PROJECT DELIVERY SYSTEM DECISION FRAMEWORK USING THE WEIGHTING FACTORS AND ANALYTIC HIERARCHY PROCESS METHODS

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M.S., University of Pittsburgh, 2002

Submitted to the Graduate Faculty of

The School of Engineering in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2003

UNIVERSITY OF PITTSBURGH

SCHOOL OF ENGINEERING

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There is a range of contract types and project delivery systems (PDS) that owners can use in executing facilities. Examples include the traditional Design-Bid-Build (DBB) process, Design-Build (DB) and Construction Management-at-Risk (CM-R). A number of owners in Saudi Arabia, particularly governments, prefer some form of competitive bidding (typically the DBB method), and most of the time they insist on it. However, the use of non-traditional delivery systems is increasing, and the system variations are becoming numerous. The selection of project delivery system influences the entire life-cycle of a construction project, from concept through construction into operation and decommissioning. Owners, engineers, contractors, material suppliers and laborers are all affected by the decisions that owners make concerning project delivery systems. Owners need to assess what type of construction services procurement program is best suited to their needs. Selecting a PDS means choosing the best delivery system to carry out a particular project, which is not always an easy and clear decision. The success or failure of a project can depend on the project delivery method, and whether the method is suited to the project.

There are many factors and parameters or key considerations, such as cost (budget), time (schedule), quality (level of expertise), risk assessment (responsibility) and safety which determine whether a particular style of PDS is suited to a project. A model is a representation of a real or planned system and can be used as an aid in choosing a PDS. The purpose of this

research is to try to develop a project delivery system decision framework (PDSDF) by identifying the factors and parameters that have to be considered in such a model. A survey was conducted to determine the values of factors and key parameters from completed projects. The research attempts to identify patterns of project factors, owner objectives, and project parameters that could best be met by one or another PDS. This model is intended to be very easy for owners to use, while at the same time providing meaningful results that can be used in making a selection of a suitable project delivery system.

A weighting factors approach and the analytic hierarchy process (AHP) was used to construct the decision framework. In this process the relative advantages of the three project delivery systems are compared according to each criterion. The relative importance of the criterion is determined on the basis of the owner's needs and project characteristics. The results of comparing the three delivery systems according to each criterion and of determining the order of importance among the criteria were integrated into a model to help the owner reach a decision about which project delivery system he should adopt.

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ACKNOWLEDGMENTS

First, all praise and thanks are due to Allah, the Merciful, the Compassionate, who provided me with health, strength, and success. He helped and guided me to overcome the difficulties and obstacles during the whole period of my study.

Second, from the depths of my heart, I would like to express my sincere gratitude and appreciation to Professor Robert J. Ries, my academic advisor and the chair of my dissertation committee, for his generous academic advice, discussions, suggestions, close attention, continuous support and encouragement throughout the development and writing of this dissertation.

Also, I owe a lot to the professional gentlemen, who agreed to serve on my committee, Dr. Rafael Quimpo, Dr. Jeen-Shang Lin, Dr. Michael Bridges, and Dr. William Matlack. Without their assistance, encouragement, and commitment, this dissertation could never have become a reality.

Similarly, my sincere gratitude and appreciation is to the General Directorate of Military works, Saudi Arabia, for providing me with a scholarship to support my graduate study at the University of Pittsburgh.

I express my special high appreciation and gratitude to my dear parents, brothers, Mohammad, Ali, and Saleh, and to my sisters. Their motivation, encouragement, love, and also prayers were as the foundation for me to further study in the United Stated of America, a part of the world far away from my homeland, Saudi Arabia. I am very proud of them.

In the same time, I cannot find enough words to thank my wife and my lovely children, Rema and Abdullah, how were very patients while I was away from them working in this study. They gave me inspiration and motivation for struggling and becoming a winner, even, in hard situation.

Also, I would like to recognize these people: Major General/Eng. Ali M. Alassaf, for his support, assistance, and constant encouragement; Eng. Abdullah Alrasheed and Mr. Mohammed Alrasheed for their assistance and moral support; Dr. Elaine Rubinstein, for sharing her statistical expertise in such a gentle and understanding manner; Eng. Ibrahim Alshuaibi, Major/Eng. Fakhri Bukhari, Eng.Abdulaziz Albrikan, Eng. Samer A. Samad, and Eng. Shamim Khan, for their help during the data collection stage of this study; and to those who have helped me to accomplish this study.

Finally, I wish to dedicate this work to:

- My parents, for their continuous sacrifices, loving guidance, and for instilling in me the importance of education.

  "*And lower unto them the wing of submission and humility through mercy, and say: My Lord! Bestow on them Your Mercy as they did bring me up when I was young*" Holy Qur'an, Surah 17- Al-Isra: 24.

- The memory of my brother, Suleiman, may Allah grant him mercy. His dream was to see me receiving my Ph.D. His congratulations would have been the highest honor in addition to my parents that I could dream of.

- My beloved wife, for her tolerance, loving support, thoughtful consideration, patience, and many sacrifices during my graduate studies. Without her devotion, this study would not have been completed.

1.0 INTRODUCTION AND STATEMENT OF THE PROBLEM

A project delivery system (PDS) is defined here as the process by which projects are designed and constructed. Others have defined PDS as “a general term describing the comprehensive design/construction process, including all the procedures, actions, sequences of events, contractual relations, obligations, interrelations, and various forms of agreement--all aimed at successful completion of design and construction of a building and other structures.” [(1)] Other definitions include: the system that controls the process of the project by organizing and coordinating between components; and “the organizational, contractual, and compensational method used in acquiring the services of a designer, a construction manager, a general contractor, subcontractors, and vendors, in building and delivering the required facilities or services.”[(2)] Everyone involved in today's construction industry needs to have a thorough understanding of PDSs. By understanding the various delivery systems, practical information about when and how to best use any of them should be gained.

There is a range of contract types and project delivery systems (PDS) that owners can use in executing facilities. Examples include the traditional Design-Bid-Build (DBB) process, Design-Build (DB) and Construction Management-at-Risk (CM-R). A number of owners in Saudi Arabia, particularly governments, prefer some form of competitive bidding (typically the DBB method), and most of the time they insist on it. Several owners in Saudi Arabia feel they have had bad experiences with cost overruns on their projects when all services were negotiated. The DBB process acts as an incentive to lower contractor or consultant costs and fees, or at least it prevents their inflation. In recent years, some owners in Saudi Arabia have added experienced professional engineers to their staffs to monitor their construction projects. With such staff support they can take a much more active role on some projects, and they have decided to use other project delivery methods (DB and CM-R).

The use of non-traditional delivery systems is increasing and the system variations are becoming numerous. The selection of project delivery system influences the entire life-cycle of construction projects, from concept through construction into operation and decommissioning. Owners, engineers, contractors, material suppliers and laborers are all affected by the decisions that owners make concerning project delivery systems. Owners need to assess what type of construction services procurement program is best suited to their needs. Selecting a PDS means choosing the best delivery system to carry out a particular project, and that is not always an easy and clear decision. The success or failure of a project can depend on the project delivery method and whether the method is suited to the project. "The process of selecting the appropriate project delivery system that responds to the project's nature and the owner's requirements is a very important step that may significantly affect the success or failure of the project".(3)

There are many factors and parameters or key considerations, such as cost (budget), time (schedule), quality (level of expertise), risk assessment (responsibility) and safety which determine whether a particular style of PDS is suited to a project. A model is a representation of a real or planned system and can be used as an aid in choosing a PDS. It is usually simpler and easier to understand than the thing it represents. The purpose of this research is to try to develop a project delivery system decision framework (PDSDF) by identifying the factors and parameters that have to be considered in such a model. A survey will be conducted to determine the values of factors and key parameters from completed projects. The research will attempt to identify patterns of project factors, owner objectives, and project parameters that could best be met by one or another PDS. This model is intended to be very easy for owners to use, while at the same time providing meaningful results that can be used in making a selection of a suitable project delivery system.

1.1 Construction Industry in Saudi Arabia (Background and Procedures)

The construction industry in Saudi Arabia is one of the major areas of government investment. It has faced the same challenge as many other growing industries – limited resources. Also, as of late, the competition has increased dramatically and there is a high risk of business failure. For these reasons, engineers and practitioners in this field need efficient tools and planning strategies to overcome these difficulties by optimizing the purpose, quality, and cost of new construction projects. Within the last 30 years, planning has become an important part of the government's commitment to developing this industry. What follows will be a clarification and description of the planning process and some procedures that are followed by the construction industry in Saudi Arabia.

1.1.1 Review National Development Plans

Planning during Prosperity: Saudi Arabia is a developing country where the construction industry represents one of the largest economic sectors. During the decade of 1970-1980, Saudi Arabia experienced a very high level of construction activity, attracting construction professionals from all over the world. The first national development plan (1970-1975), was established to set up the systematic construction of modern infrastructure that would lay the foundation for the country's long-term strategic goals.

In the second plan (1975-1980) there was a sharp increase in government revenues and expenditures devoted to the construction of infrastructure. The budget was increased dramatically in response to available resources and in recognition of the need to rapidly overcome the then present barriers to economic growth. The government provided the majority of capital investment in the economy, while private sector activity concentrated mainly on construction and trade (Fifth Development Plan, 1990). The construction industry received 69 percent of the total government expenditures during the first national development plan, 1970-1975, and 32 percent during the second plan, 1975-1980. [(4)]

Planning for Completion: The third national development plan, 1980-1985, was directed toward the completion of infrastructure facilities and the maintenance and operation of infrastructure already in place. The second half of this was marked by negative growth in the international oil market, resulting in an unexpected downturn in the Kingdom's revenues and a much lower level of government spending, as well as overall lower levels of economic growth.

Planning during Change: The fourth development plan, 1985-1990, clearly indicated that economic changes were expected in the coming five years. For this plan, the government enhanced its future purchasing power by implementing stronger criteria of control, wider competition and a review and adjustment of cost levels to the current conditions. In spite of the declining revenues, the government intended to complete the remaining portion of the infrastructure. Its objectives in the field of construction at that time included the following:

- Strengthening the Saudi construction industry.
- Improving the quality of construction and maintenance.
- Reducing the cost of construction and related maintenance of theFourth Plan, 1985-1990.

Shifting toward Private Sector Responsibility: The fifth development plan, 1990-1995, also called for the maintenance of the completed infrastructure projects, which were subject to premature decay resulting from the harsh climatic conditions of Saudi Arabia and low quality of building standards during the 1980's. This plan emphasized stimulation of the private sector's role in construction maintenance (Fifth Plan, 1990). The construction spending of the fifth plan achieved a positive average annual growth rate of 3.8 percent.

Calling for Accountability with a Look towards the Future: The sixth and seventh development plans, 1995-2000 and 2000-present, called for controlling the cost of services and increasing the operating life of facilities, in order to lower the future capital budget of existing facilities. They also specified the development of a complete base information system and periodic reports covering on-going and future building and construction. In addition, they advocated support for academic research in the field of construction (Sixth Plan, 1995; Seventh Plan, 2000).

1.1.2 Bidding for Government Contracts

After preparing the bid package (comprising plans and drawings, general conditions, special conditions, technical specification, and proposal form), the government informs bidders, usually by means of notices in a city daily newspaper.

The Saudi government requires at least three bids for all contracts larger than one million Riyals (US$ 266,667) and bids from at least five contractors for other types of construction projects. A committee of three or more people from the Ministry of Finance and National Economy, or from the government agency responsible for the project, must review the bids, which are open to the public. The contract will be awarded according to a vote decided by a majority. Companies with the lowest bids and who also meet all specifications will be awarded the contract. In most cases, the completion price has been estimated by the Saudis Riyals government and if all bids are significantly higher, the price will be negotiated. This also applies if the lowest bidder's proposal does not meet the conditions of the project.

Tender regulations allow price increases for variations in transportation charges, insurance rates or the price of raw materials. If all bids significantly exceed the estimate, the government agency may cancel all of them. The government insists that bids come reasonably close to practical estimates. Since January 1979, all contracts over 100 million Riyals have required the personal approval of the authorized person (Minister of Financing).

Foreign companies who wish to bid on projects supervised or undertaken by government ministries must be known to that ministry or agency. A list of these foreign companies is compiled and bidders are selected from this list when projects are available. In order for a company to be properly registered in the kingdom, a questionnaire must be completed in both Arabic and English.

1.1.3 Price Analysis and Contract Negotiations

The government's purpose in performing a price analysis record is to identify the scope of the price analysis and to translate price analysis findings into objectives for price negotiation. It also provides a foundation for the strategy of achieving price negotiation objectives, the purpose being to obtain the best price among all bidders. In general, the government uses a negotiated contract in the following cases:

- Emergency projects.
- Secret projects.

- In regular projects when the lowest bid is higher than the budget for the job. In this case, the engineers negotiate the contract with the lowest bidder to stay within the budget for the job. If a particular bidder does not accept, negotiation begins with the second lowest bidder, and so on, until an acceptable price is found.

1.1.4 Project Classification

Construction projects in Saudi Arabia are classified depending on the type of project and the project size. This will be discussed later because size correlates to the cost of the project.

Small Projects: This means any project costing less than one million Riyals (US $ 266,667). Many contractors are capable of this scale project and therefore the need for bidding is reduced. In this case, project price is mostly determined by negotiation to obtain a contractor's best price.

