

to helping decision makers i.e. as an owner, simplification is an important issue here. The research suggests a user friendly methodology, with few complicated calculations. Although it is possible to set up a complicated model, it will achieve the same result. Therefore, when using a simple model, it is important to utilize the model at the implementation stage.

In this research there is an attempt to identify the risks and find the best solution for it, before it happens, because the unknown risk cannot be managed when we are not prepared for it. Table 6.2 shows the possible item in the project that could be one of the changes in the project's functions. These items have been drawn from experiences in the last five years, with similar projects.

The items are divided into three categories as follows:

- 1- Large and small projects: supposed to give us the feel of the probability to have risk in both.
- 2- Large projects alone: to observe the size of the risk on the investment project
- 3- Small projects.

The aim is to examine the risk in each case on its own.

These data have been collected from forty five projects over five years, and finding that most of the changes in the specifications, in the case of a large project are in air conditioning, toilets, electricity, and lighting respectively. Usually these changes occur, when the senior management wants to reduce the budget or when the tenant wants to change some specifications of the building.

Some analysis is needed to tackle the risk and to ease dealing with the risk and make it manageable. One of these analyses is qualitative risk analysis where PMBOK (2004) describes it as the “process of assessing the impact and likelihood of identified risks. This process prioritises risks according to their potential effect on project objectives. Qualitative risk analysis is one way to determine the importance of addressing specific risks and guiding risk responses. The time-criticality of risk-related actions may magnify the importance of a risk. An evaluation of the quality of the available information also helps modify the assessment of the risk.”

Therefore, the first stage is to plan for risk management activities, which the risk management assessment guide from PMBOK (2004), will develop in the next section.

### 6.3.2 Planning for the risk

This planning stage used to be applied at the Awqaf (Endowments) Department in the form of meetings held with the purpose of studying risk and planning for it. This method was efficient, but it does not seem to follow the same sequence or the same way of thinking. In this study, we proposed the best practice in this field as well as its implementation.

There are several tasks that should take place as follows:

1. Project charter: this means is as simple as providing the project manager with the authority to apply organisational resources to project activities.

2. Organisation's risk management policies: a number of organisations might have previous experience, that allow them to have their own approaches to risk analysis and response that have to be tailored to a particular project.
3. Defined roles and responsibilities: the responsibilities and roles should be predefined for the decision maker in the project.
4. Stakeholder risk tolerances.
5. Templates for the organisation's risk management plan: some organisations have developed templates (or a pro-forma standard) for use by the project team.
6. Work Breakdown Structure (WBS)

Once these tasks have been clarified then a meeting should be held for all the team members to make sure the team are at the same stage, hence the risk management plan should be clear as this meeting will have all main stockholders such as project manager, the project team leaders, anyone in the organisation with responsibility to manage the risk planning and execution activities, and others, as needed.

### 6.3.3 Risk identification

There are four main resources to pinpoint risk identification, respectively:

- Risk management plan as it has been mention above;
- Project planning outputs, since risk identification requires an understanding of the project's mission, scope, and objectives of the owner, sponsor, or stakeholders. Outputs of other processes should be reviewed to identify possible risks across the entire project;

- Risk categories and risks that may affect the project for better or worse can be identified and categorised. Risk categories should be well defined and should reflect the common sources of risk for the industry or application area. Categories include the following technical, quality, or performance risks, poor allocation of time and resources, organisational risks and external risks;
- Historical information, that is information on preceding projects which may be available from the following sources: Project files or published information;

Table 6.2 Items could be one of the changes in specifications in the project

Items	Large and Small	Large	Small
1. Flooring	15	12	3
2. Doors	15	12	3
3. Toilet	9	8	1
4. Lighting	9	8	1
5. Landscape	7	2	5
6. Windows	5	4	1
7. External Painting	5	4	1
8. Internal Painting	5	4	1
9. Car Parking	5	1	4
10. Forestation	5	2	3
11. Air conditioning	4	3	1
12. Electricity	4	2	2
13. External Design	3	2	1
14. Internal Design	2	2	0
15. Add new item has not in contact	2	2	0
16. Ducting	1	1	0
17. Fittings, fixtures and installation	1	1	0
18. Extra Floor	1	1	0
19. Add lift	1	1	0
20. Change Function	1	1	0
21. Enclosure or boundary wall	1	1	0

There are many techniques and tools for risk identification which have been mentioned in the previous section, such as documentation reviews, information-gathering techniques, checklists, assumptions analysis and diagramming techniques.

### 6.3.4 Qualitative risk analysis

Once the risk identification has been done, qualitative risk analysis should take place, where qualitative risk analysis is the process of assessing the impact and likelihood of identified risks. This process prioritises risks according to their potential effect on project objectives.

### 6.3.5 Quantitative risk analysis

In this case PMBOK (2004) has been quoted as they mention “quantitative risk analysis process aims to analyse numerically the probability of each risk and its consequence on project objectives, as well as the extent of overall project risk. This process uses techniques such as Monte Carlo simulation (but in this research the Arena simulation was applied) and decision analysis to:

- Determine the probability of achieving a specific project objective.
- Quantify the risk exposure for the project and determine the size of cost and schedule contingency reserves that may be needed.
- Identify risks requiring the most attention, by quantifying their relative contribution to project risk.
- Identify realistic and achievable cost, schedule, or scope targets.

Quantitative risk analysis generally follows qualitative risk analysis. It requires risk identification. The qualitative and quantitative risk analysis processes can be used separately or together”

## 6.4 Input data preparation

Input analyser of ARENA (Kelton et al 2007), can be used to analyse the input data to find the best fit of the data under investigation. Therefore, instead of using a table of numerical input value, ARENA input analyser software was used to specify the probability distributions from which observations are generated and then use them to drive the simulation.

Table 6.2 shows an observation of how many times each item occurred in the past five years for large and small projects together, then the input analyser has been used to generate the best distribution which is shown in Figure 6.1.

As can be seen the best fit reveals that the large and small projects follow exponential distribution. Figure 6.2 shows large and small projects with beta distribution, which proposed the best fit according to the input analyser output shown in Figure 6.5 where the beta distribution scored the less square error amongst the ten different distributions considered in the analysis.

Figure 6.3 and Figure 6.4 show large and small projects distribution's summary for Exponential and Beta distributions respectively, where each distribution has the summary of the distribution and provides the reader with a picture of what is different between the chosen distributions; then Figure 6.5 shows all the distributions and their square error recorded in an ascending order.