Medium Projects: These projects cost between one million Riyals (US $ 266.667) and fifty million Riyals (US $ 13,300,000).

Large Projects: These projects cost between fifty million Riyals and one hundred million Riyals (US$1 = 3.75 SR).

Extra Large Projects: These projects exceed more than one hundred million Riyals in cost.

All medium and large projects mainly employ the same types of procedures: extra large projects require the personal approval of the authorized person (Minister of Financing). In the latter case, it may be necessary to involve a foreign company. International companies working with this size project in Saudi Arabia play a specific role, which will be discussed later.

1.1.5 Contractor Classifications

The "Contractor Classification Committee" classifies all Saudi contractors. The contractor has to submit a yearly report to this committee which then has one of its own engineers visit the contractor's site, see the equipment being used and make sure of the contractor's financial situation. Based on these observations, the contractor is classified as to which size project he is capable of performing.

1.1.6 Foreign Companies

Foreign companies working for the Saudi Arabian government are required to have either a Saudi agent or a joint-venture partner in the country. The local representative will receive notices regarding forthcoming projects and should ensure that the foreign company is on the list of bidders for a proposed project. This Saudi agent is further expected to advise the foreign company on the best ways of presenting proposals to Saudi clients. All foreign companies working in Saudi Arabia must be registered with the Ministry of Commerce.

Non-Saudis are not permitted to act as commercial agents in Saudi Arabia. Furthermore, the Saudi commercial agent cannot conduct any business until he has been registered with the Ministry of Commerce. His function is vital since he is held responsible for the company and its personnel in the Kingdom. Details of these requirements can be obtained from the Department of Commercial Registration, Agencies Section of the Ministry of Commerce.

All foreign contractors and their Saudi agents fall under a regulation issued in 1978. The regulation stipulates:

- If a foreign contractor does not have a Saudi partner, then he should have a Saudi service agent.

- The Saudi agent must be living in the Kingdom and must be registered as an agent for the foreign company in the Commercial Register of the Ministry of Commerce.
- An Agency agreement governs and defines the obligations and relations between the Saudi agent and the foreign contractor.
- The foreign contractor pays fees to the agent in return for his services. These fees should not exceed 5 percent of the cost of the total contract.
- More than one Saudi agent may be employed by a foreign contractor involved in different kinds of work.

For government bidding, a company may be represented by only one agent. Regulations forbid an agent from representing both the consulting engineer and the implementing contractor in a single contract.

No more than one service agent is allowed to participate in the bidding process on any Saudi project in which a company is interested. A foreign company may, however, have more than one Saudi agent performing services in commercial functions. A Saudi agent is not permitted to represent more than ten foreign companies (Department of Commercial Registration, Agencies Section, Ministry of Commerce).

1.1.7 Performance Requirements and Dispute Settlement

The Kingdom of Saudi Arabia requires bid and performance bonds from companies in the amount of 1 percent and 5 percent, respectively, of the total value of a given contract. Bonds may be in the form of a bank guarantee payable on demand, a certified check from a local bank, or cash. A bank in Saudi Arabia acting as an agent for the foreign bank must approve each guarantee.

The government of Saudi Arabia issues a list of acceptable insurance companies. The limits which these companies may underwrite are also specified. A performance bond is not required for consulting work, service contracts, the supplying of spare parts, nor for contracts which the government awards for direct-purchase and whose value is less than one million Riyals. Furthermore, these do not have to be tendered.

A bid is always required except in the case of a purely negotiated contract where there are no competitors. The performance bond is generally due from the winning bidder within ten days of notification of the award of a contract. It is returned to the contractor on completion of the project even though the contractor remains liable for defects of the structure for ten years, unless the structure was not meant to last ten years.

A Saudi client, upon the signing of the construction contract, must make an advance payment of 10 percent of the cost of the project. A contractor with a bank guarantee must also provide an advance of 10 percent of the project's cost. As work progresses, payments of up to 90 percent will be made on the completed work. The remaining 10 percent will be held pending final delivery of the project or it may be paid against bank guarantees as the work advances.

Provisions for settling disputes are included in contracts as a matter of course. Commercial disputes are normally settled through personal contract and negotiation or through the Saudi arbitration system which involves arbitration and grievance boards set up for that purpose. Both litigants may accept a board's decision or they may appeal to the Shari's court. In major disputes, the Council of Ministers may become involved.

1.1.8 Types of Contracts Used by the Saudi Arabian Government

There were a great many infrastructure projects in the period 1970 to 1985, but not enough staff to work them. At that time, the government mostly preferred lump-sum contracts. However, this type of contract is not conducive to allowing changes to be made easily and government projects of necessity have huge numbers of changes. This problem caused the government to convert to a different type of contract. Within the last 23 years, the government has turned to unit price contracts, which solved many of the previous problems. Two other types of contracts were also used by the government: cost-plus and design build.

Overall, the construction industry in Saudi Arabia is mainly the same as in the USA; however, there are some government constraints that must be followed:

- Although English is widely used in the Kingdom, companies must conduct all their business with the government in Arabic. Tender announcements for projects specify the language of the bid. Most major contracts use English. Documents establishing joint-venture or agency representation must be in Arabic in order to be legally binding. In case of dispute, the Arabic text will be the basis of any decision made in settlement.
- There are some differences in the value of bonds and payment bonds do not exist.

1.1.9 Summary

The construction industry in Saudi Arabia is still developing and it changes every year. Most of the changes are related to the kinds of mistakes that have occurred and what the market needs. For example, 25 years ago a particular contractor received an advance payment of 20 percent of the cost when the contract was signed. It was a large project ($ 7,000,000,000) and it was to be completed within five years. When the contractor signed the contract, he received ($

1,400,000,000). It became clear that this was too much money to have paid in advance over such a long and uncertain period of time. The government responded by changing the advance payment policy from 20 percent to 10 percent. This exemplifies how the industry will continue to change as Saudi Arabia faces new challenges and meets new goals.

1.2 Statement of Problem

The purpose of this research is to develop a project delivery system decision framework (PDSDF) by exploring the factors, parameters and key consideration elements that will help the project owner in Saudi Arabia determine what type of PDS to select for a building project, based on the project objectives. There are many factors working together and separately that make one of the PDS methods more appropriate than the others. These factors will be identified and discussed later (Chapter 3).

1.3 Research Questions

There are five research questions for which this study will attempt to find answers:

a. Are there differences in the cost of projects built under the three project delivery system methods: design-bid-build (DBB), design-build (DB), and construction management at risk (CM-R)?

It is expected, based on the results of previous studies that cost will be highest for projects built under the DBB system, and lowest for projects built using the DB system

b. Are there differences in the project duration of projects built under three project delivery system methods: design-bid-build (DBB), design-build (DB), and construction management at risk (CM-R)?

It is expected, based on the results of previous studies, that project duration will be longest for projects built under the DBB system, and shortest for projects built under the DB system.

c. Are there differences in the quality of projects built under the three project delivery system methods: design-bid-build (DBB), design-build (DB), and construction management at risk (CM-R)?

It is expected, based on the results of previous studies, that project quality will be highest for projects built under the CM-R method, and lowest for projects built under the DB system.

d. Are there differences in the safety of projects built under the three project delivery system methods: design-bid-build (DBB), design-build (DB), and construction management at risk (CM-R)?

It is expected based on the results of previous studies that safety will be highest for projects built under the DBB system, and lowest for projects built under the CM-R system.

e. What PDS method should a project owner in Saudi Arabia adopt to achieve his project objectives and increase the probability of project success?

1.4 Role of the Survey

A questionnaire was developed and distributed to the target population to collect information. The collected information was used to estimate values of key parameters from which a PDSDFM could be developed, tested and refined. For that reason, project owners (public and private), project contractors and project engineers were surveyed and asked to complete a brief questionnaire (aproximately 15 minutes). In addition, the questionnaire was intended to identify the primary selection factors available to owners. It was divided into three sections. The primary section asked respondents to answer questions related to the experience and financial position of the owner. The second section asked respondents to answer questions related to the experience and financial position of the contractor. The final section asked about project background, e.g. schedule, cost, quality, etc. Copies of the survey (English & Arabic versions) are presented in appendix C (C1 English form; C2 Arabic form).

1.5 Survey Variables

There were many variables in the survey, organized into the following categories:

Cost: The amount of money paid by the owner for a facility. Costs are limited to the design and construction of the facility and did not include owner costs.

Time: The time taken by the facility team to design and construct the facility, measured in months or days.

Quality: The degree to which the facility met the specified facility requirements.

Safety: The degree to which all aspects of the project were safe, including labor, equipment, and project facilities.

1.6 Research Questions Answers

The following survey items were used in answering question a.

Indirect questions about cost (see appendix C)

Section I: Items 5, 6

Section II: Item 6

Section III: Items 7.1-7.5, 8, 14a, 14b

Direct question about cost (see appendix C)

Section III, item 11 (to compute cost growth)

The following survey items were used in answering question b.

Indirect questions about time (see appendix C)

Section II: Item 5

Direct question about time (see appendix C)

Section III, item 12 (to compute schedule growth).

The following survey items were used in answering question c.

Indirect questions about quality (see appendix C)

Section I: Items 3, 4, 5

Section II: Item 2, 3, 4

Direct question about quality (see appendix C)

Section III, item 13a,13b, 13c (to measure the quality).

The following survey items were used in answering question d.

Direct question about safety (see appendix C)

Section III, item 15 (to compute the safety).

Most survey items were used to answer question e (see appendix A).

1.7 Scientific Aspects of the Study

Much has been written about PDSs and how the project parties, especially the owner, can select and adopt a PDS for their project. This researcher did not find any previous studies about developing and creating a project delivery system decision framework (PDSDF) that could help the project owner in Saudi Arabia determine which type of PDS to select for a given building project.

This appears to be the first study to attempt to evaluate and develop a PDSDFM in that country. In addition, this study uses and compares two decision frameworks, weighting factors (WF) and analytical hierarchy process (AHP) for the selection of project delivery systems. The primary purpose of this research is to help an owner achieve success with a project by completing it on time, within budget, and with high quality.

2.0 REVIEW OF PROJECT DELIVERY SYSTEMS

This chapter describes the definition of each PDS studied in this research. Related project delivery research and studies are discussed with specific mention of several completed in the U.S.

2.1 Project Delivery Systems

There is a variety of delivery systems that are used to design and construct projects. The primary ones are as follows, but not limited to: Traditional design-bid-build (DBB) process, design-build (DB), and construction management-at-risk (CM-R). In general, the public sector has gained significant flexibility in the procurement of construction services with the ability to select from two additional project delivery methods previously available only to the private sector due to government policy: "Recent changes in federal laws and regulations have created a much wider range of options for the ways in which design and construction teams are structured and the ways consultants and constructors are selected".[5] In addition to the traditional (DBB) delivery method, which is still available, public sectors may choose from the following alternative methods (with certain considerations for, time, budget, and quality): (1) Design-Build (DB), and (2) Construction Management-at- Risk (CM-R).

The alternative methods allow for greater cooperation among owners, design consultants (architect / engineer), and contractors, as well as lower cost. Perhaps the greatest advantage to the public owner is that by using these methods, they can select contractors based on past performance, and on quality of work and reputation, which can be determined by the pre-qualification of bidders instead of by costs alone. Those types of delivery systems are fundamentally people systems, since people remain the most valuable construction resource.

2.1.1 Traditional Design-Bid-Build (DBB)

In the DBB project delivery process, the owner selects a design team to prepare design plans, technical specifications and construction bid documents. Bids are obtained from interested contractors who base their proposals on these prepared documents. The DBB project delivery method places the owner at the center of the project parties as the result of separate contractual relationships with the design entity and the contractor (see Figure 2.1). In this arrangement, the owner warrants to the contractor that the plans and specifications are buildable. If problems arise during the course of construction - or even after substantial completion - the owner becomes the intermediary between the contractor and design firm.

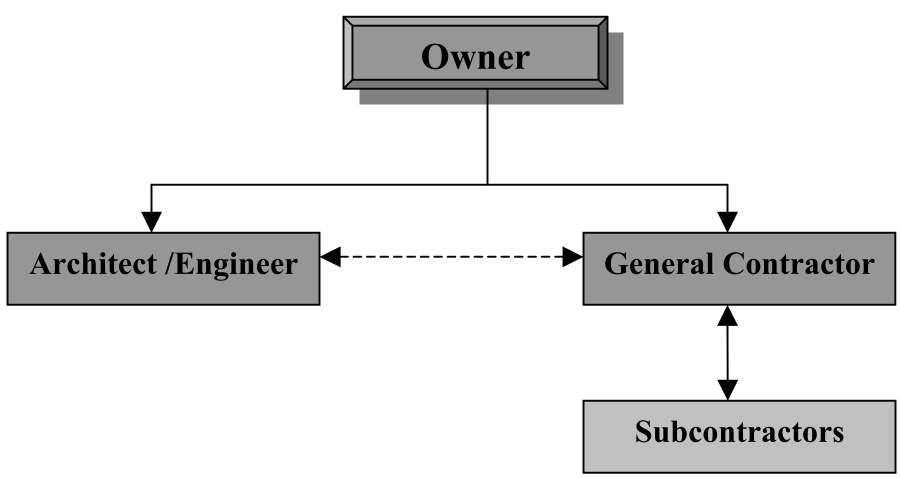

Figure 2.1. Design-Bid- Build Method (DBB), Traditional Method

In other words, under this method:

a) There is a sequential award of two separate contracts;

b) The first contract is for design services;

c) The second contract is for construction;

d) Design and construction of the project are in sequential phases;

e) Financial services, maintenance services and operations services are not included;

f) This method provides familiarity and a defined project scope;

g) This method lends itself to longer schedule duration, more expense and an adversarial relationship between the design team and construction team, which can lead to claims and other legal issues;

h) The client is able to customize the design better to meet special building design and operational needs;

i) The overall project and construction costs are estimated throughout the design program by the design project team, with the result that the exact cost to construct is not known until bids are opened and any negotiations are completed.

j) Increasingly, many owners are turning to the DB project delivery method to remove themselves from the intermediary role inherent in the traditional DBB system and to eliminate disadvantages such as item (i).

2.1.2 Design-Build (DB)

With the DB project delivery, owners are no longer in the center between the project parties (see Figure 2.2). Under DB, the owner contracts with a single point of responsibility to provide both the design and construction services. Unlike the DBB scenario where the owner warrants the design to the contractor, the single point of responsibility now has responsibility for and warrants the design to the owner. In this situation, the owner will call upon the single point of responsibility to respond to and correct any design problem that may arise during construction, or following completion of the project. DB gives design firms and contractors the opportunity to work as a team, and to deliver a quality project on time and within budget. The DB project delivery method can minimize many of the problems which often lead to claims in the DBB process.

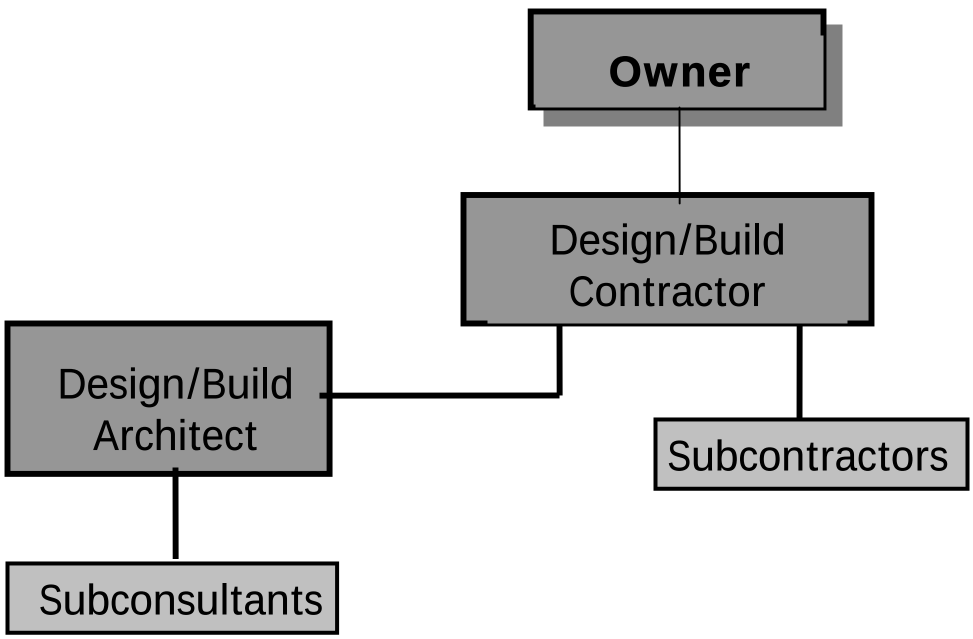

Figure 2.2. Design-Build Method (DB)

In other words, under the DB method;

a) There is a single contract for both design services and construction services;

b) Design and construction of the project may be in sequential or concurrent phases;

c) Financial services, maintenance services, operating services, design services and other related services may be included;

d) There is a single point of responsibility for design and construction;

e) This method may result in faster schedule delivery;

f) This method may result in fewer claims and legal issues between the DB team and the owner;

g) The contractor cannot claim an extra cost for design problems from the owner, and the contractor and design team will have to resolve such issues amongst themselves;

h) The owner has less input into the process and little control of the quality of the materials used in the project, unless the owner has taken the time to create a very detailed project program document and identified other project controls that the DB team is to meet. In other words, without a well-defined specification program, the DB concept offers little opportunity for the owner to have control over the quality of the materials used.

i) Some DB teams have internal suppliers and construct their own equipment, furniture, etc. or have special associations with suppliers that provide materials for all their projects.

j) The owner believes that everything is being taken care of by the DB contractor and its team, and often has little knowledge of the details that are involved in the process or has very little time to devote toward making sure that the team is doing what they agreed to--a potential disadvantage of the system.

2.1.3 Construction Management-at-Risk (CM-R)

CMR is a construction delivery method in which a construction manager is brought on during the design phase to be part of the design team and to propose a guaranteed maximum price at or towards the end of the design development phase (see Figure 2.3). If the owner accepts the guaranteed maximum price, this contractor will construct the facility.

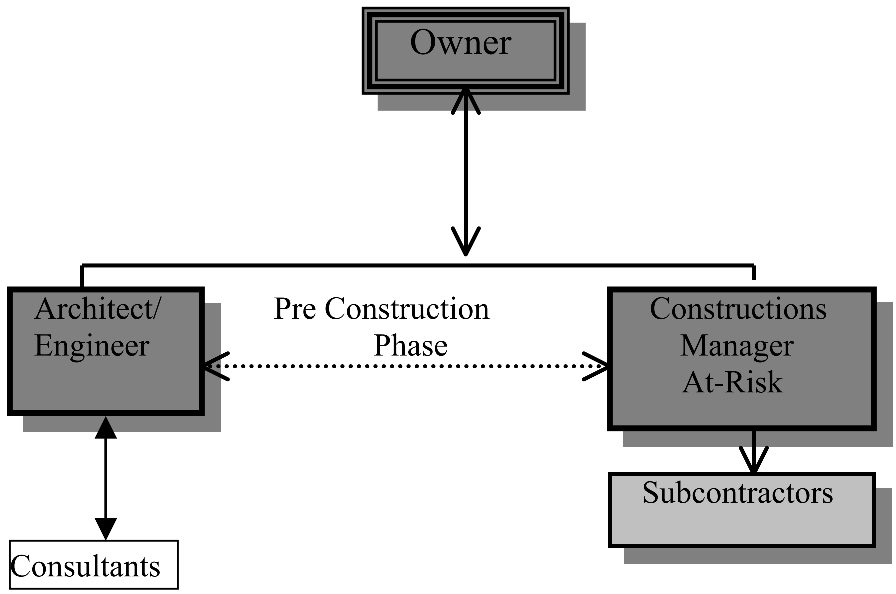

Figure 2.3. Construction Management-At-Risk (CM-R)

In other words, CMR is a project delivery method in which:

a) There are separate contracts for design services and construction services;
b) The contract for construction services may be entered into at the same time as the contract for design services or at a later time;
c) Design and construction of the project may be in sequential phases or concurrent phases;
d) Financial services, maintenance services, operations services, pre-construction services and other related services may be included;
e) The construction manager is actively involved in the design from the perspective of budget concerns and constructability, providing more of a team concept than DBB;
f) Faster schedule delivery at reduced cost if the team concept is effectively implemented.

2.1.4 Multiple Prime Contractors (Separate Prime Contracts)

The prime contractor is a contractor who has a direct contractual relationship for work with the owner or with the owner's agent, i.e., CM-at-Risk (CM-R), as distinguished from a sub-contractor whose contractual relationship is with a general or prime contractor rather than the owner (see Figure 2.4). Multiple prime contractors may be used with sequential design and construction by splitting the plans and specifications into packages pertinent to recognized trade specialties. The owner may undertake to manage and coordinate their work or contract with a construction manager as an agent to do so. The contracts may provide that responsibility for successful completion of the entire project rests with the owner, the owner's agent, or one of the multiple prime contractors. The contracts shall specify where this responsibility shall rest. Multiple prime contractors may be used effectively with phased design and construction only if the architect-engineer's work is closely coordinated with the specialty contractors' work. The specialty contractors may either contract directly with the owner or with his construction manager.

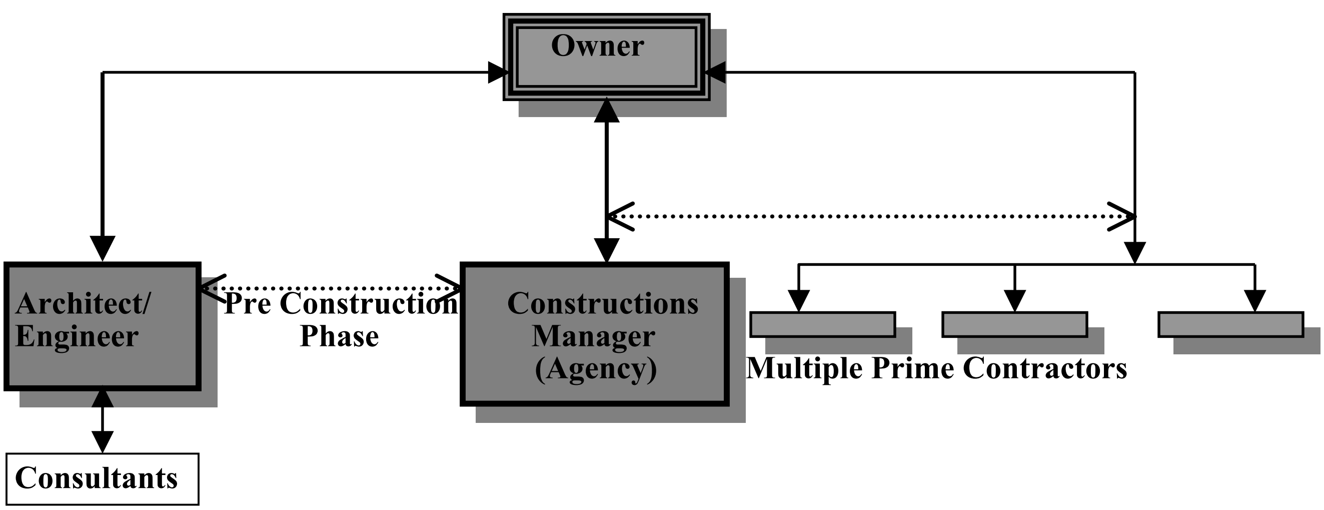

Figure 2.4. Multiple Prime Contractors (Separate Prime Contracts)

Where the choice is made to let multiple contracts, a number of issues must be considered. The advertisement for bids, invitation for bids, instructions to bidders, form of bid, and agreement, as well as the body of the contract documents, must reflect the multiple contract nature of the project. If the multiple contract system is utilized, then coordination of documents and delineation of the responsibilities of the separate prime contractors is required. To avoid debate, contention, claim or litigation, it is imperative that each of the separate primes be instructed as to its responsibilities. In other words, the multiple prime contractor method places all the risks of managing and coordinating the construction work with the owner. The owner or his representatives must actively and aggressively supervise the project to ensure timely and successful completion. A contract that merely requires specialty contractors to cooperate and to coordinate their work is insufficient. To undertake this responsibility successfully requires vesting clear authority in the owner representative to quickly make decisions essential to the continuation of the project.

The use of multiple prime contracts affords the owner the opportunity of eliminating excess overhead and profit which would normally be charged by a prime contractor on its subcontractor's work. This savings is usually substantial enough to offset the entire fee of the construction manager. However, multiple construction contracts increase administrative cost and coordination problems and also increase the potential for construction disputes and claims.

2.1.5 Build-Operate-Transfer (BOT)

Build-Operate-Transfer (BOT) is a project financing and operating approach that has found an application in recent years primarily in the area of infrastructure privatization in developing countries. BOT is being hailed by industry, government and multi-national banks as the wonder solution to constructing large infrastructure projects such as dams and roads by creating public infrastructure without using as much public capital. Contractors the world over are discovering how to use private-public partnerships to build much needed infrastructure projects quickly, efficiently, while minimizing the use of public funds.

Under this system, the private partner builds a facility to the specifications agreed to by the public agency, operates the facility for a specified time period under a contract or franchise agreement with the agency, and then transfers the facility to the agency at the end of the specified period of time. In most cases, the private partner will also provide some, or all, of the financing for the facility, so the length of the contract or franchise must be sufficient to enable the private partner to realize a reasonable return on its investment through user charges. At the end of the franchise period, the public partner can assume operating responsibility for the facility, contract the operations to the original franchise holder, or award a new contract or franchise to a new private partner.

A variation of this system, the Build-Transfer-Operate (BTO) model, is similar to the BOT model except that the transfer to the public owner takes place at the time that construction is completed, rather than at the end of a franchise period.

2.1.6 Project Delivery System (PDS) Selection

Selecting a PDS means choosing the best way or system to organize the design and construction process, and that is not always an easy or clear decision. Selecting the right project delivery method that meets specific project requirements is the question that usually faces any owner or client. The choice of a particular style of PDS will depend on many factors, for example:

- Ease of design;
- Degree of design flexibility during construction;
- Availability of suitable contractors/project managers, and balance sheets of such contractors;
- Political considerations;
- Budget constraints vs. performance of completed project.