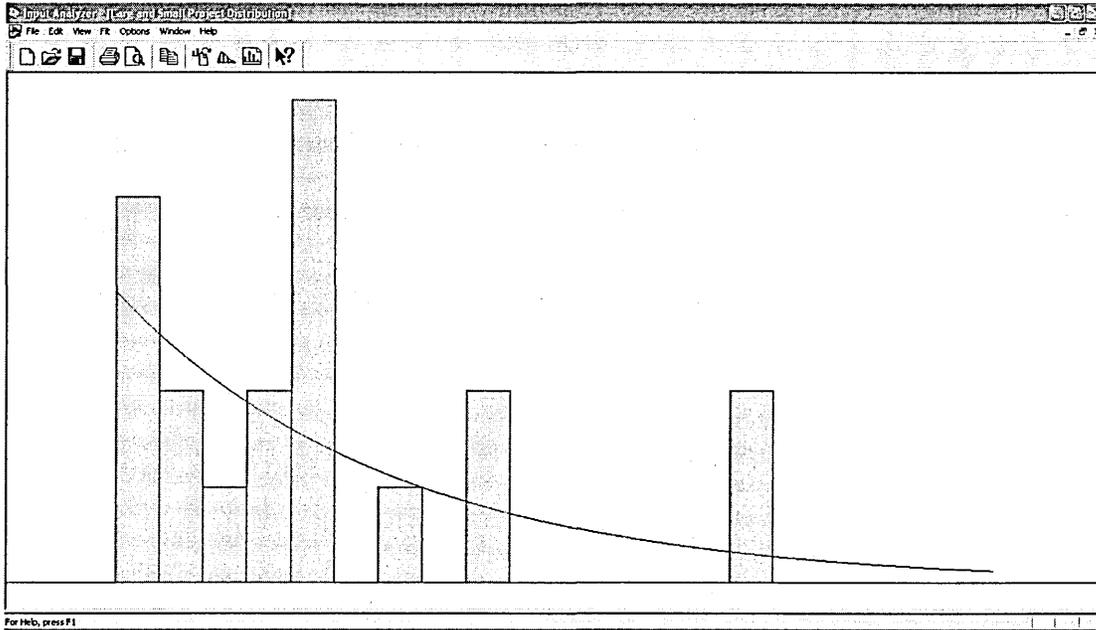


Figure 6.1. Large and Small Project Exponential Distribution

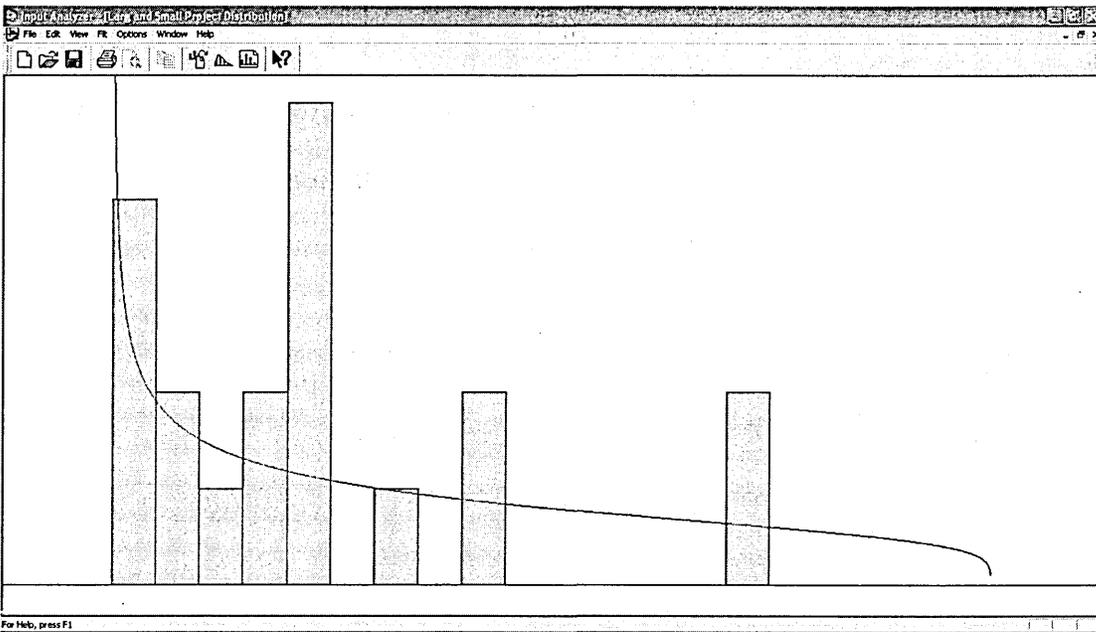


Figure 6.2. Large and Small Project Beta Distribution

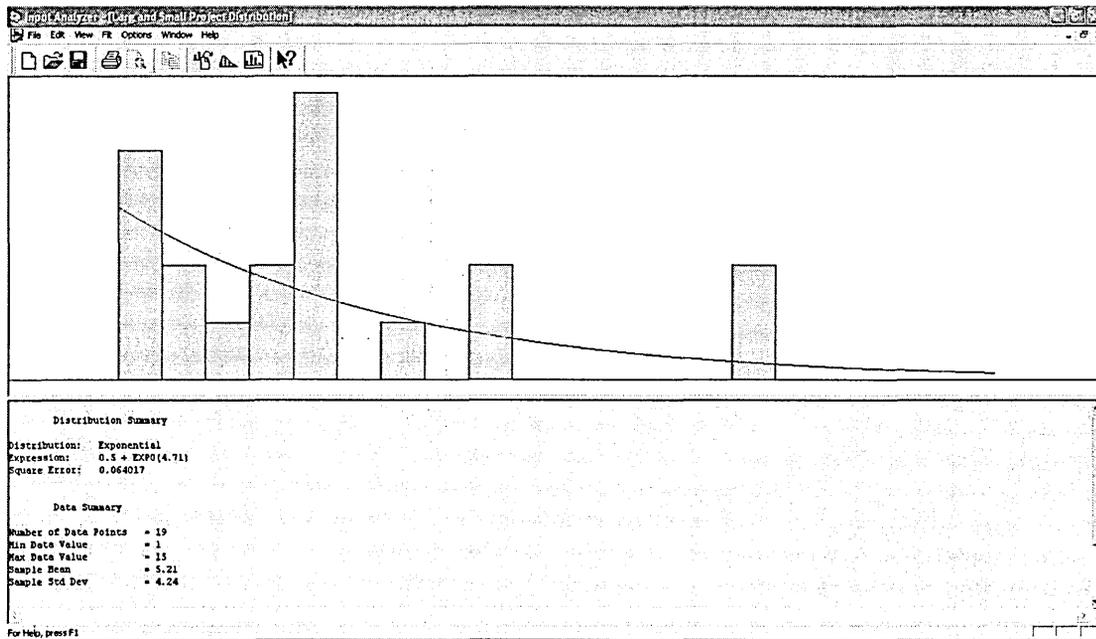


Figure 6.3. Large and Small Exponential Distribution Summary

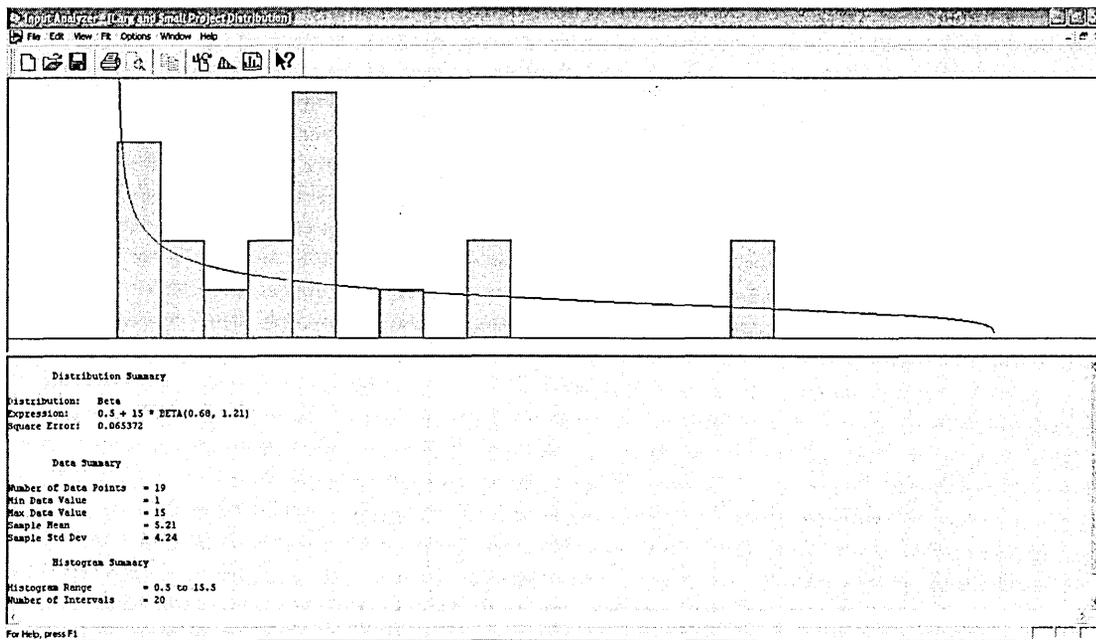


Figure 6.4. Large and Small Beta Distribution Summary

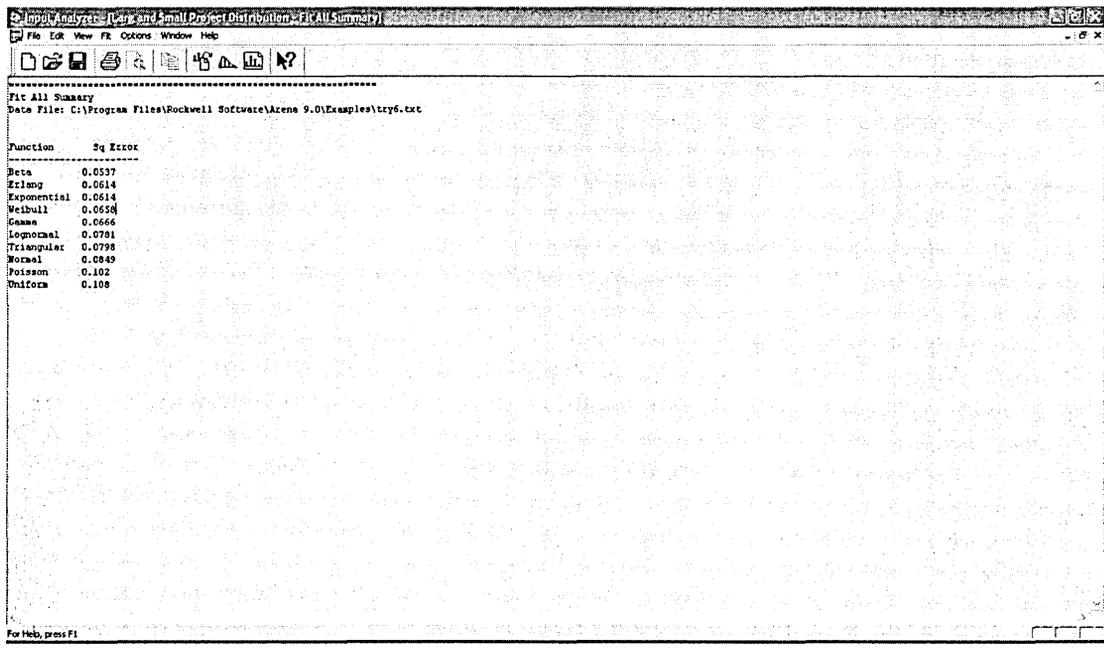


Figure 6.5. Square errors recorded for all distribution considered in the analysis

## 6.5 Logic of the proposed simulation model

Figure 6.6 displays the logic of the proposed simulation model through which the risk will be evaluated. As can be seen from this figure the process starts with the total project cost as important input data based on which the level of risk is identified. If changes in the specifications are received, this will lead to a particular level of risk. The level of risk can be identified through six different levels namely; no risk, very low risk, low risk, moderate risk, high risk, and very high risk. These categories are proposed based on a percentage of the total cost of the project as shown in Table 6.3.

Table 6.3 Value of the change of the project cost

Value of the change of the project cost	Level
If the change less than one percent (< 1%)	Very low risk
If the change between 1 % to 5%	Low risk
If the change between 5.1% to 10%	Moderate risk
If the change between 10.1% to 20%	High risk
If the change more than 20%	Very high risk

## 6.6 Development of the simulation Model and Experimental design

Figure 6.7 displays a snap shot of the developed simulation model for the Awqaf Tower Model which consists of three main stages. First stage: during which the input data is read; second stage: identification of different risk levels is carried out according to the

logical flow chart shown in figure 6.6. The last stage: in which the output from the simulation model is reported into the output files.