2.2 Related Studies

The increasing number of variations in project delivery systems (PDS) has made it more challenging than ever to choose the most effective method for each construction project. According to John E. Deklewa, president of Master Builder Association, "Ask any contractor, owner or engineer about their delivery system preferences and you will likely get a different response from each".(6) Evaluation of the best project delivery systems (PDS) available to owners or contractors in executing their facilities has been introduced and studied by previous researchers. Research on this topic often has been limited and/or has relied heavily on surveys. These previous studies on this subject can be summarized and divided into two groups. In the first group, a weighting/decision analysis methodology was used, and in the second group, the researchers limits their study to determining the important factors and key elements (time, size, type project, etc.) that can help project parties choose the appropriate delivery method.

2.2.1 Group One

There are many examples in group one, such as, “Comparison of U.S. Project Delivery Systems”. [7] In this study, the researcher collected, checked and evaluated industry data for each project. The methodology of this research was divided into four phases. Phase one was about developing a tactic to collect and analyze the project data. In this phase the researcher defined the key performance matrices - cost, schedule, and quality- as follows:

- Cost can be measured in three ways:

1. Unit Cost ($\$/m^2$) = (Final Project Cost / Area) / Index

The index used to adjust cost for time and location.

2. Cost Growth % =

[(Final project Cost – Contract Project Cost) / Contract Project Cost] * 100

3 Intensity [($\$/m^2$)/ month] = (Unit Cost / Total time)

Total time is the period from the as-built design start date to the as-built construction end date.

- Schedule was measured by:

1. Construction Speed (m^2 /month) =

Area / [(As-Built Construction End Date - As-Built Construction Start Date) / 30].

2. Delivery Speed (m^2/month) = Area / Total Time / 30.

3. Schedule Growth (%) =

[(Total time – Total As-Planned Time) / Total As-Planned Time] * 100

- Quality divided into three major specific areas as below, the owner was asked to rank the actual performance of the facility versus expected:

A. Turnover quality measures

1. Difficulty of facility startup.

2. Number of call backs.

3. Operation and maintenance cost.

The owner ranked turnover quality measures as high (10), medium (5) or low (zero).

B. System quality measures the performance of the envelope:

1. Roof

2. Structure

3. Foundation

4. The interior space lay out

The owner ranked the system quality as above expectations (10), met expectations (5), or did not meet expectations (zero).

C. Quality of equipment process.

The owner ranked this as above expectations (10), met expectations (5), or did not meet expectations (zero).

The second phase was collecting project data. The researchers used a survey to collect specific data for each of 351 U.S. building projects. A comprehensive data collection instrument including quantitative cost, schedule, and quality performance data was created for each project. In the third phase, the author used several critical data-checking techniques to verify project data. In fourth phase, the researcher evaluated and analyzed the data by using several statistical methods such as means, medians, and deviations to compare the scores of cost, schedule and quality performance of the three PDS.

A number of key performance measures were identified by the authors: unit cost, cost growth, schedule growth, construction speed and intensity. For each of these measures there was a variable that accounted for the greatest proportion of variation, in order of importance, such as, contract unit cost, facility type, project size, project delivery system, project complexity and percent design completed before construction entity joined the project team. A multivariate liner regression model and ranking method was to identify the impact of those variables on each PDS, and to develop three models to explain the variability of unit cost, construction speed and delivery speed.

In the beginning, PDS were compared by using the key performance metrics regardless of facility type. The study classified the project facility into six classes: light industrial, multistory, dwelling, simple office, complex office, heavy industrial, and high technology. Then the study compared the PDS for each metric by involving the facility type.

Finally the study clearly indicated the differences between the PDS and showed that use of the design-build (DB) delivery system significantly improved cost and schedule advantages. In addition this delivery system sometimes produced a more acceptable quality performance.

The second study of this type was on "Selecting Design-Build: Public and Private Sector Owner Attitudes" [8]. There was a huge growth in use of the design-build (DB) system which stimulated a focus on this particular delivery strategy. The researcher's goals were to identify primary selection criteria specific to the DB delivery system and to compare public and private owner DB attitudes. These criteria were:

- Establish cost.
- Reduce cost.
- Shorten duration.
- Reduce claims.
- Large project size / complexity.

- Constructability innovation.

The data were collected by means of a survey (questionnaire) to 290 owners. As part of this questionnaire, the owners were asked to select which of these criteria had more priority than the others and to rank them 1 through 7, 1 being most important. There were only 108 responses, 63 percent public sector owners and 37 percent private sector owners. Of these 108 responses, 83 percent were building construction, 14 percent were industrial construction, and the remaining 3 percent represented highway construction. A static analysis (mean, standard deviation and median) in addition to priority ranking was used by the authors to analyze the data collected through the survey. Finally, the authors concluded that both private and public owners strongly preferred to use the DB delivery system rather than any other system. This was due to the two most vital factors, "shorten duration", and "establish and reduce cost".

The third and last example of this type of study was about “Measurement of construction phase success of project”[9]. The purpose of this study was to develop a construction phase success metric. The data used were from the Construction Industry Institute’s Benchmarking and Metrics data base. Scoring ranges based on statistical distribution for construction cost growth, construction schedule growth, lost workdays, case incident rates and rework factor were presented in this research. An equation, developed to measure the construction phase success, contained four components of success: cost, schedule, quality and safety. Those criteria were clearly understood by all construction parties (owner, contractor, subcontractor, …, etc). The equation was:

Construction Phase Success = f (Cost, Schedule, Quality, Safety). …… (A)

Cost was represented by cost growth and construction cost growth (ccg) is defined as:

$$\frac{\text{Actual Construction Phase Cost} - \text{Initial Predicted Construction Phase Cost}}{\text{Initial Predicted Construction Phase Cost}} \tag{1}$$

Schedule was represented by schedule growth; construction schedule growth (csg) was defined as:

$$\frac{\text{Actual Construction Phase Duration} - \text{Initial Predicted Construction Phase Duration}}{\text{Initial Predicted Construction Phase Duration}} \tag{2}$$

Quality was represented by the rework factor, defined as:

$$\frac{\text{Total Direct Cost of Field Rework}}{\text{Actual Construction Phase Cost}} \tag{3}$$

And finally, the lost workday case incident rate (LWCIR), representing safety for the construction phase of a project, was defined as:

$$\frac{\text{Number of Lost Workday Cases X 200,000}}{\text{Site Craft Workhours}} \tag{4}$$

A weighting equation was created based on cost ratios which included the four components (ccg, csg, LWCIR, and RFS). The weights calculated were stand-in equation A. The following equation was the result:

$$CPS = 0.4\ CGS + 0.25\ SGS + 0.3\ RFS + 0.05\ LWCIRS \quad \ldots\ldots \quad (B)$$

Many types of projects were involved in this study; heavy and light industrial classification as well as five laboratory projects. The researcher concluded his study by showing that cost and schedule were the most vital factors indicating and determining the success of the construction.

2.2.2 Group Two

In these studies, the researchers limited their focus to exposing the important factors and elements that helped the owner decide which project delivery system he should select, for example, "Choosing the Best Delivery Method for Your Facility Project" [10]. In this study, the authors mention key elements that should be of concern to the owners and considered by them when proceeding on a construction program. These elements were: budget, design, schedule, risk assessment and owner's level of expertise. The authors concluded that these elements would help the owner to decide which project delivery system would be superior to the others for their purposes. In addition, the authors listed, defined and clarified all the characteristics of each system that they considered, namely:

- Traditional Design-Bid-Build (DBB).
- Construction Management-at-Risk (CM-R) (CM as GC).
- Multiple-Prime Contracting (MPC).
- Design-Build (DB).
- Agency Construction Managements Services (ACMS).

Finally the authors recommended that the following characteristics should be considered by the owner as a guide in selecting the proper delivery method:

- Type of project.
- Size of project.
- Owner capabilities.
- Time considerations.
- Possibility of changes.

2.3 Conclusion

From the previous studies, this researcher learned that different methodologies had been used to analyze data: the weighting method and the ranking method. Both of these measurement methods had been successfully used to help construction parties, especially owners and contractors in their decisions regarding choice of project delivery system. These methods had helped them discover and decide on the more appropriate delivery system for their projects.

These measurement methods depend on similar vital variables, namely, budget achievement, schedule achievement, design and construction performance, quality, and safety. Based on this review, this research study will use the weighting method because, first, it is easier to apply and understand, "Considering that this model is developed with simplicity in mind, only the maximum weighted values method is considered"(11). Because it is easier to apply and understand it is preferred by owners and researchers. Second, the weighting method is in general more common than other methods (12),

There is an important issue that has to be considered by those who want to use either the weighting method or the ranking method; one must avoid having one person carry out the weighting process. It is strongly recommended that experts meet to discuss and assign either a weighting factor or ranking number to each parameter, as a way to guard against personal biases and lack of experience.

Finally, it should be noted that this researcher did not find any previous studies about developing and creating a project delivery system decision framework (PDSDF) to help the project owner in Saudi Arabia determine which type of PDS to select for a building project.

3.0 METHODOLOGY

The purpose of this study was to develop a project delivery system decision framework (PDSDF) for selection of a project delivery system by the project owner. The goal of the model was to help the owner decide which project delivery system to adopt. Based on the results of previous studies, major criteria that impact on owners' decisions were identified. These criteria were conceptualized as comprising the following three groups: project factors, owner objectives, and project parameters. The research methodology is presented in Figure 3.1.

At the stage of data collection two major sources of input into the model were used. The first of these was the data collected from a survey administered to the owners, contractors, and engineers of selected projects. Data on project factors and owner objectives were drawn from this source. After assigning numerical values to qualitative responses from the surveys, data were entered into the tables shown in Appendix A, following the steps outlined in Section 3.11. To assess the validity of survey data, the relationships among variables that would be expected based on previous studies were tested.

The second source of input into the model was the results of previous studies that had been done in this area. Data on project parameters were drawn from this second source.

To represent the structure of the decision-making process, three matrices (the project factors matrix, the owner objectives matrix, and the project parameters matrix) were designed, based on the weighting factors method (see evaluation matrix, Figure 3.2). Within each matrix there was a column for weights to be determined by the owner based on both his needs and project characteristics. Once data were entered into the three matrices, they were combined into one matrix which generated a numerical score for each project delivery system that guided the owners in their selection among the alternative methods.

In addition to the weighting factors method, the analytic hierarchy process was also used to analyze the data. In this process the relative advantages of the three project delivery systems were compared according to each criterion. The relative importance of the criterion was determined on the basis of the owner's needs and project characteristics. The results of comparing the three delivery systems according to each criterion and of determining the order of importance among the criteria were then integrated into a model to help the owner reach a decision about which project delivery system he should adopt.

The final step in the methodology was to compare the results obtained under the weighting factors and analytic hierarchy process approaches to learn whether both approaches would lead the owner to the same decision.

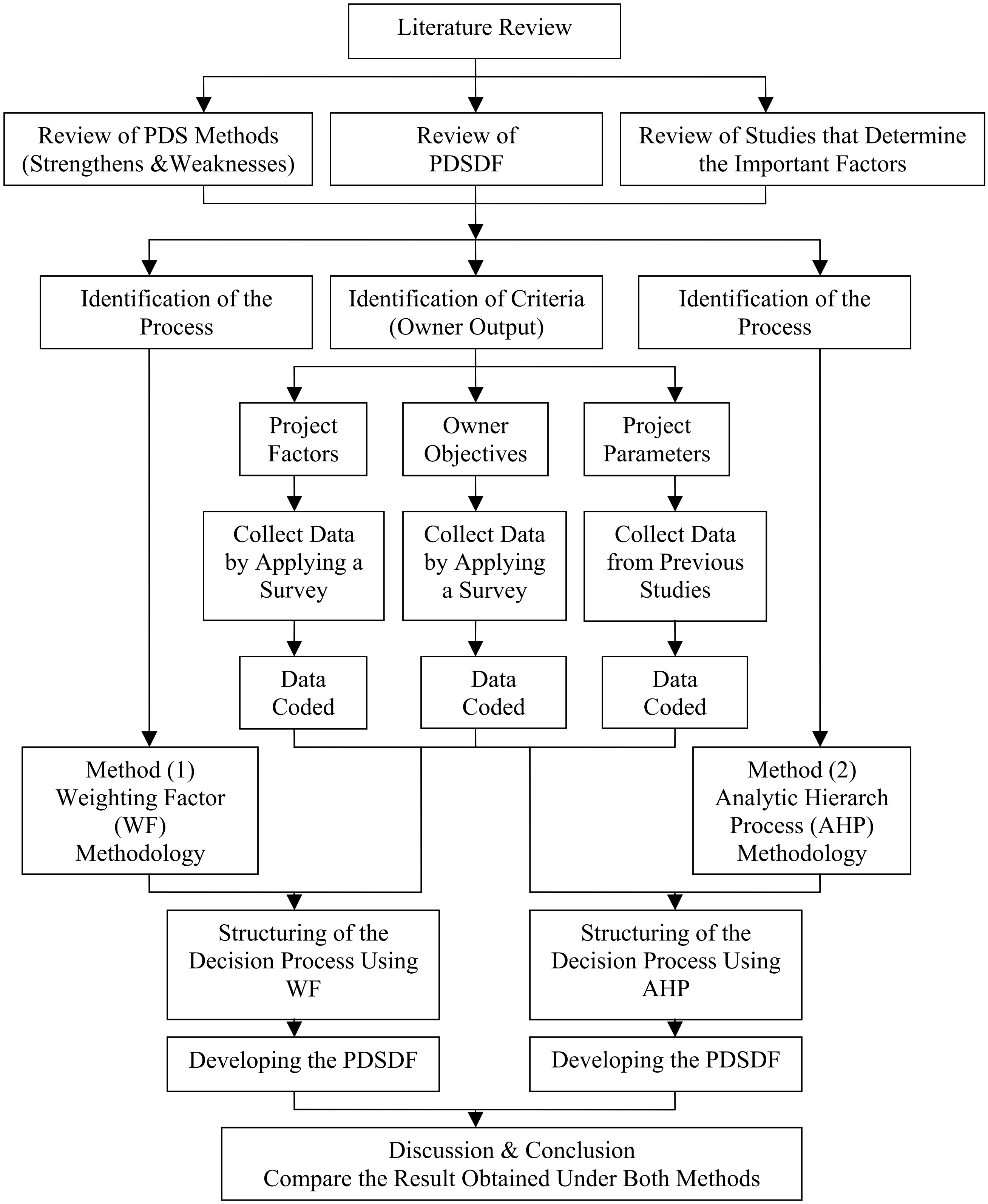

Figure 3.1 Research Methodology

3.1 Creating a Decision Model Framework

Owner output influenced the selection of PDS for projects that were considered in the selection analysis. Those outputs were divided into three categories: project factors, owner objectives (key consideration points), and project parameters (key decision points) (see Table 1). The following is a brief description of each category and its contents.

Category I, project factors, included the most important factors that had to be considered by all of the project parties (see Table 25). In addition, those factors had a direct effect on the success or failure of a project and on the decision that determines which PDS method should be adopted. Project factors included:

- Project Cost: the amount of money paid by the owner for a facility.
- Project Time: the time taken by the facility team to design and construct the facility.
- Project Quality: the degree to which the facility met the expected facility requirements according to the project drawings and specifications.
- Project Safety: the process and rules of safety that had to be considered during the project construction for labor, equipment, and project facilities.

The second category of owner output was the owner's objectives (key consideration points) (see Table 24.), which included:

- Type of project: level of complexity and uniqueness of the project, and the corresponding appropriate level of control. For example:
  - The more complex and unique project needed more control. In this case, CM-R was the appropriate method for this type of project, because in this construction system most, if not all, the decision power was retained by the owner.

- The less complex and unique the project, the less control was needed. In this case, the DB method was the most appropriate system for the project. DB reduces owner representation and has fewer checks and balances.

- Size of project: the more complex and costly ($\$/ft^2$) a project, the greater the need for professional management and advice.
- Owner capabilities: the owner should determine his capabilities to adopt any PDS in relation to his financial position and experience.
- Contractor capabilities: the owner also should find out what are the contractor's capabilities to adopt any PDS in relation to his financial position and experience. By applying the prequalification selection process, the owner would be able to know the experience and financial position of the contractor.
- Time consideration: if the project needed to be constructed within severely compressed time limits, methods adaptable to DB construction should be considered. However, the owner must weigh the need for a compressed time limit against the increased risk of DB.
- Possibilities of changes (project change orders): from previous similar projects the owner should determine the probabilities of changes in the project's scope of work. From previous study and construction experience, usually the DBB method leads to change orders and a high probability of change, while the CM-R method limits changes in the scope of the work (mostly scope changes are difficult).

Project parameters (key decision points) (see Table 26), which included the third category of owner output, included the following: owner risks, owner control and involvement, transfer technology, owner satisfaction, ease of design, constructability innovation, political considerations and government limitations, ensuring confidentially, resource availability, well-defined scope and, finally, knowledge of final cost before starting.

Categories I and II were identified by a survey that was distributed in Riyadh, K.S.A. while category III was identified from the previous studies and research.

3.2 Evaluation Matrix

The project factors, owner objectives (key consideration points) and project parameters (key decision points) were organized in a matrix form to smooth the progress of the decision-making process. The matrix was usually performed as in Figure 3.2.

Owner Output (1)	WF Wj (2)	PDS alternatives DBB (a1) (3)	DB (a2) (4)	CM-R (a3) (5)	…………	ai
Project Factors Matrix (Questionnaire)	W1	Ua11	Ua21	Ua31	………..	Uai1
Project Key Consideration Matrix (Questionnaire)	W2	Ua12	Ua22	Ua32	……….	Uai2
Project Parameters (Key Decision Points) (Previous Study)	W3	Ua13	Ua23	Ua33	……….	Uai3
.	. Wj	. Ua1j	. Ua2j	. Ua3j	………..	. Uaij
Total Points(Uai)		Ua1	Ua2	Ua3	…………	Uai

Figure 3.2 Evaluation Matrix

Where,
$U_{(aij)}$ = outcome of alternative ai for owner outcome j;
Wj = weighting factor for the owner outcome j.

"In order to aid the decision-maker in systematic thinking and arriving at a good decision, it is better to develop a series of matrices instead of just one".[13] A PDSDF consists of the owner output as provided by the survey and previous studies and a series of decision-making tools (see Figure 3.3). Decision-making tools consisted of a series of decisions matrix (these matrices will be discussed in detail in section 3.11). The problem of using only one matrix was that of collecting all the criteria. There might have been confusion and neglect of some of the important criteria that might have had a greater impact on the final decision.

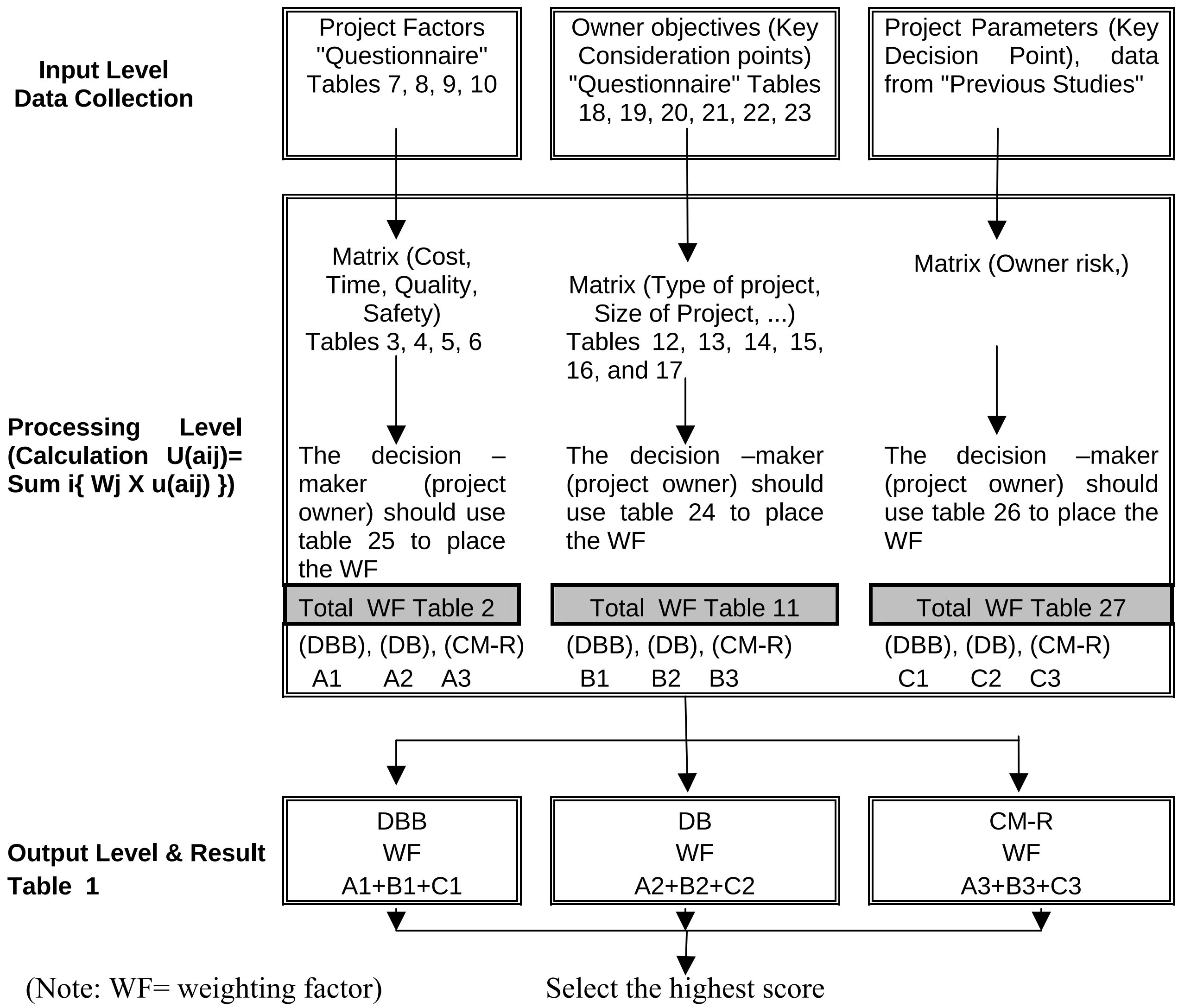

Figure 3.3 PDS Selection Process Model (Maximum Weighted Values Method)

3.3 Weighting Factors Estimation [Method 1]

A weighting factors (WF) estimation method was used in this study. After the important criteria and data had been identified and collected, the researcher developed a weighting system to estimate the weighting factors that could be assigned to each criterion. A scale of one to ten was developed (see Appendix A, Tables 24, 25, and 26) based on the previous studies. The scale also contained a word range of weighting, from low, through medium, to high in parallel with the numbers scale, where the medium represented neither a negative nor a positive WF. The decision-maker (project owner) was to select the WF for each criterion and for each owner outcome by placing his expected factor in the top row of the scale. For example, cost reduction was a very important factor, so it had to be placed at high which took number 10. Similarly, time reduction obviously had to be placed at medium-high which was number 8, and so on with the other criteria. In section 3.9, how numerical codes were assigned to each factor on each matrix (owner outcome) will be explained. The outcomes of WF were totally dependent on the experience and expectation of the decision-maker and on his preference. The equation used in the matrix calculation was as follows:

$$U_{(ai)} = \text{SUM } i\ [WF_j \times U_{(aij)}]$$

Where:

$U_{(ai)}$ = total points for the alternative ai;

SUM= summation;

$U_{(aij)}$ = outcome of alternative ai for owner outcome j;

WFj = weighting factor for the owner outcome j.

From this equation calculate the total points of each PDS for each outcome were calculated. The highest total value of the three alternatives represented the method that had to be chosen by the owner.

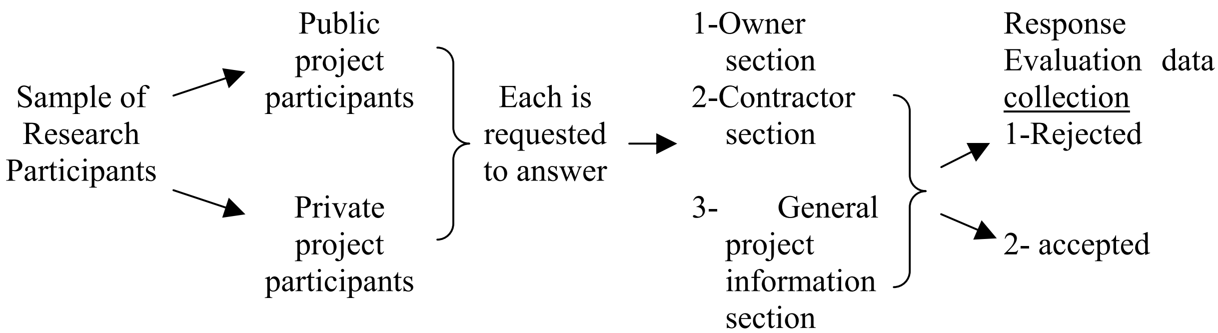

Figure 3.4: Design of the Survey

3.4 The Design of the Study

This study attempted to identify the parameters, factors and key consideration elements that had to be considered in the PDSDF and would lead to project success. A questionnaire was developed to facilitate data collection by the researcher and to ensure the validity of the study in Saudi Arabia. The questionnaire (see appendix C) was divided into three sections, Owners (client), Contractor, and General Project Information. Each of these sections contained a number of multiple choice questions. The questions were mostly related to the five major factors [cost, time, quality, safety, and owner objectives (key consideration points)] that were considered by the owners in most of their projects. The survey questionnaire was prepared and distributed to 100 project owners or owners, agents.

3.5 Target Population and Sampling Frame

According to Christensen (2001), a target population is "the large population to which the results are to be generalized"(14). The target population of this research was all of the building projects (building and utilities construction projects) built in Riyadh, Saudi Arabia. The researcher knew from his own experience that a great many building and utilities construction projects had been built during the last 15 years. This was confirmed by the Ministry of Municipalities and Rural Affairs, who reported that more than 600 building projects were constructed during the last 15 years (from January, 1988 until January, 2003) in Riyadh which they represent the sampling frame. The sampling frame was the "physical" list of buildings and utilities projects from which the researcher drew the study sample. The accessible population for this study was the project owners.

3.6 The Sample

The Ministry of Municipalities and Rural Affairs had a numbered list of building projects and their owners, names, addresses and phone numbers for the last 15 years. By using Gay and Airasian (2000), it was determined that a sample of 100 was appropriate. After that, the Simple Random Method Technique was applied through a randomization site on the Internet so that each project in the list had an equal probability of being selected.