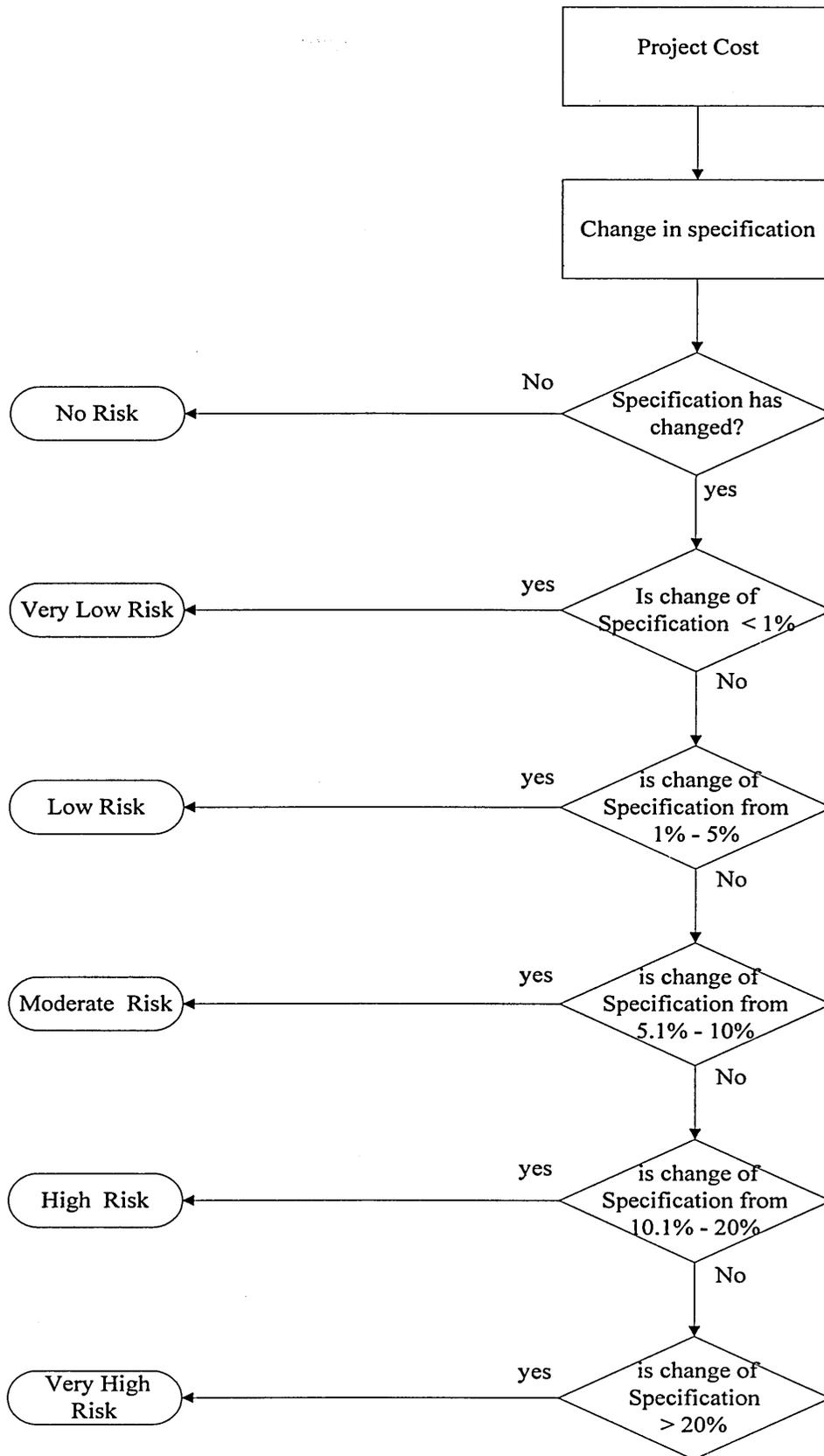


Figure 6.6. Conceptual flow chart for Risk Management

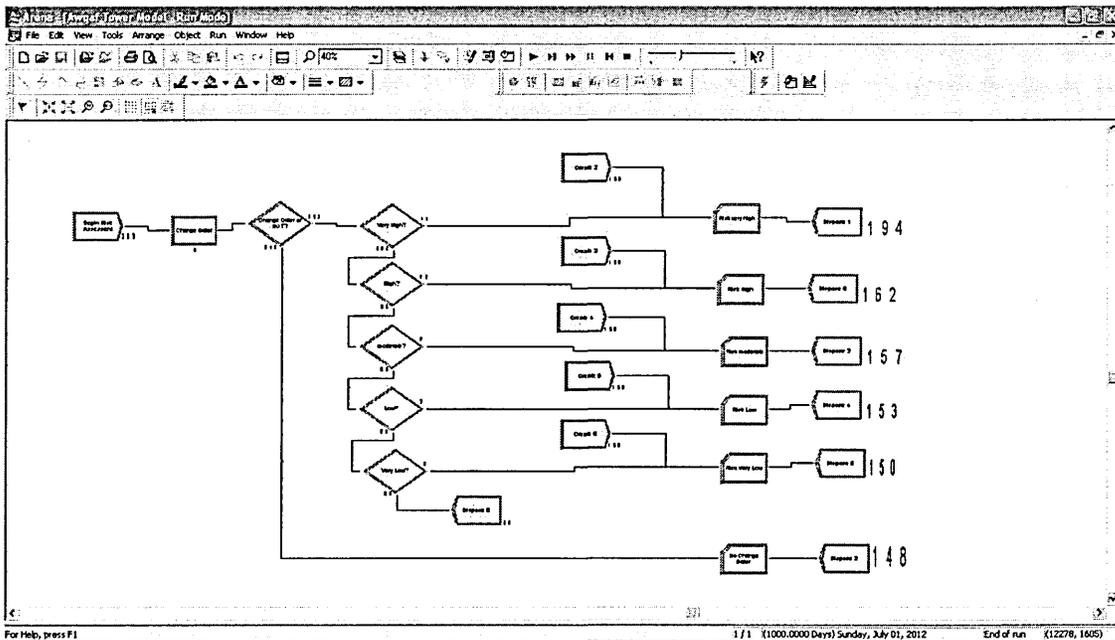


Figure 6.7 Awqaf (Endowment) Tower Model

The proposed simulation model was applied to three of Awqaf (Endowments) Department projects. These projects are: Awqaf tower as shown in figure 6.7, Kassem Darwish Fakhroo centre, shown in figure 6.8 and Rebuild Mosque No. 536 displayed in figure 6.9. These three major projects can be classified as investment project, mix of investment and charity project and charity or public project respectively.

The developed three simulation models will be used to examine the impact of the risk levels and how the department could handle these risks identified.

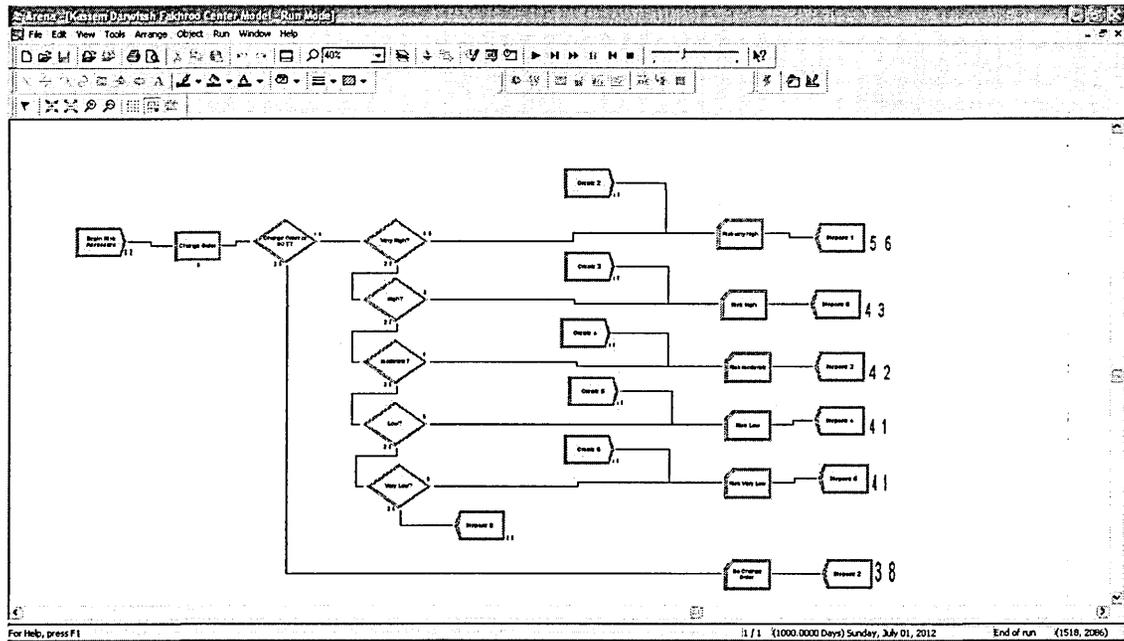


Figure 6.8. Kassem Darwish Fakhroo Centre Model

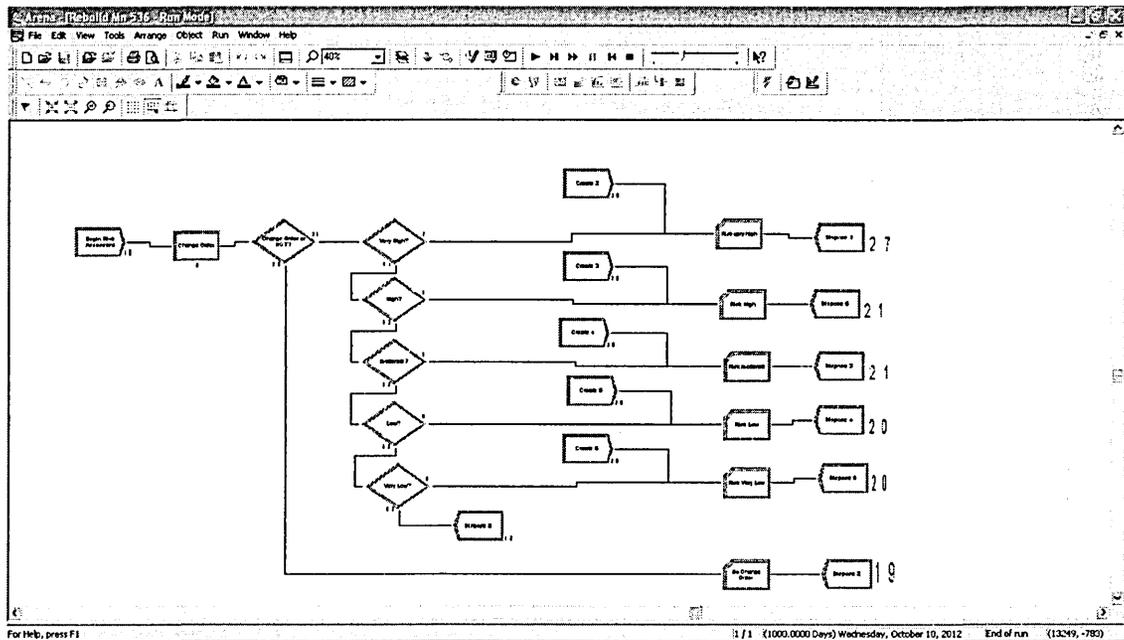


Figure 6.9. Rebuild Mosque No. 536 Model

## 6.6.1 Input variable

The data obtained from the input analyser presented in sections 6.5 regarding the best fit distribution is used as input data for all chosen projects to examine the risk management using simulation.

Table 6.4 shows the budget as the main input variable with its levels used in the simulation experiments. Where the risk levels were calculated as a percentage of the budget is shown in Table 6.3

Table 6.4 Input Variable

Variable		Levels		
		Investment Project (Awqaf tower)	Mix Project (Kassem Darwish Fakhroo centre)	Charity Project (Rebuild mosque number 536)
Budget	150,000,000 QR	41,000,000 QR	2,000,000 QR	
	100,000,000 QR	20,000,000 QR	1,000,000 QR	

The screenshot shows a 'Create' dialog box with the following fields and values:

- Name: Begin Risk Assessment
- Entity Type: Entity 1
- Time Between Arrivals:
  - Type: Random (Expo)
  - Value: 1
  - Units: Days
- Entities per Arrival: 1
- Max Arrivals: 300
- First Creation: 0.0

Figure 6.10 start entity for Awqaf (Endowment) Tower

The model starts with creating entities using CREATE Module (see figure 6.10), usually based on time but we consider it here as amount of financial means or the budget of the total project.

Then the entities get processed by PROCESS module shown in figure 6.11 using the best fit results to consider the expected change in the project specifications based on which, the risk level will be identified. As can be seen Beta distribution was used here as best fit distribution.

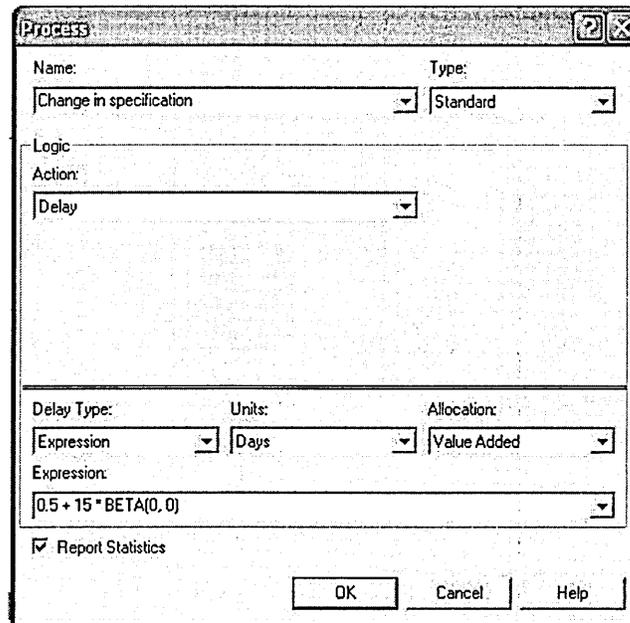


Figure 6.11 Process Entity

Due to the limitation of the education version of Arena software, "2-way by chance" option in DECIDE Module is used (see figure 6.12), the double of the cost has been used in Arena software in order to get the correct results. For example in Awqaf Tower

the total cost of the project is 150,000,000 Qatari Riyals we place 300 instead and this is applied on the other two projects.