3.7 Method of Data Collection

Figure 3.4 presents the design of the survey in regard to data collection; the following issues were taken into consideration:

- First, the researcher contacted the Ministry of Municipalities and Rural Affairs in Saudi Arabia, to introduce himself and the study. A study proposal was submitted and they were asked to support it by providing a list of all building projects that had been undertaken in the last 15 years in Riyadh, and the project owner's names. The Ministry of Municipalities and Rural Affairs usually supports researchers in these kinds of studies.

- The list that was provided was numbered.
- The researcher randomly selected 15 projects included in a pilot study. This pilot study helped to ascertain the validity and reliability of the larger study and also to revise the questionnaire. These 15 projects were not used as part of the sampling frame.
- After analyzing the pilot study, the researcher determined the size of the sample according to the projects list that was provided by the Ministry of Municipalities and Rural Affairs.
- A Simple Random Method Technique was used in selecting the sample for this study, so that each public project on the list had an equal probability of being selected.
- The survey was sent to 100 building project owners using e-mail and standard mail. A return confirmation of receipt of the questionnaire was attached. Certain issues were emphasized at this point:
    - A cover letter was included to explain to the responder the purpose of the survey and the importance of the study. The researcher's contact information was included, in case there were any questions.
    - All respondents were asked to respond within a certain time (three weeks).
    - A return stamped envelope addressed to the researcher was enclosed.

3.8 Check Data

In all survey research efforts the possibility of bias or lack of participation by the respondents is expected. In this study, the questionnaire was coded to help identify the responders who didn't respond. Three weeks after sending out the questionnaires, a follow-up e-mail (or phone call) was sent to participants who had not responded. The survey was sent a second time to owners who had not returned the first mailing.

All communication with respondents was directly from the researcher. In the questionnaire itself there were some questions which had to be answered, such as question # 9 part III. The responder was excluded if this question was not answered.

3.9 Data Coding

Numerical codes were assigned to the response categories for each question. Decisions about coding were made on the basis of what had been learned from previous studies and what would lead to the best functioning of the model.

For example, question I 5 related to the level of staffing which is a factor in cost. If the level of staffing hired by the owner was low, this would reduce the cost from the point of view of the owner. The Design-Build method was the PDS that required the lowest level of staffing from the owner's perspective. Therefore if an owner chose "low" as the response to question I 5, the model should lead the owner to choose the Design-Build method. For that reason the code of 3 was given to "low", the code of 1 was given to "high" and the code of 2 was given to "medium", as illustrated in the diagram below.

Q I 5 Level of staffing (# of people)

	DBB	DB	CM-R
	High Level	Low Level	Med. Level
Coding#	1	3	2

As a second example, question I 6 related to the owner's financial position which was a factor in cost. If the owner's financial position was poor, the model should lead the owner to the

Design-Build method because this method usually generates the lowest cost to the owner in comparison to the other two methods (DBB and CM-R). For this reason, the code of 3 was given to "poor", the code of 1 was given to "excellent", and the code of 2 was given to "good", as illustrated in the diagram below.

Q I 6 Financial Position (Owner)

	DBB	DB	CM-R
	Excellent	Poor	Good
Coding#	1	3	2

As a third example, question III 12 related to the project schedule which was a factor in time consideration. If the owner indicated that there was a limited (rigid) schedule, meaning that the project must be completed within a severely compressed time limit, the model should lead the owner to the DB method. The DB method minimized the time required to complete a project since under this PDS the design and construction would be managed and performed under one contractor. Therefore, the code of 3 was assigned to "rigid", the code of 1 was assigned to "flexible", and the code of 2 was assigned to "critical but some flexibility", as illustrated below.

Q III 12 Project Schedule

	DBB	DB	CM-R
	Flexible	Limited	Critical but has some flexibility
Coding#	1	3	2

For a final example, question III 13a1 related to facility startup which was a factor in project quality. If the owner chose "good" the model should lead to the CM-R method which offered the owner a high level of quality. Therefore, the code of 3 was given to "good", the code of 1 was given to "poor" and the code of 2 was given to "average", as illustrated below.

III 13 a1 Facility startup

	DBB	DB	CM-R
	Poor	Average	Good
Coding#	1	2	3

The above examples describe the rationale for assigning codes to the responses to individual items which measured the project factors of time, cost, quality, and safety. However, there were many other factors to consider in choosing the best PDS. Therefore, in addition to project factors, the model also took owner objectives (key consideration points) and project parameters (key decision points) into consideration. Key consideration points included such characteristics as type of project, owner capability, and possibility of change (see Table 11, Appendix A). Data coding for the remaining factors is illustrated in Appendix B. Key decision points included parameters such as owner risk, owner controlling and involvement, transfer technology, and political considerations or government policies. The coding for key decision points is summarized in Table 27 (Appendix A).

3.10 Data Entry

After survey responses were coded, data was entered into an Excel spreadsheet. Once data entry were completed, the data were imported to SPSS for analysis.

3.11 Inputting Survey Data into the Model and Outcome Estimation

The following procedures were used to build the project delivery decision model (PDDS):

3.11.1 Procedure for Completing Project Factors Matrix

Step 1

Fill out Tables 7, 8, 9 and 10 (Appendix A) for each project, based on project owners, responses to survey items. Data from each project were entered for only one PDS as reported by the owner in survey item III, 9. To serve as an example, data on items related to cost for a subset of projects in the sample are shown in Figure 3.5 below.

Data entry…Cont. (2) Cost (for a subset of project)

Project ID	1	2	3	4	5						11	12	13				17	18
Items\ PDS	**DBB**	**DBB**	**DBB**	**DBB**	**CM-R**						**DBB**	**DB**	**DBB**				**DBB**	**DBB**
I5	1	1	1	2	1						1	1	3				2	1
I6	3	2	1	2	1						1	1	1				2	2
II6	2	3	2	1	3						1	2	2				3	3
III5	2	2	2	2	1						1	3	1				2	2
III 7.1	3	3	3	3	3						3	3	3				3	3
III 7.2	3	3	3	3	3						3	3	3				3	3
III 7.3	3	2	3	2	3						2	2	2				2	2
III 7.4	3	1	3	3	1						3	1	1				1	1
III 7.5	3	1	3	3	1						1	1	1				1	1
III 8	3	1	1	1	1						3	1	1				1	1
III 11	2	2	2	1	2						3	3	3				3	2
III 14-a	3	3	3	3	3						3	3	3				3	3
III 14-b	3	1	3	3	3						3	3	3				3	3
Mean	**2.6**	**1.9**	**2.3**	**2.2**	**2.0**						**2.2**	**2.1**	**2.1**				**2.2**	**2.1**

Figure 3.5 Data Entry Example for the Cost Factor

Step 2

Calculate the mean for each factor (time, cost, quality and safety) for each project.

Step 3

Transfer means for Tables 7, 8, 9 and 10 to Tables 3, 4, 5 and 6, (Appendix A), for each project, respectively.

Example: mean for project ID 1 was entered in Row 1, etc.

Step 4

After Tables 3, 4, 5, and 6 (Appendix A) were completed for all projects, calculate the mean for each PDS for that factor; for example, Table 3 for cost, Table 4 for time, etc. For example, data entry of the cost mean for a subset of projects included in the sample is shown in Figure 3.6 below.

Data entry…Cont. (3) Cost (for some project)

Project ID	1	2	3		5						11	12	13				17	18	Mean
DBB	2.6	1.9	2.3								2.2		2.1				2.2	2.1	2.1
DB												2.1							2.1
CM-R					2														2

Figure 3.6 Data Entry Example for the Cost Factor Mean.

Step 5a

Transfer the means that had been calculated in Step 4 to Table 2 (Appendix A): Project Factors Matrix.

Step 5b

The weight for each factor was decided by the owner in Table 25 (Appendix A). The owner gave qualitative answers. For example, the options cost and time were very important to not important. The options for quality were exceeded expectations, met expectations, or did not meet expectations. For safety, the options were high level, acceptable level, or low level. The qualitative responses were converted to quantitative responses in Table 25. The quantitative information in Table 25 was transferred to the weighting factor column of Table 2 for each factor.

Step 6

Use equation $U_{(ai)}$ = SUM i [W_j x $U_{(aij)}$] for data in Table 2 for each PDS to calculate the total for each delivery system. The matrix shown below illustrates the procedure.

Project Factors Matrix

Factors	WF To be decided by owner	DBB (a1)	DB (a2)	CM-R (a3)
Cost	WF1	Ua11	Ua21	Ua31
Time	WF2	Ua12	Ua22	Ua32
Quality	WF3	Ua13	Ua23	Ua33
Safety	WF3	Ua13	Ua23	Ua33
Total (Should be transferred to Summary Results Table 1)		Ua1	Ua2	Ua3

Step 7

The result of the equation displayed in Step 6 was transferred to Table 1 for each PDS.

3.11.2 Procedure for Completing Project Owner Objectives Matrix

Step 1

Fill out tables 18, 19, 20, 21, 22 and 23 (Appendix A) for each project, based on project owner's response to survey items. Data from each project were entered for only one PDS as reported by the owner in survey item III, 9.

Step 2

Calculate mean for each owner objective, key consideration point (type of project, size of project, owner capabilities, etc.) for each project.

Step 3

Transfer means for Tables 18, 19, 20, 21, 22 and 23 to Tables 12, 13, 14, 15, 16 and 17, respectively, for each project.

Example: mean for project ID 1 was entered in Row 1, etc.

Step 4

After Tables 12, 13, 14, 15, 16 and 17 (Appendix A) were completed for all projects, calculate the mean for each PDS for that owner's objectives, key consideration points; for example, Table 12 for type of project, table 13 for size of project, etc.

Step 5a

Transfer the means that had calculated in Step 4 to Table 11: Owner Objectives, Key Consideration Points, Matrix.

Step 5b

The weight for each owner objective, key consideration point, was decided by the owner in Table 24 (Appendix A). The owner gave qualitative answers. The response options varied across the key consideration points. For example, for type of project, the options are more complex and unique (more control), medium, or less complex and unique (less control). The qualitative responses were converted to quantitative responses in Table 24 and the quantitative information in Table 24 was transferred to the Weighting Factor column of Table 11.

Step 6

Use equation $U_{(ai)}$ = SUM i [W_j x $U_{(aij)}$] for data in Table 11 for each PDS. The matrix below illustrates the procedure.

Owner objectives (key consideration matrix) (example**)**

Characteristics	WF To be decided by the owner	DBB (a1)	DB (a2)	CM-R
Type of project	6.00	2.00	1.00	3.00
Size of project $Cost/ ft^2	4.00	3.00	2.00	1.00
Owner capabilities (Financial & Experience)	10.00	3.00	1.00	2.00
Contractor capabilities (Financial & Experience)	4.00	1.00	3.00	2.00
Time Consideration	9.00	1.00	3.00	2.00
Possibilities of Changes	7.00	2.00	3.00	1.00
Total (Should be transferred to Summary Results Table # -1-)		81.00	84.00	75.00

Step 7

The result of the equation displayed in Step 11 was transferred to Table 1 for each PDS.

3.11.3 Procedure for Completing Project Parameters Matrix

Step 1

The weight for each parameter was decided by the owner in Table 26 (Appendix A). The owner gave qualitative answers. The response options varied across the parameters. For example, for owner risk, the options were high risk, medium risk, or low risk. The qualitative responses were converted to quantitative responses in Table 26 and the quantitative information in Table 26 was transferred to the Weighting Factor column of Table 27.

Step 2

The weights that were placed in the DBB, DB, and CM-R columns of Table 27 for each parameter were based on the results of previous research.

Step 3

Use equation $U_{(ai)}$ = SUM i [W_j x $U_{(aij)}$] for data in Table 27 for each PDS.

Step 4

The result of the equation displayed in Step 3 was transferred to Table 1 for each PDS

3.11.4 Executing the Model

After the three main matrices representing the three major criteria, project factors, owner objectives, and project parameters (see Table 2, Table 11, and Table 27 in Appendix A) were completed, the data from these matrices were integrated to form the WF model which led to the PDSDF illustrated in Table 1. The relative importance of these major criteria on a scale of 1 to 10 as evaluated by the decision maker (project owner) were input into the Weighting Factors column (Column 2) of Table 1. For the purpose of testing the model, it was necessary for the researcher to make assumptions about the relative importance of the three major criteria. The scheme for Table 1 is shown in the matrix below.

Summary Results of project Evaluation Matrices of Decision Model

Criteria (1)	WF by owner (2)	DBB (a1) (3)	DB (a2) (4)	CM-R (a3) (5)
Project Factors Matrix (Questionnaire)	WF1	Ua11	Ua21	Ua31
Project Key Consideration Matrix (Questionnaire)	WF2	Ua12	Ua22	Ua32
Project Parameters (Key Decision Points) (Previous Study)	WF3	Ua13	Ua23	Ua33
Total Points		Ua1	Ua2	Ua3
Select Maximum				

3.12 Data Analysis

3.12.1 Validating Questionnaire Items

In this context, validity means that items that were included in the questionnaire because the researcher believed they were, for example, related to quality, actually were related to quality. Chi-square analysis was used to validate questionnaire items.

3.12.1.1 **Chi-square Test** The chi-square test of independence or association is a statistical technique that is used to assess whether there is a relationship or association between two categorical variables. Computations for this test are based on a two-way cross-tabulation table of frequencies within pairings of each category on one variable and each category on the other. For example, if the two categorical values were gender (male/female) and test result (passed/failed), the cross-tabulation table would display the frequency or count of males who passed, males who failed, females who passed, and females who failed. Observed frequencies within each cell of the cross-tabulation table are compared to the frequencies that would be expected if the two variables were independent of each other.