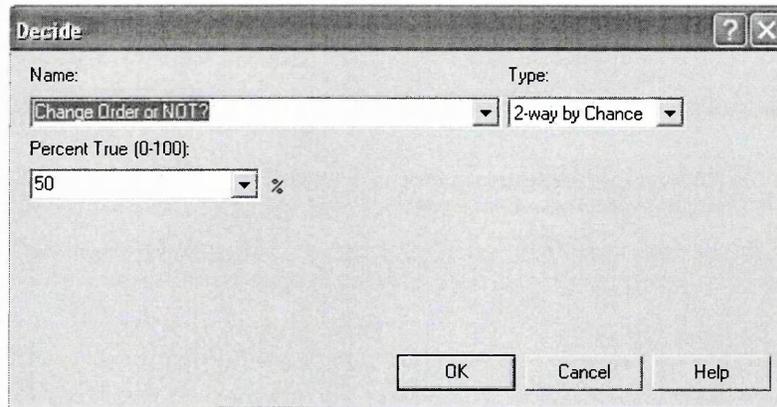


Figure 6.12 Decide Module for Awqaf (Endowment) Tower

## 6.7 Experimentations and result

This section illustrates the findings of the simulation experiments carried out to investigate the impact of the risk of introducing changes in the project specifications. In total, six simulation experiments were carried out based on the combinations shown in Table 6.4. A summary of the results are reported in tables 6.5, 6.6, 6.7, 6.8, 6.9 and 6.10.

Table 6.5 shows the obtained results for the largest possible budget for the Awqaf Department and table 6.6 displays the obtained results when the budget was set to its minimum level for the department.

Table 6.5 Awqaf Tower with total budget of 150 million QR

Value of the change in specification of the project cost	Level	Result
No change in specification	No Risk	148,000,000
If the change less than one percent (< 1%)	Very low risk	150,000,000
If the change between 1.1 % to 5%	Low risk	153,000,000
If the change between 5.1% to 10%	Moderate risk	157,000,000
If the change between 10.1% to 20%	High risk	162,000,000
If the change more than 20.1%	Very high risk	194,000,000

Table 6.6 Awqaf Tower with total budget of 100 million QR

Value of the change in specification of the project cost	Level	Result
No change in specification	No Risk	95,000,000
If the change less than one percent (< 1%)	Very low risk	100,000,000
If the change between 1.1 % to 5%	Low risk	102,000,000
If the change between 5.1% to 10%	Moderate risk	103,000,000
If the change between 10.1% to 20%	High risk	107,000,000
If the change more than 20.1%	Very high risk	134,000,000

Table 6.7 shows the result of a mixed project, where the project includes an investment part as well as charity part or public as the Kassem Darwish Fakhroo Centre has shops, training centre, multipurpose hall and Mosque. Table 6.8 shows results for the minimum budget that could be allocated for a project constructed under supervision of the department.

Table 6.7 Kassem Darwish Fakhroo Center with total budget of 41 million QR

Value of the change in specification of the project cost	Level	Result
No change in specification	No Risk	38,000,000
If the change less than one percent (< 1%)	Very low risk	41,000,000
If the change between 1.1 % to 5%	Low risk	41,000,000
If the change between 5.1% to 10%	Moderate risk	42,000,000
If the change between 10.1% to 20%	High risk	43,000,000
If the change more than 20.1%	Very high risk	56,000,000

Table 6.8 Kassem Darwish Fakhroo Center with total budget of 20 million QR

Value of the change in specification of the project cost	Level	Result
No change in specification	No Risk	19,000,000
If the change less than one percent (< 1%)	Very low risk	20,000,000
If the change between 1.1 % to 5%	Low risk	20,000,000
If the change between 5.1% to 10%	Moderate risk	21,000,000
If the change between 10.1% to 20%	High risk	21,000,000
If the change more than 20.1%	Very high risk	27,000,000

There are many small projects, mainly charities or public buildings such as Mosque, Imam Houses or Moazen House. Table 6.9 displays the results for the maximum budget allowed for these types of projects which has total budget of 2 million Qatari Riyals and Table 6.10 shows the results obtained for the minimum budget for the Mosque with the Imam house to give the engineers the range that they can work with in case of change in specifications is occurred.

Table 6.9 Rebuild Mosque no. 536 with total budget of 2 million QR

Value of the change in specification of the project cost	Level	Result
No change in specification	No Risk	1,900,000
If the change less than one percent (< 1%)	Very low risk	2,000,000
If the change between 1.1 % to 5%	Low risk	2,000,000
If the change between 5.1% to 10%	Moderate risk	2,100,000
If the change between 10.1% to 20%	High risk	2,100,000
If the change more than 20.1%	Very high risk	2,700,000

Table 6.10 Rebuild Mosque no. 536 with total budget of 1 million QR

Value of the change in specification of the project cost	Level	Result
No change in specification	No Risk	900,000
If the change less than one percent (< 1%)	Very low risk	1,000,000
If the change between 1.1 % to 5%	Low risk	1,000,000
If the change between 5.1% to 10%	Moderate risk	1,000,000
If the change between 10.1% to 20%	High risk	1,000,000
If the change more than 20.1%	Very high risk	14,000,000

## 6.8 Conclusion

In this chapter the third problem concerning this study was solved by developing the simulation model in which the level of the risk management was assessed at different levels such as no risk, very low risk, low risk, moderate risk, high risk and very high risk.

In order to develop the simulation model the definition of the risk management was given and the parameter involved in the risk management was mentioned.

Input data was driven from Arena Input analyser software to find the best fit distribution, instead of using a table of numerical input value, where the best fit was decided to be beta distribution. Then the simulation model was developed to consider the expected levels of risk which has been represented in a logical flow chart to facilitate understanding of the proposed simulation model.

Then experiments were carried out and results were collected for the different combinations considered in the experimental design stage for different environments of investment such as investment projects, mixed projects (investment/charity) and finally charity or public projects.

It is clear how it is important to have risk management involved in the tracking system to enhance the decision making process that could be made with a full image about what will happen in the future by taking into consideration all the necessary analysis and

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expected results which simulation helped in understanding a 'what if' scenario. The next chapter concludes the research work carried out in this thesis.

## 7 CHAPTER SEVEN

### Conclusion, contribution to knowledge, limitations and future work

#### 7.1 Conclusion

This thesis tried to find a solution for the problems involved in multi-project planning and control environment, which has been identified in this thesis as projects priority selection, resource allocation and handling the risk management including uncertainty involved in planning and controlling this complicated situation.

An integrated framework was developed to tackle the above three problems by using three different methodologies. First, Analytical Hierarchy Process (AHP) to tackle a priority selection problem; second, a mathematical programming to tackle resource allocation problem; and finally, simulation to tackle risk management problem.

It is acceptable to say that this research has come up with an integrated framework to plan and control multi projects in the owner perspective by using the above methodologies, where the following points have been identified to implement the proposed tracking system:

- Criteria for the projects: both the investment and public have been setup in order to have equivalent opportunities.
- Approach to prioritise these projects has been developed

- Mathematical programming has been used to optimize the resources that are used in supervision of a shortage of resources and sharing resources to enable efficiencies.
- Analysed the risk and identified the risk levels
- Developed a predicting system for the risk that might be incurred during the project period.
- Developed a tracking system help to save time and effort by using Analytical Hierarchy Process (AHP), mathematical programming and simulation.

This research provides the decision maker with appropriate tools for planning and preparing strategies for the future, in terms of the budget availability, resource limitation and risk management, where senior management would make the decision and plan for the near future. It is anticipated that the proposed framework will help them to make the right decision in the environment of uncertainty and complexity. For example, it is possible to predict how many engineers are needed in the future according to the number of projects that have been submitted, how much is the budget that is needed to accomplish the projects, what kind of utilities might be needed, what kind of engineer should be recruited and what is the whole set up of the department or section should be. Therefore, it gives the decision maker the whole picture which may lead to the right decision being made.

It has been noticed that the achieved results are superior where they hit the targets that have been made in the first place where the researcher came with new ideas to tackle the

three problems respectively: priority selection, resources allocation, and risk management in an integrated environment.

In addition, the developed tools that form the framework were characterised with simplicity that will encourage the end users to rely on and help them in the decision making process in this complicated environment.

The developed framework has been applied on a real case study in Qatar's Awqaf (Endowments) Department where they could utilise their resources by using the proposed framework.

The department's staff used to think that it was not possible to supervise more than thirty five projects a year. That is according to the available resources in the department. But by using the proposed framework, which is presented in this research, it was established that there is a possibility to manage more than forty projects at a time. This research also concluded the possibility of mixing the projects together. By using goal programming, there is a possibility to know how many large projects could be supervised.

In addition to that, this research provides the department with a solution of priority selection, where the Analytical Hierarchy Process helps decision makers to formulate the right decision, in terms of which project should be launched first. Then using goal programming to determine how many projects per year the department could supervise. This will help in developing good short/long term strategic plans.

The results show that the department could supervise forty four small projects with four large projects at a time. In this case, the analytical hierarchy process should be used again to generate the up-to-date priorities for the current projects in the list and rank them in descending orders.

## 7.2 Contribution to knowledge

The integrated framework developed in this thesis is a major contribution to knowledge due to the nature of handling the three problems that have a direct impact on the multi-project and the proposed tracking system combining them all together.

The Analytical Hierarchy Process is a very useful tool that can be applied in the Awqaf (Endowments) Department and have an equal opportunity for all the project applications received by the department and to decide on which project is to be launched first.

The mathematical model can be considered as systematic tool for the Awqaf (Endowments) Department to improve their supervision on the projects as well as help them to manage their budget in terms of human resources.

The efficiency of the Department Engineers will be increased as well as saving money and time with better planning where the image is clear for the decision maker in advance.

Simulation modelling was used to investigate and predict the risk before it occurs and the predicted cost if it has happened, which is a very important development in this study. In this case, the simulation model gives the decision maker a clearer picture if they want to change the specification of the project or not which is considered as very crucial for the investment type of projects where the cost is a major issue.

### 7.3 Limitations and Future research work

The proposed framework developed in this research has been applied at the Awqaf Department in the Ministry of Awqaf (Endowments) and Islamic Affairs for construction projects, but not to services projects. For more generalisation of the proposed framework, it could be applied in:

- other ministries such as the Ministry of Municipality Affairs or the Ministry of Health;
- in other regional and
- even at international organisations

Lingo/Lindo were applied to implement the optimisation of the man-hours and budget. However, other integrated software such as JAVA or VB could be used to provide a user-friendly interface to allow use by non-expert users.

# Appendix 1

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## Appendix 2

### 1. Lindo/Lingo formulae and their solution report

Try one:

$$\text{min} = \text{yy1} + \text{y2} + \text{yy2} + \text{yy3} ;$$

! subject to;

$$2 * \text{x1} + 1 * \text{x2} + (\text{y1} - \text{yy1}) = 10400;$$

$$12 * \text{x1} + 0.8 * \text{x2} + (\text{y2} - \text{yy2}) = 80;$$

$$4.95 * \text{x1} + 2.6 * \text{x2} + (\text{y3} - \text{yy3}) = 900;$$

$$\text{x1} \leq 4;$$

$$\text{x2} \geq 36;$$

Report solution

Global optimal solution found.

Objective value: 0.000000

Total solver iterations: 1

Variable	Value	Reduced Cost
YY1	0.000000	1.000000
Y2	0.000000	1.000000
YY2	0.000000	1.000000

YY3	0.000000	1.000000
X1	4.000000	0.000000
X2	40.00000	0.000000
Y1	10352.00	0.000000
Y3	776.2000	0.000000

Row	Slack or Surplus	Dual Price
1	0.000000	-1.000000
2	0.000000	0.000000
3	0.000000	0.000000
4	0.000000	0.000000
5	0.000000	0.000000
6	4.000000	0.000000

Try Two

In this try the number of small projects have been added up to a greater or equal forty four, in the report solution

$$\min = yy1 + y2 + yy2 + yy3 ;$$

! subject to;

$$2 * x1 + 1 * x2 + (y1 - yy1) = 10400;$$

$$12 * x1 + 0.8 * x2 + (y2 - yy2) = 80;$$

$$4.95 * x1 + 2.6 * x2 + (y3 - yy3) = 900;$$

$$x1 \leq 4;$$

$$x2 \geq 44;$$

### Solution report

Global optimal solution found.

Objective value: 0.000000

Total solver iterations: 1

Variable	Value	Reduced Cost
YY1	0.000000	1.000000
Y2	0.000000	1.000000
YY2	0.000000	1.000000
YY3	0.000000	1.000000
X1	3.733333	0.000000
X2	44.00000	0.000000
Y1	10348.53	0.000000
Y3	767.1200	0.000000

Row	Slack or Surplus	Dual Price
-----	------------------	------------

---

1	0.000000	-1.000000
2	0.000000	0.000000
3	0.000000	0.000000
4	0.000000	0.000000
5	0.2666667	0.000000
6	0.000000	0.000000

Try three

$$\text{min} = yy1 + y2 + yy2 + yy3 ;$$

! Subject to;

$$2 * x1 + 1 * x2 + (y1 - yy1) = 10400;$$

$$12 * x1 + 0.8 * x2 + (y2 - yy2) = 80;$$

$$4.95 * x1 + 2.6 * x2 + (y3 - yy3) = 900;$$

$$x1 \leq 4;$$

$$x2 \geq 40;$$

Solution Report

Global optimal solution found.

Objective value: 0.000000

Total solver iterations: 1

---

Variable	Value	Reduced Cost
YY1	0.000000	1.000000
Y2	0.000000	1.000000
YY2	0.000000	1.000000
YY3	0.000000	1.000000
X1	4.000000	0.000000
X2	40.00000	0.000000
Y1	10352.00	0.000000
Y3	776.2000	0.000000

Row	Slack or Surplus	Dual Price
1	0.000000	-1.000000
2	0.000000	0.000000
3	0.000000	0.000000
4	0.000000	0.000000
5	0.000000	0.000000
6	0.000000	0.000000

Other try

$$\min = yy1 + y2 + yy2 + yy3 ;$$

! subject to;

$$2 * x1 + 1 * x2 + (y1 - yy1) = 10400;$$

$$12 * x1 + 0.8 * x2 + (y2 - yy2) = 80;$$

$$4.95 * x1 + 2.6 * x2 + (y3 - yy3) = 900;$$

$$x1 \leq 5;$$

$$x2 \geq 0;$$

### Solution Report

Global optimal solution found.

Objective value: 0.000000

Total solver iterations: 1

Variable	Value	Reduced Cost
YY1	0.000000	1.000000
Y2	0.000000	1.000000
YY2	0.000000	1.000000
YY3	0.000000	1.000000
X1	5.000000	0.000000

X2	25.00000	0.000000
Y1	10365.00	0.000000
Y3	810.2500	0.000000

Row	Slack or Surplus	Dual Price
1	0.000000	-1.000000
2	0.000000	0.000000
3	0.000000	0.000000
4	0.000000	0.000000
5	0.000000	0.000000
6	25.00000	0.000000

Other try

$$\min = yy1 + y2 + yy2 + yy3 ;$$

! subject to;

$$2 * x1 + 1 * x2 + (y1 - yy1) = 10400;$$

$$12 * x1 + 0.8 * x2 + (y2 - yy2) = 80;$$

$$4.95 * x1 + 2.6 * x2 + (y3 - yy3) = 900;$$

---

$x_1 \leq 30$ ;

$x_2 \geq 0$ ;

### Solution report

Global optimal solution found.

Objective value: 0.000000

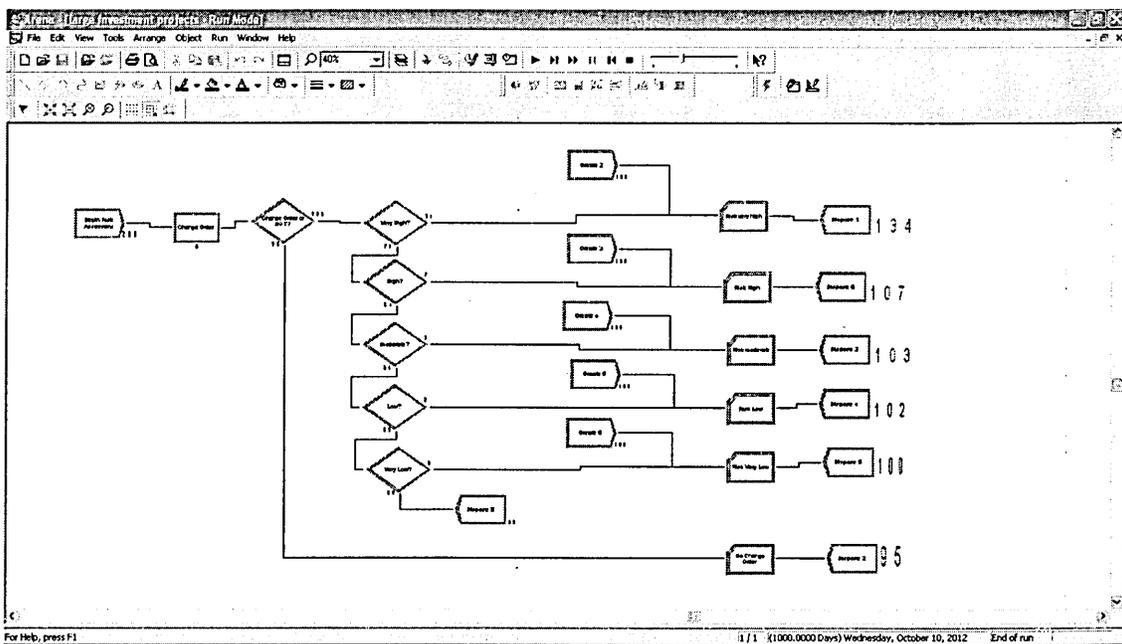
Total solver iterations: 1

Variable	Value	Reduced Cost
YY1	0.000000	1.000000
Y2	0.000000	1.000000
YY2	0.000000	1.000000
YY3	0.000000	1.000000
X1	6.666667	0.000000
X2	0.000000	0.000000
Y1	10386.67	0.000000
Y3	867.0000	0.000000

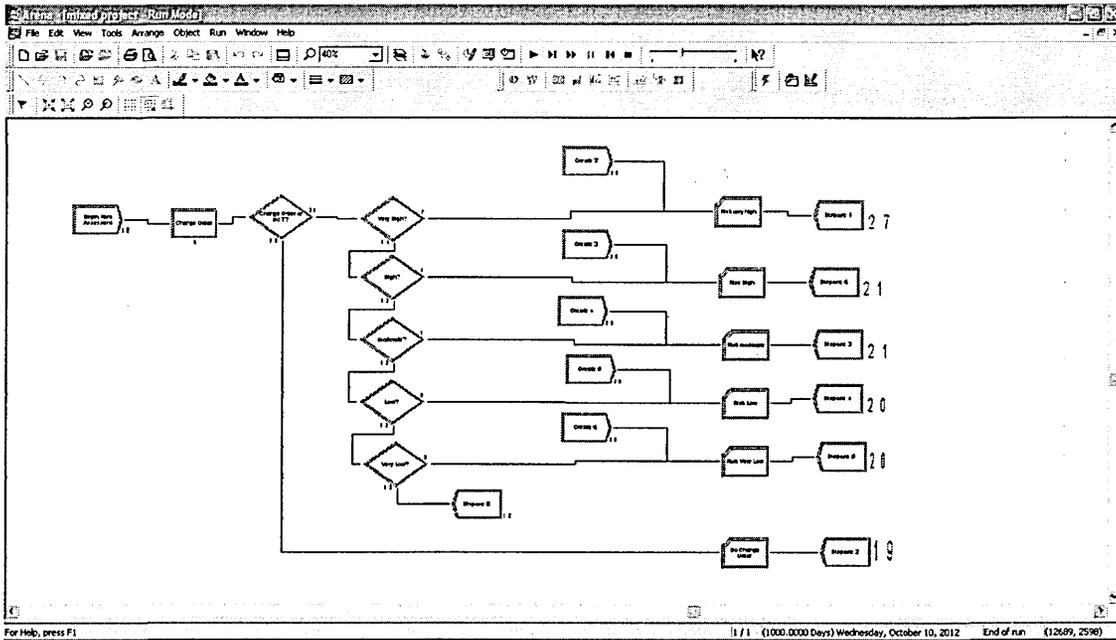
Row	Slack or Surplus	Dual Price
-----	------------------	------------

1	0.000000	-1.000000
2	0.000000	0.000000
3	0.000000	0.000000
4	0.000000	0.000000
5	23.333333	0.000000
6	0.000000	0.000000

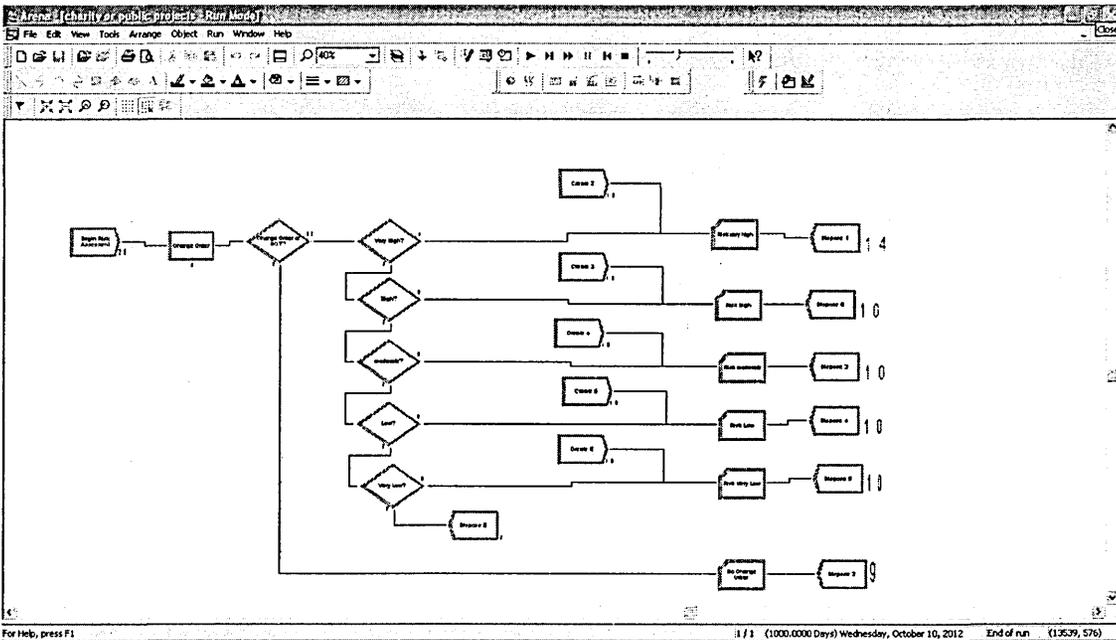
## 2. Arena simulation model experiment



Awqaf Tower with total budget of 100 million QR



Kasm Drwish Fakhro Center with total budget of 20 million QR



Rebuild Mosque no. 536 with total budget of 1 million QR

## Appendix 3

The results of the statistical tests are presented in table F, values as well as the significance levels are presented along with the results of whether or not a correlation was found between each variable and success.