In this research the following items were tested in this way:

1. The relationship between items intended to relate to quality (for example, I3 – construction experience) (low, medium, high) and items that directly asked about quality (III13). (3 category)

Chi-square analysis was used to look at one part (for example, 13a.1). The result indicated if there was a significant relationship between owner experience and performance quality of the project. A total score for quality could also be created by adding all the parts.

for each part

13a.1, 13a.2, 13a.3, 13b.1, 13b.2, 13b.3, 13c

for each part scores are 1, 2 or 3

for total scores would be from 7 to 21

2. The researcher will examined the relationship between items that were intended to relate to cost (for example, I6/II6 owner's financial position) (3 category) and items that directly asked about cost (III11).

3. The researcher examined the relationship between items that were intended to relate to time (for example, III4 size of project) and items that directly asked about time (III12).

3.12.2 Compare PDS's:

One-way analysis of variance (ANOVA) was used to compare the average cost, time and quality of projects built under the three PDS methods.

3.12.2.1 **One Way Analysis (ANOVA)** One way analysis of variance (ANOVA) is a statistical technique that tests for differences between the means of two or more groups. The underlying logic of (ANOVA) is based on comparing the variance among group means to the variance within each group. One way (ANOVA) is typically used in situations where the independent variable is categorical and the dependent variable is quantitative and continuous. Therefore it was an appropriate technique to compare the mean costs of the three project delivery systems.

As an example, one-way (ANOVA) tested for significant differences in the average total quality scores for owners with low, medium, and high experience.

One-way analysis of variance (ANOVA) was used to compare the average time (duration) of projects built under the three PDS methods, time being expressed as days and cost was standardized as dollars per square foot ($\$/ft^2$). The ratio was MST/MSE [(15)], where MST stands for mean square of treatments and MSE stands for mean squared error.

3.13 The Analytic Hierarchy Process (AHP) [Method 2]

The Analytic Hierarchy Process (AHP) is a powerful and flexible decision- making tool for complex, multi-criteria problems where both qualitative and quantitative aspects of a problem need to be incorporated. The AHP helps decision- makers (who in this case were project owners) structure the important components of a problem into a hierarchical structure. Then, by reducing complex decisions to a series of simple pairwise comparisons, and synthesizing the results, the AHP helps decision-makers arrive at the best decision. The AHP was formalized by L. Thomas Saaty in the 1970s and continues to be the most highly regarded and widely used decision-making theory in use. In other words, the AHP is an analytical tool, supported by simple mathematics, that enables decision-makers to explicitly rank tangible and intangible factors against each other for the purpose of resolving conflict or setting priorities (Satty 1980, 1990, 1994).

The process involves structuring a problem from a primary objective to secondary levels of objectives. Once these hierarchies have been established, a pairwise comparison matrix for each element within each level is constructed. Participants can weigh each element against each other element within each level, each level being related to the levels above and below it, and the entire scheme tied together mathematically. The result is a clear priority statement of an individual or group.

3.14 Pairwise Comparisons

In this study AHP enabled decision-makers (project owner) to make pairwise comparisons of importance between decision elements with respect to the scale shown in Table 3.1. For example, comparing objective *i* and objective *j* (where *i* was assumed to be at least as important as *j*), gave a value a_{ij} as shown in the same table. "Saaty has shown that we can use the whole numbers 1 through 9 to represent approximately the comparisons of homogenous elements, to indicate smaller differences, decimals are added to these numbers." [16] Figure 3.7 is an example of a typical pairwise judgment comparison matrix.

Table 3.1 Intensity Scale, Developed and Adopted from Saaty

Comparative Importance	Definition	Explanation
1	Equally important	Objectives *i* and *j* are of equal importance.
3	Moderately more important	Objectives *i* is weakly more important than *j*.
5	Strongly more important	Objectives *i* is strongly more important than *j*.
7	Very strongly more important	Objectives *i* is very strongly more important than *j*.
9	Extremely more important	The difference between influences of the two decision elements is extremely significant. On other words, Objectives *i* is absolutely more important than *j*.
2, 4, 6, 8	Intermediate judgment values	Judgment values between equally, moderately, strongly, very strongly, and extremely.
Reciprocals		If v is the judgment value when *i* is compared to *j*, then 1/v is the judgment value when *j* is compared to *i*.

3.15 Assessing Consistency of Pairwise Judgments

In pairwise comparison of factors, if the decision-maker says "I care about project cost more than project schedule", "I care about project schedule more than project quality", and "I care about project quality more than project cost", he would be very inconsistent in his pairwise judgments.

Specific Criterion	C_1	C_2	C_3	……….	C_n
C_1	1	3	1/7		9
C_2	1/3	1	1/4		3
C_3	7	4	1		1/2
.					
.					
C_n	1/9	1/3	2	.	1

Figure 3.7 Typical Pairwise Judgment Comparison Matrix

3.16 AHP Methodology

This section provides an introduction to AHP with an emphasis on the presentation of the general methodology.

Step 1.

Develop the hierarchical representation of the problem. At the top of the hierarchy is the overall objective which in this study was that the project owners should be able to choose the best PDS; and the decision alternatives were at the bottom (DBB, DB and CM-R). Between the top and bottom levels are the relevant attributes of the decision problem, such as selection criteria and the various project factors, owner objectives and project parameters, if appropriate, that provided significant input in the decision process. The number of levels in the hierarchy depends on the complexity of the problem and the analyst/decision-maker model of the problem hierarchy. Figure 3.8 shows a typical hierarchy model.

Step 2.

Generate relational data for comparing the alternatives (from survey and previous study). This requires the analyst (decision-maker) to make pairwise comparisons of elements at each level relative to each activity at the next higher level in the hierarchy (using Table 3.1).

Step 3.

Estimate the relative priorities (weights) of the decision criteria and alternatives.

Step 4.

Check the consistency of pairwise judgments.

Step 5,

Put together a list of priorities for the criteria which gives the rank of the alternatives.

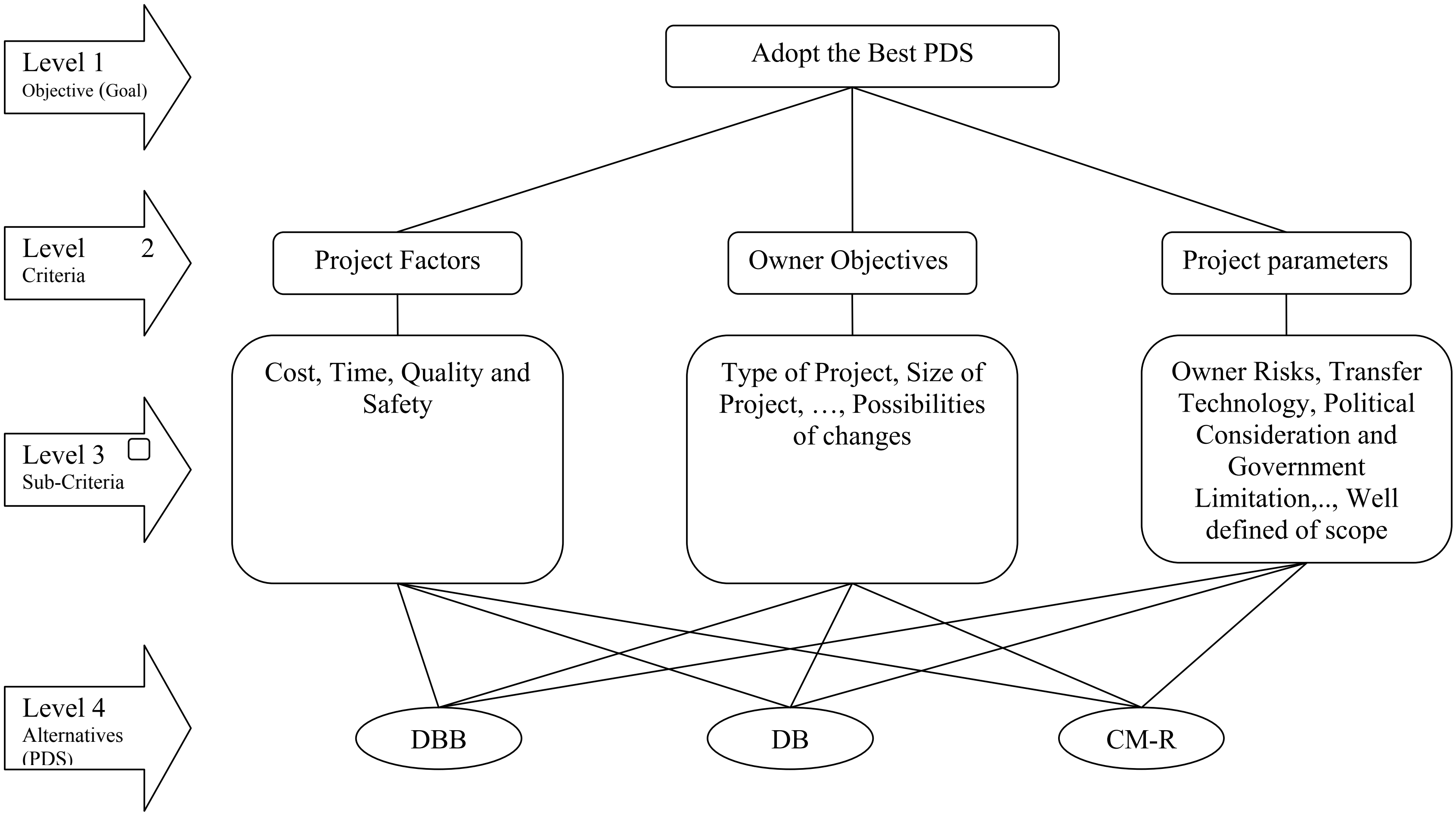

Figure 3.8 Hierarchy Model

4.0 RESULTS AND ANALYSES

This chapter will present the characteristics of participants, and then the results of chi-square tests carried out to evaluate the consistency of participants' responses to questions that are related to the same factor or variable. Comparison of project delivery systems (PDSs) will be discussed by answering research questions a, b, c, and d. Next, this chapter will present the results of the study. The results obtained from Method 1, the WF method, will be presented first followed by the results obtained from Method 2, AHP. Finally, the results obtained from the two methods will be analyzed and compared and any differences will be discussed.

4.1 Characteristics of Participants

As described in chapter three, the sample for the present study consisted of projects currently listed in Riyadh, S.A. as completed within the last 15 years. A total of 150 questionnaire packets were sent to participants. Although the original plan was to distribute 100 questionnaires, this number was later changed to 150. The additional 50 questionnaires were included to make allowances for respondents who were unwilling to participate, and for the possibility that some questionnaires would be lost or undeliverable. Also, it was anticipated that some portion of the questionnaires that were completed and returned would not be usable. A total of 101 were returned: 14 questionnaires could not be used in the analyses as they were did not have the proper experience to respond and incomplete, 10 responses were received after the deadline; resulting in a total 77 were usable surveys that qualified for analysis.

Of the 77 participants' projects, 59 (77 %) were from the public sector and 18 (23 %) were from the private sector (see Figure 4.1). The majority of the projects (70 %) were performed by DBB method while 22 percent and 8 percent were performed by DB and CM-R, respectively (see Figure 4.2). Forty percent of the projects were typical for the owner; however 44 percent of the participant's projects were typical for the contractor. The majority of projects (80 %) were constructed by general contractors while 13 percent were performed by special contractors. Forty-five percent of the projects cost from SR11 to SR50 million, 25 percent from SR51 to SR100 million, 20 percent from SR01 to SR10 million, and 10 percent cost more than SR100 million (see Figure 4.3). Finally, most of the projects (95 %) were new projects. Table 4.1 summarizes the characteristics of the subjects included in this study.