Success factors				
Factors and determinants within main categories	Observed correlation with success (+/-no correlation)	F-value	Significance (F-test)	Significance level
<i>Single project level characteristics and activities</i>				
1. Use of project process/project model	+	4.916	.008	**
<i>2. Decision-making practices</i>				
2.1 Formal decision making related to conducting a feasibility study on a project idea	No correlation	2.471	.117	
2.2 Formal decision making related to project planning phase initiation	No correlation	.939	.333	
2.3 Formal decision making related to project execution phase initiation	+	9.636	.002	**
2.4 Formal decision making related to project's proceeding during project execution	+	12.874	.000	***
2.5 Formal decision making related to project close up	+	6.655	.010	*
3. Management style commonly understood and accepted	+	20.427	.000	***
<i>Multi-project level characteristics and activities</i>				
1. Number of projects	No correlation	1.845	.101	
2. Structural linkages between project	+	3.763	.003	*
3. Comparison and evaluation of project ideas	+	19.189	.000	***
<i>4. Methods in project and project idea evaluation</i>				
4.1 Use of discounting-based financial methods	+	4.764	.030	*
4.2 Use of scoring model	No correlation	2.081	.151	
4.3 Use of structured discussion	+	6.097	.014	*
4.4 Use of informal discussion	No correlation	.000	1.000	
4.5 Use of group work method(s)	+	7.543	.006	**
4.6 Use of opinion or scenario thinking	No correlation	0.685	.409	
<i>5. Reviewing set of projects</i>				
5.1 The set of projects is reviewed as a whole	+	17.583	.000	***
5.2 The review of the set of projects is based on predefined methods and rules	No correlation	.057	.812	
5.4 The management approach is flexible with different types of projects	+	7.646	.000	***
5.5 The set of projects is reviewed on a regular basis	+	4.275	.040	*
<i>The linkage between projects and strategy process</i>				
<i>1. Ongoing projects and strategy process</i>				
1.1 The objectives of ongoing projects are revised in linkage with strategy formulation	+	4.894	.028	*
1.2 The objectives of ongoing projects are revised in linkage with strategy follow-up	No correlation	1.363	.244	
<i>2. Multiple projects and strategy process</i>				
2.1 The set of projects is reviewed in linkage with strategy formulation	No correlation	1.364	.244	
2.2 The set of projects is reviewed in linkage with strategy follow-up	+	7.868	.016	**
<i>The availability and quality of project information</i>				
1. Information sufficiency and validity	+	23.132	.000	***
2. Information reliability	+	8.092	.000	***
3. Information topicality	+	10.888	.000	***

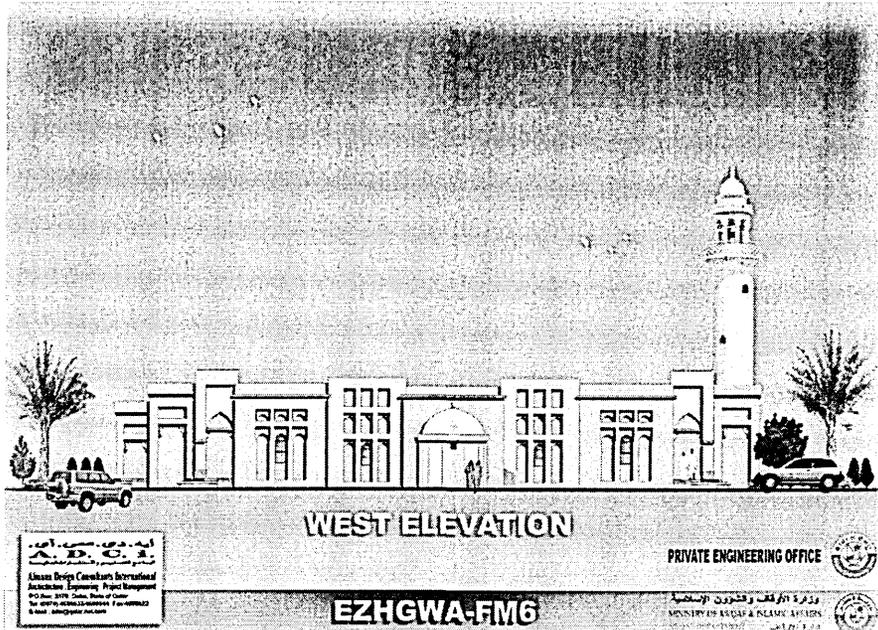
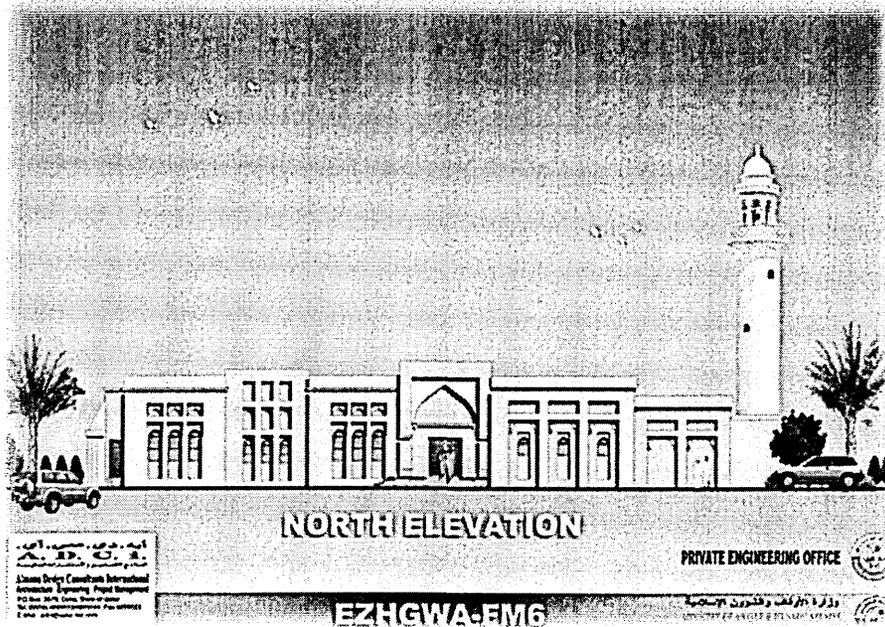
\*Indicates that the result is significant at 0.05 probability level. \*\*Indicates that the result is significant at 0.01 probability level. \*\*\*Indicates that the result is significant at 0.001 probability level.

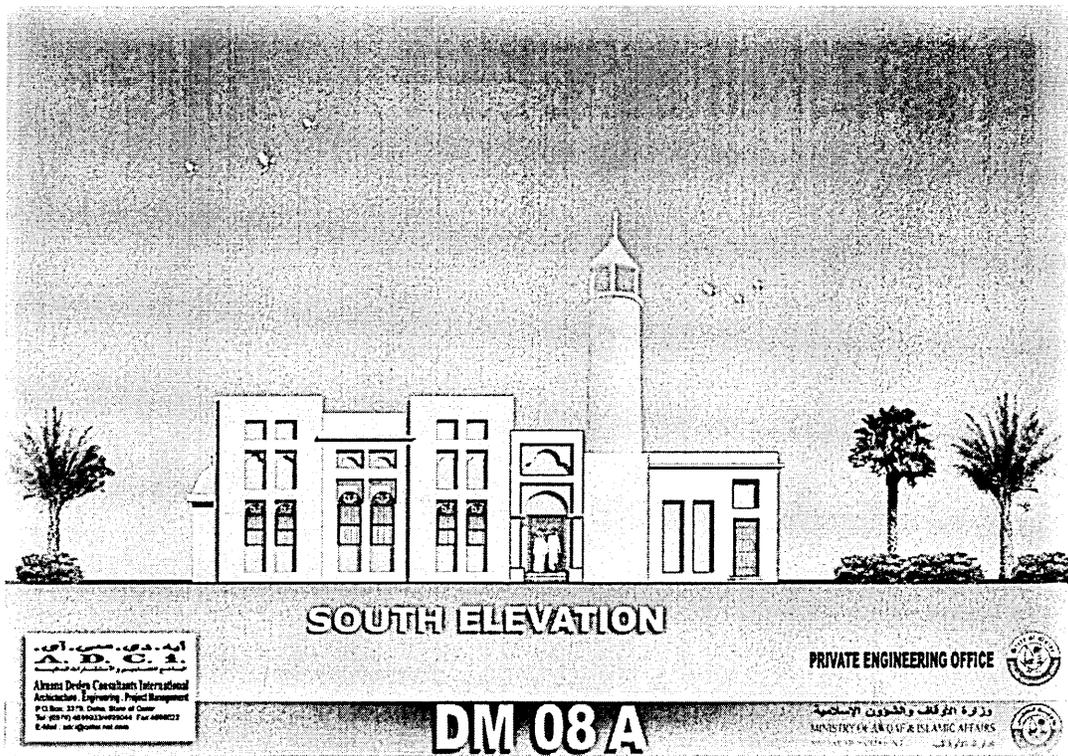
## Appendix 4

### Sample of a number of Projects:

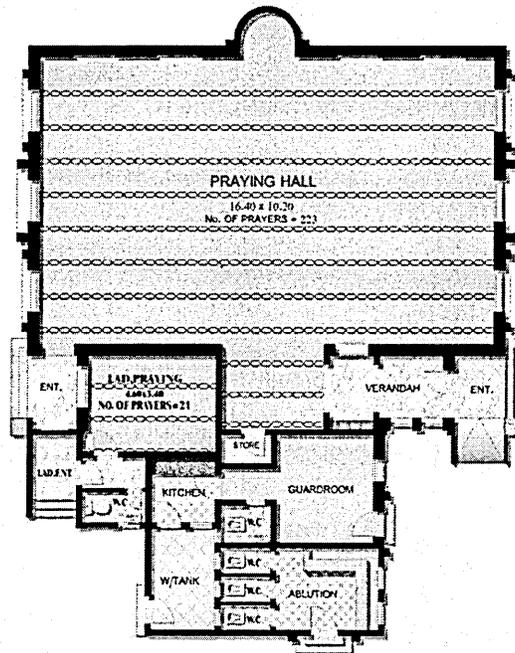
The following are samples of architectural plans of some projects which were supervised by the Awqaf (endowments) department.

### Sample of the Friday Sermon Mosque FM6





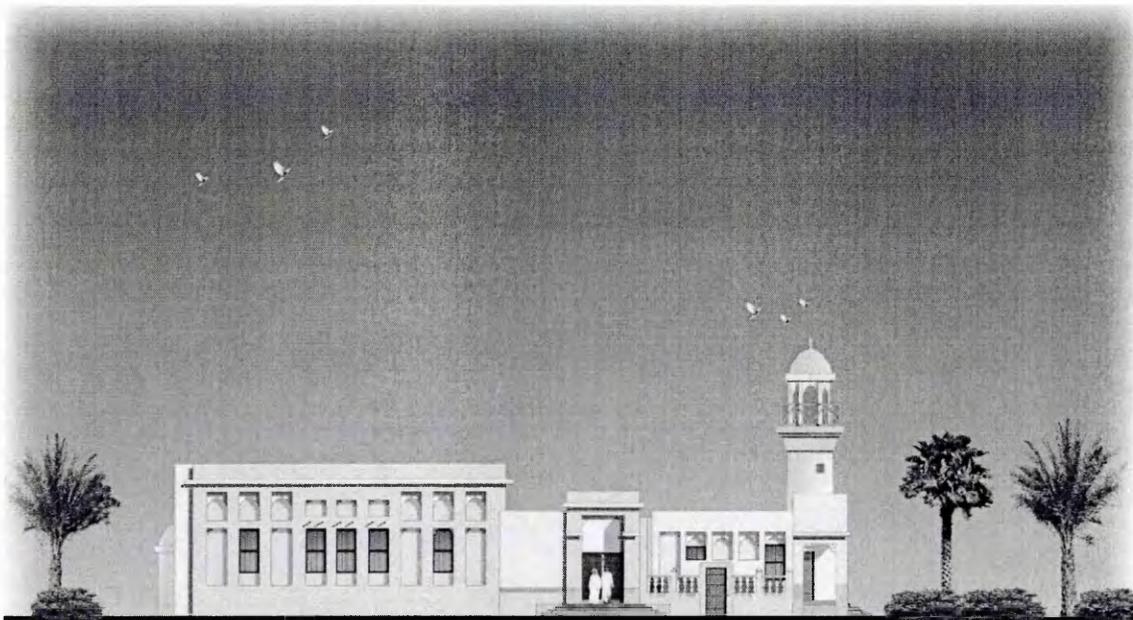
This model is one of the most popular ones with more capacity



إجمالي المصلين 244 مصلي  
 الرجال 223 مصلي  
 النساء 21 مصلي  
 مساحة البناء 330 m<sup>2</sup>  
 التكلفة التقديرية 1,700,000



The prayer hall for model mosque number DM08



## SOUTH ELEVATION

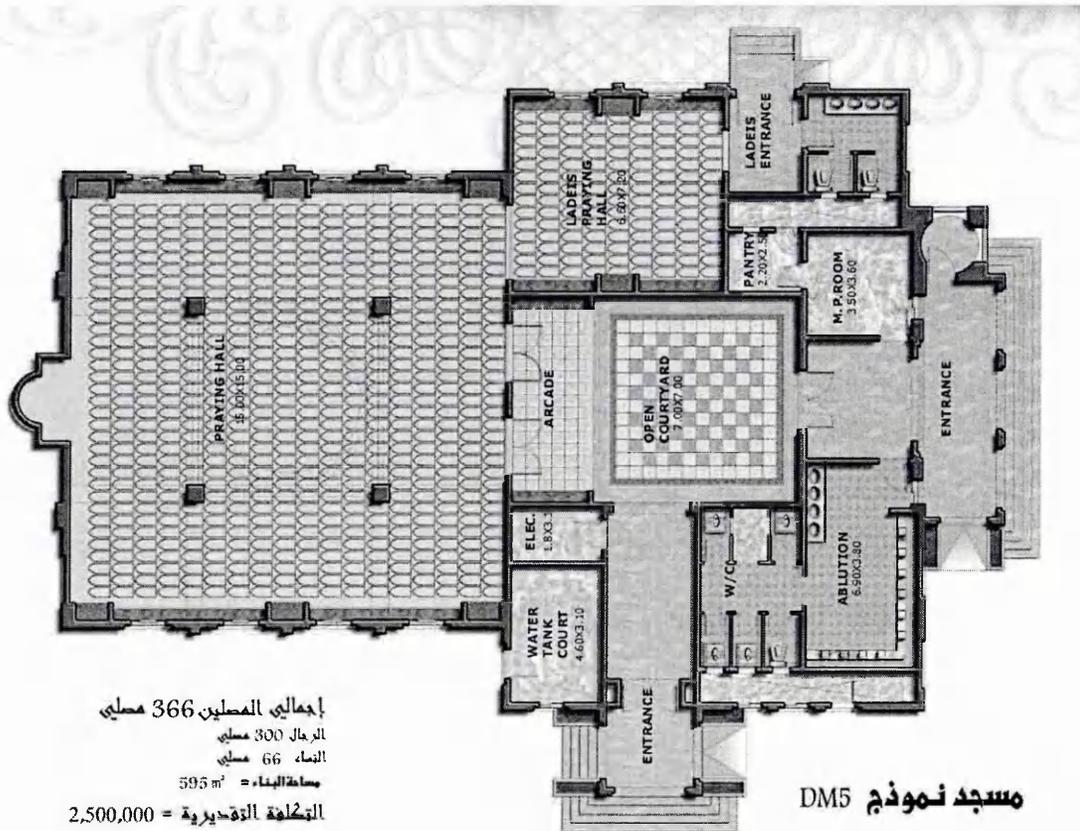
أ.د. د. م. م. م. م.  
**A. D. C. I.**  
 أ. د. د. م. م. م. م.  
 Almana Design Consultants International  
 Architecture - Engineering - Project Management  
 P.O. Box 33791, Dubai, State of Qatar  
 Tel: +974 (0)43993333 Fax: +974 4399322  
 E-Mail: adc@qatar.net.com

PRIVATE ENGINEERING OFFICE

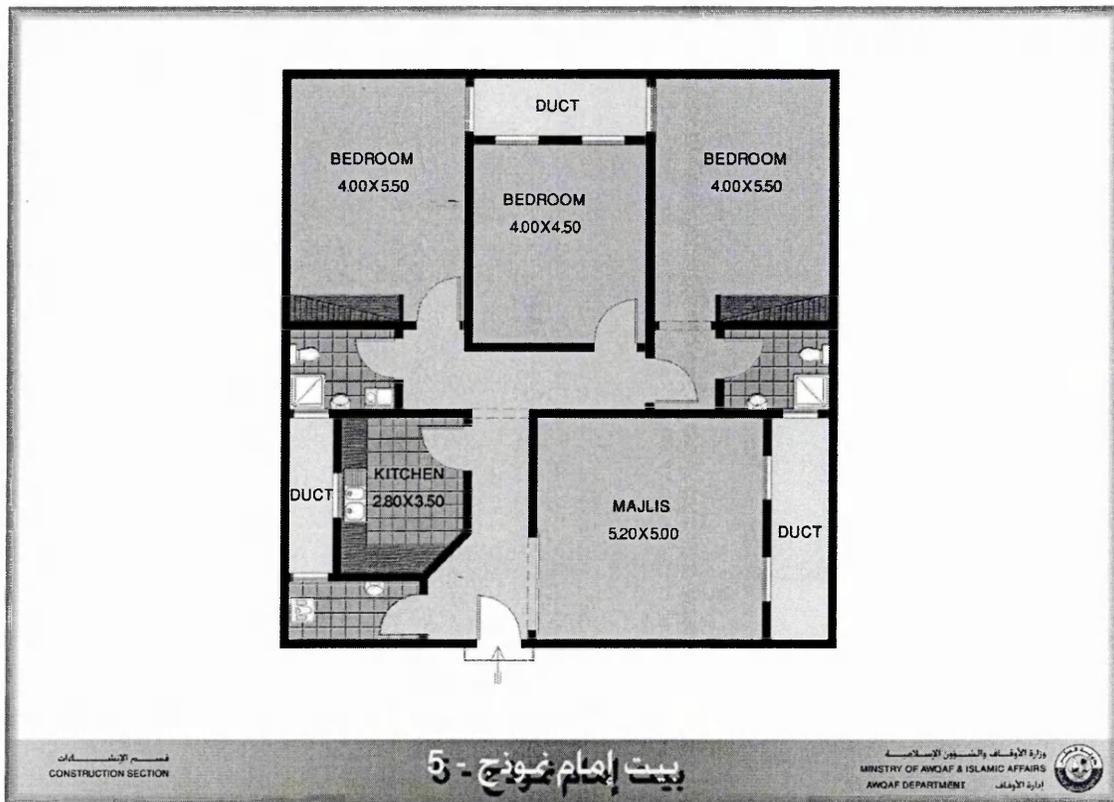
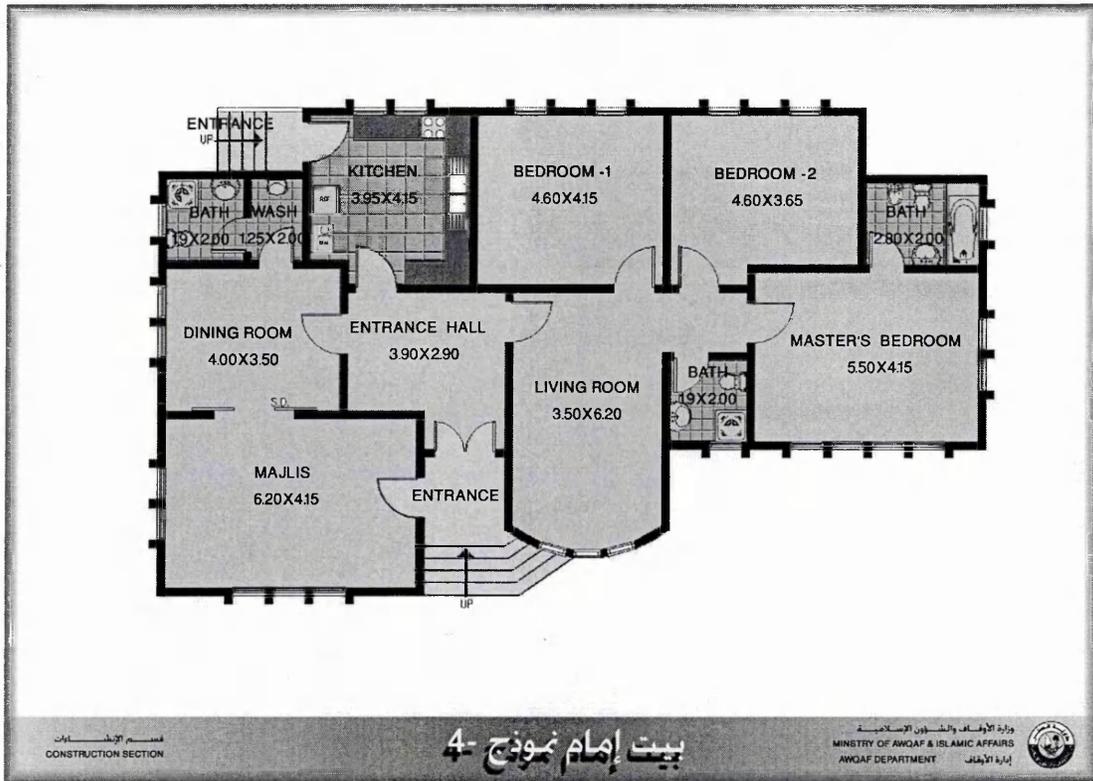


# DM 05

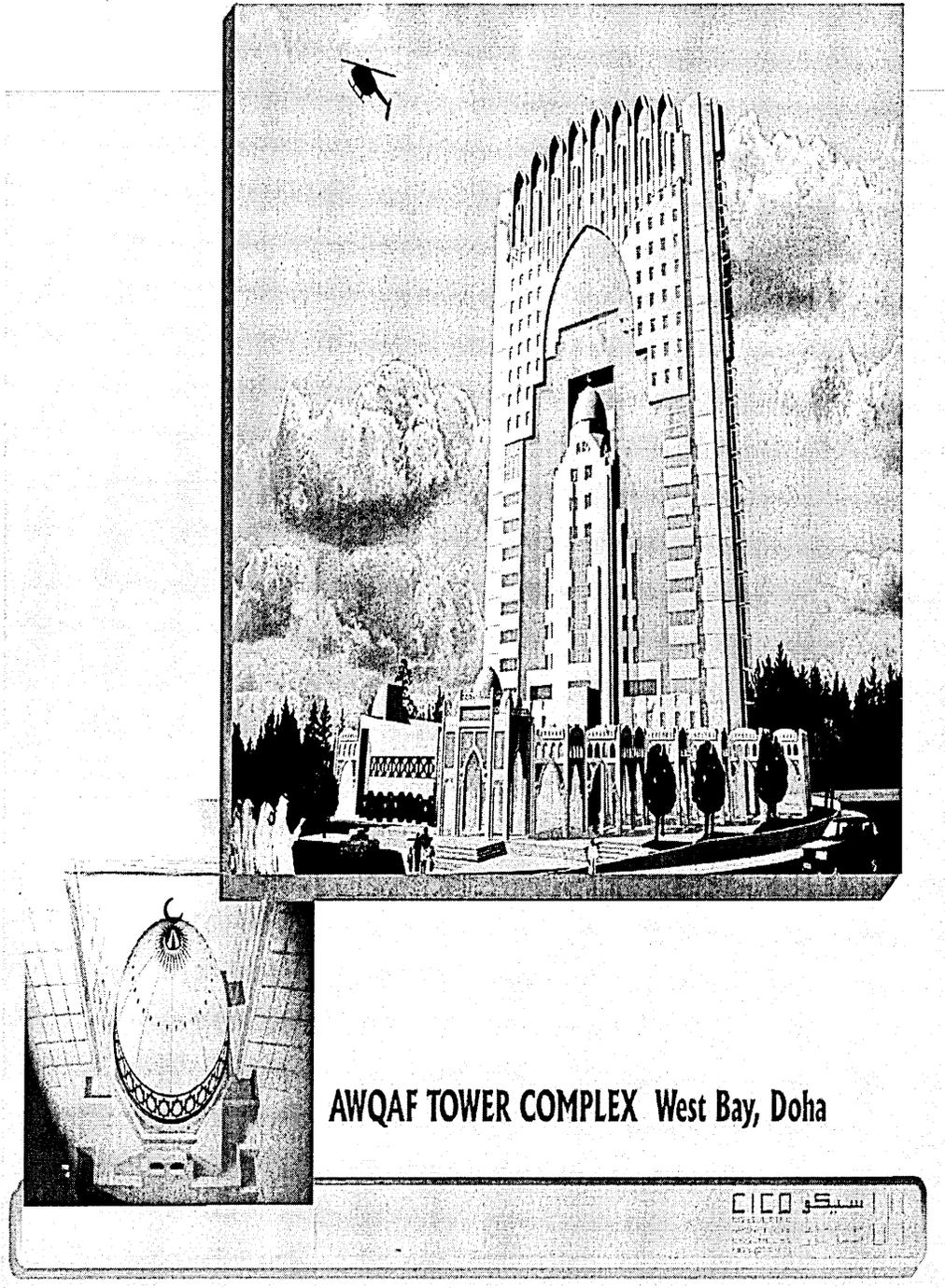
وزارة الأوقاف والشؤون الإسلامية  
 MINISTRY OF AWOAF & ISLAMIC AFFAIRS  
 قطر - دoha

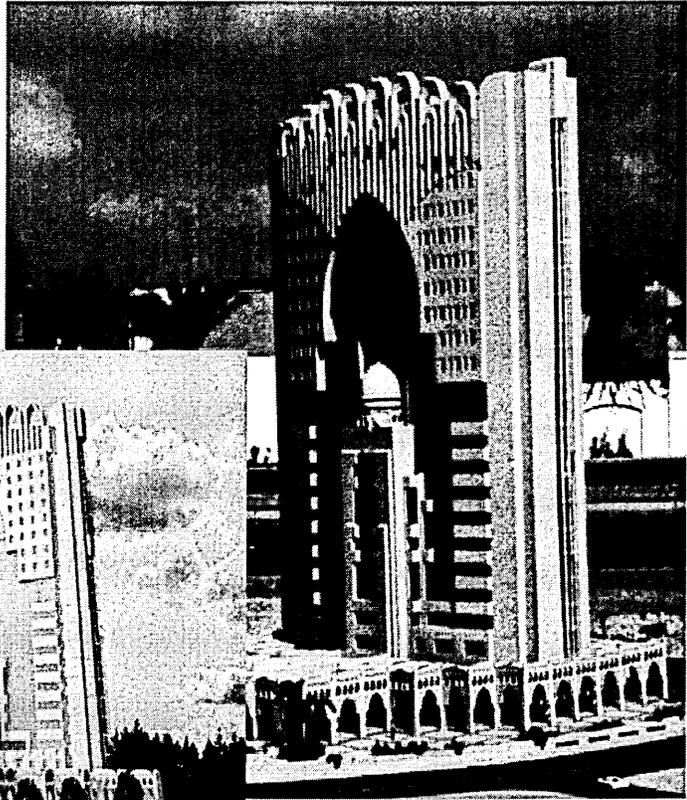


This is a sample of Imam's house

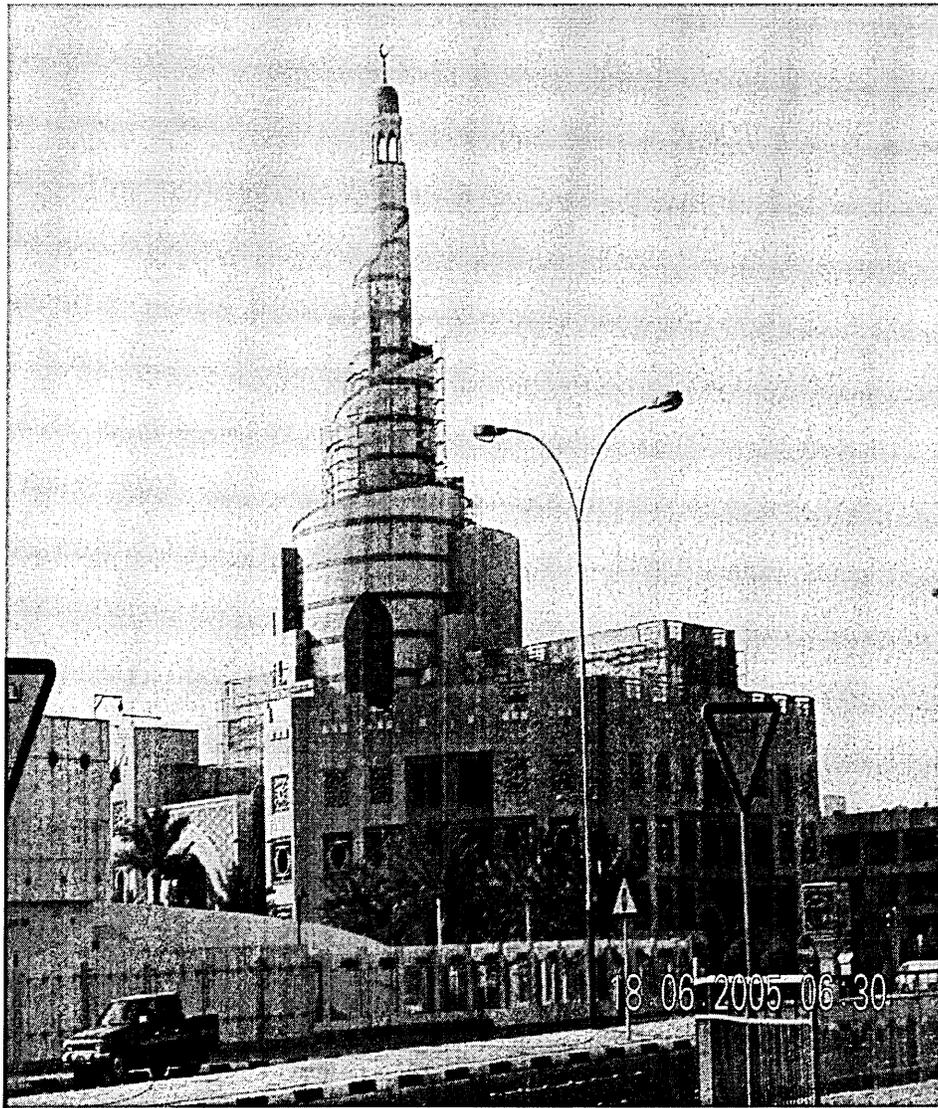


This is one of the famous investments in Awqaf (Endowments) Department and the largest so far, and at the same time the first one in this dimension





**EXTERNAL VIEWS**



Kasm Darwesh Center

## Appendix 5

The following are samples snapshot for web site of some commercially available



Promodel Corp



Rockwell Software

http://www.thefactory.com/na/en/

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a simulation development company

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**Community Sites**

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Official website related articles for ARCA SIM RACING '06. Get current info, tips and more here.  
www.motiondesign.com  
Motion Design Group is the largest and most extensive news media site covering sim racing in the United States. Check them out now!  
www.simfactory.com  
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**Sim Factory**

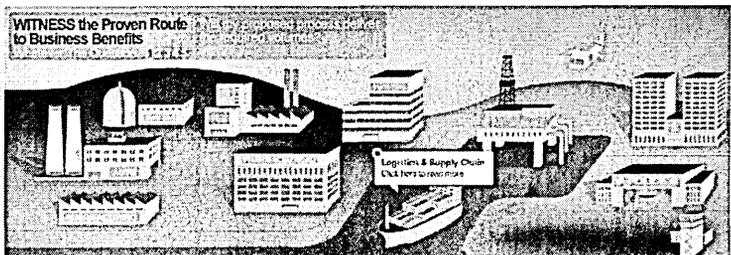
http://www.lanner.com/en/witness.cfm

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