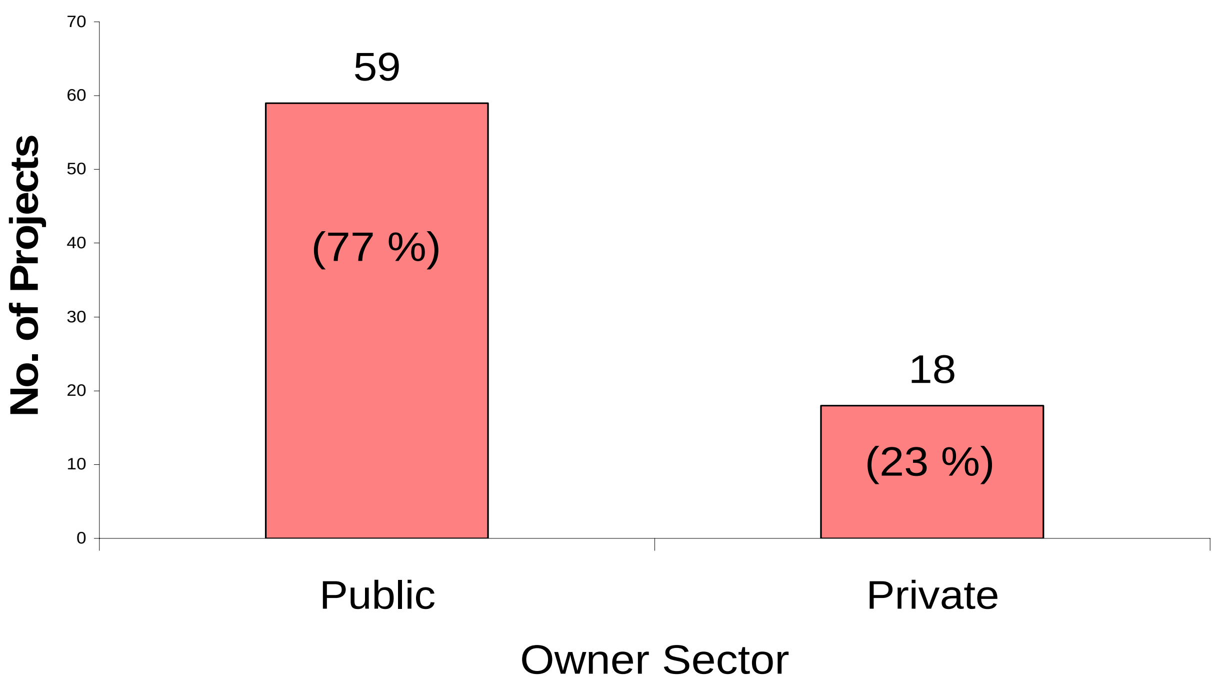

Figure 4.1 Owner Sector

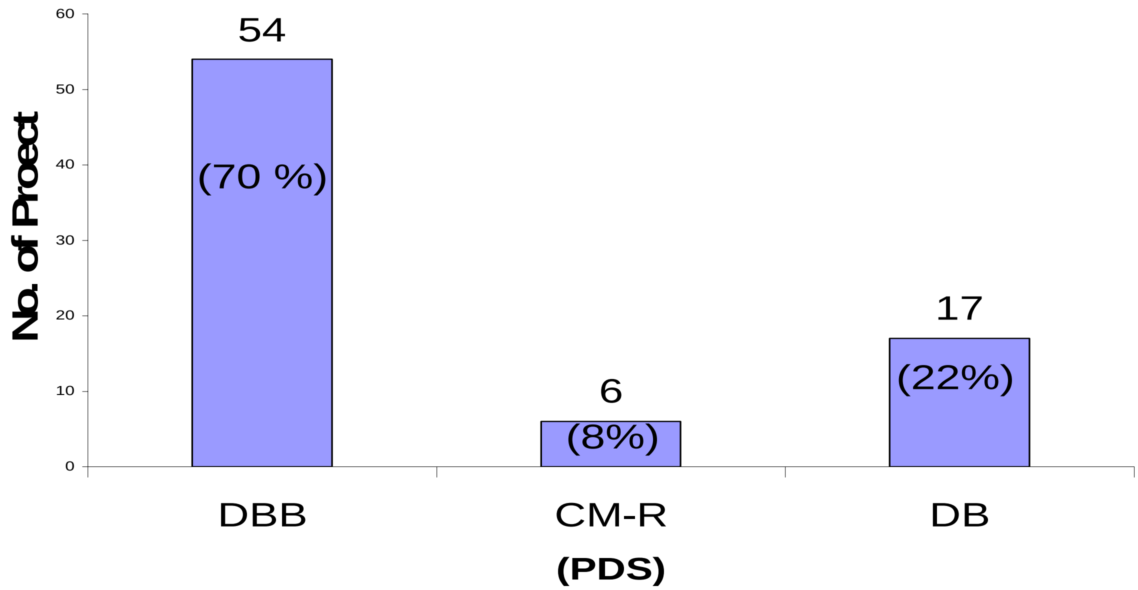

Figure 4.2 Type of Project Delivery System

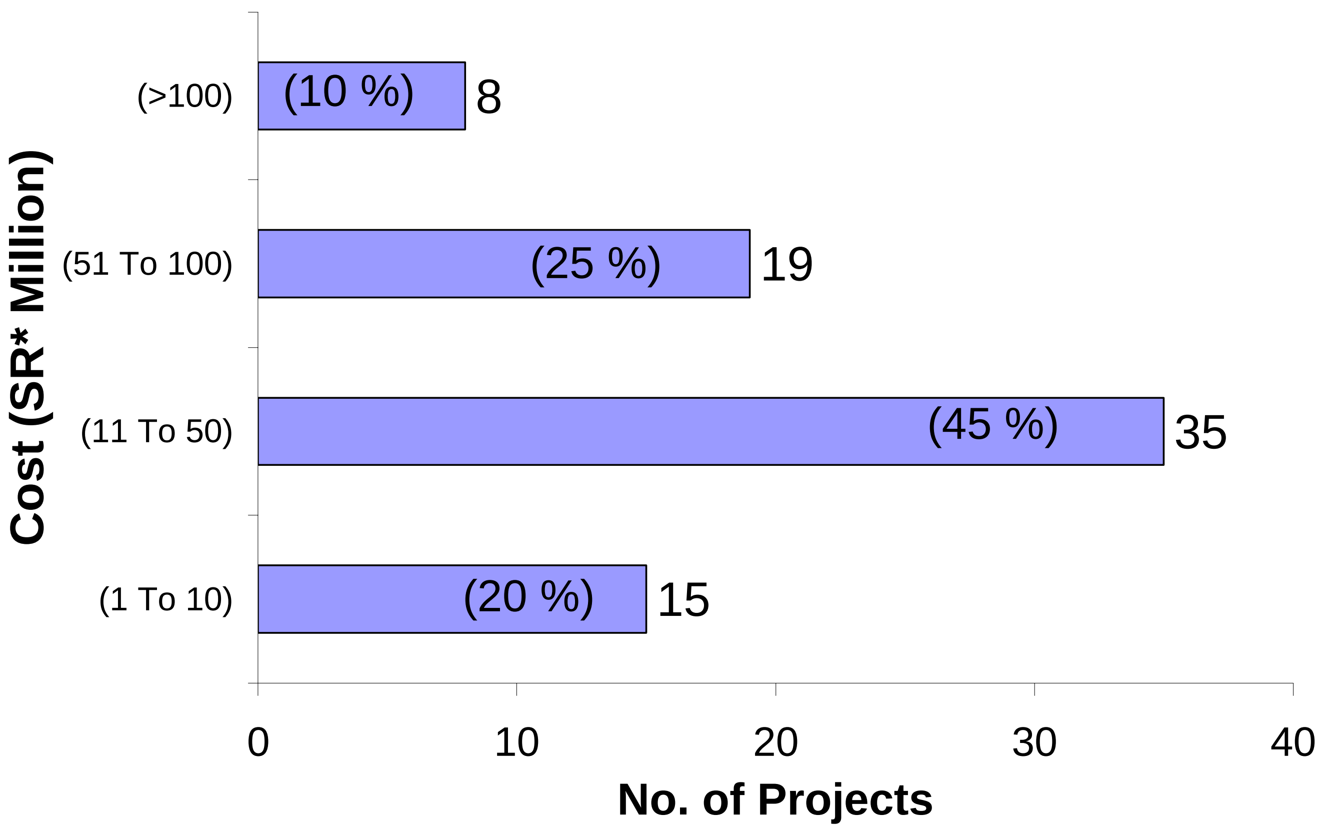

Figure 4.3 Range of Cost (SR)

Table 4.1 Characteristics of the Participating Project

Characteristics		N	%
		77	
Sector	Public	59	77
	Private	18	23
Project status	New	73	95
	Renovation	3	4
	Both	1	1
PDS	DBB	54	70
	DB	17	22
	CM-R	6	8
Type of contractor	Special	10	13
	General	62	80
	Others	5	7
Range of cost, project actual cost(SR/M)	01 to 10	15	20
	11 to 50	35	45
	51 to 100	19	25
	> 100	8	10
Project typical of work for the owner	Typical	31	40
	Not typical	46	60
Project typical of work for the contractor	Typical	34	44
	Not typical	43	56
Cost of the majority of past project for the owner (SR/M)	00 to 10	19	25
	11 to 30	24	31
	31 to 60	22	29
	> 60	12	15
Project type	Multistory dwelling and light industrial project	23	30
	Simple and complex office	35	45
	Heavy industrial and high technology project	19	25
N=77			

4.2 Chi-square Analysis

The chi-square test of independence or association is a statistical technique that is used to test whether there is a relationship or an association between two qualitative variables. The logic upon which the chi-square test of association is based is as follows. If there is no association between the row variable and the column variable, then the distribution of observations across levels of the column variable should be the same at all levels of the row variable. For example if there is no association between experience of the owner's staff in the field and the quality of startup, then the proportion of projects with poor, average, and good startup quality should be the same for staff with low, medium, and high experience. This logic leads to the formal way of stating the null hypothesis of no association:

H_0: $P_{1(1)} = P_{1(2)} = \ldots. = P_{1(c)}$
$P_{2(1)} = P2_{(2)} = \ldots = P_{2(c)}$
.
.
$P_{r(1)} = P_{r(2)} = . . . = P_{r(c)}$

Where: (r) denotes row, (c) denotes column and (P) denotes probability of indicated level of the column variable within the indicated level of the row variable.

The formal way of stating the alternative hypothesis is as follows:

Ha: At least one of the equalities in H0 does not hold.

For example, P1(1) ≠ P1(2).

Form of null and alternative hypotheses for chi-square test displayed in Table 4.3

-Null hypothesis:

H_0: $P_{1(1)} = P_{1(2)} = P_{1(3)}$

$P_{2(1)} = P_{2(2)} = P_{2(3)}$

$P_{3(1)} = P_{3(2)} = P_{3(3)}$

-Alternative hypothesis:

H_a: $P_{1(1)} \neq P_{1(2)} \neq P_{1(3)}$ or

$P_{2(1)} \neq P_{2(2)} \neq P_{2(3)}$ or

$P_{3(1)} \neq P_{3(2)} \neq P_{3(3)}$

Explanation of null and alternative hypotheses for chi-square test displayed in Table 4.3

-Null Hypothesis (H_0):

Probability of poor startup quality with low owner staff experience ($P_{1(1)}$)=Probability of average startup quality with low owner staff experience($P_{1(2)}$)=Probability of good startup quality with low owner staff experience($P_{1(3)}$).

Probability of poor startup quality with high owner staff experience ($P_{2(1)}$)=Probability of average startup quality with high owner staff experience($P_{2(2)}$)=Probability of good startup quality with high owner staff experience($P_{2(3)}$).

Probability of poor startup quality with medium owner staff experience ($P_{3(1)}$)=Probability of average startup quality with medium owner staff experience($P_{3(2)}$)=Probability of good startup quality with medium owner staff experience($P_{3(3)}$).

-Alternative Hypothesis (H_a):

Probability of poor startup quality with low owner staff experience ($P_{1(1)}$) $\neq$ Probability of average startup quality with low owner staff experience($P_{1(2)}$)$\neq$Probability of good startup quality with low owner staff experience($P_{1(3)}$). or

Probability of poor startup quality with high owner staff experience ($P_{2(1)}$)$\neq$Probability of average startup quality with high owner staff experience($P_{2(2)}$) $\neq$Probability of good startup quality with high owner staff experience($P_{2(3)}$). or

Probability of poor startup quality with medium owner staff experience ($P_{3(1)}$)$\neq$Probability of average startup quality with medium owner staff experience($P_{3(2)}$) $\neq$Probability of good startup quality with medium owner staff experience($P_{3(3)}$). [22]

The data shown in Table 4.3 lead to the rejection of the null hypothesis. It can be seen that in the sample the probability of poor startup quality with low owner staff experience (84.6%)

is much higher than the probability of average startup quality or good startup quality with low owner staff experience (both 7.7%). The null and alternative hypotheses for the remaining chi-square analysis are expressed in the same form and interpreted in the same way.

In this case this analysis was being done to evaluate the consistency of participant responses to questions that were intended to relate to the same factor or variable. Computations for this test were based on a two-way cross-tabulation table of frequencies within pairings of each category on one variable and each category on the other, The following items were tested:

4.2.1 The Experience of the Owner's Staff vs. the Quality of Facility Startup

Table 4.2 shows the results of a chi-square analysis on the relationship between the experience of the owner's management staff in the field and the quality of facility startup. The following null hypothesis was tested: There is no relationship or association between the experience of the owner staff in the field and the quality of facility startup. The alternative hypothesis was: There is an association or relationship between the experience of the owner staff in the field and the quality of facility startup. Since results of the chi-square test were significant (chi-square=68.010, df=4, p<.001), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.3) shows that when the owner's management staff experience is low, quality tends to be poor (11 out of 13 or 84.6%), but when the owner's management staff experience is high, quality tends to be good (41 out of 48 or 85.4%).

Table 4.2 Chi-Square Test (Facility Startup)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	68.010(a)	4	.000
Likelihood ratio	55.649	4	.000
Linear-by-linear association	9.078	1	.003
N of valid cases	77.00		

Table 4.3 Experience of Owner's Management Staff in the Field by Facility Startup

(Crosstab)			facility startup			Total
			poor	average	good	
experience of owner's management staff in the field	low experience	Count	11	1	1	13
		% within experience of owner's management staff in the field	84.6%	7.7%	7.7%	100.0%
	high experience	Count	2	5	41	48
		% within experience of owner's management staff in the field	4.2%	10.4%	85.4%	100.0%
	medium experience	Count	1	10	5	16
		% within experience of owner's management staff in the field	6.3%	62.5%	31.3%	100.0%
Total		Count	14	16	47	77
		% within experience of owner's management staff in the field	18.2%	20.8%	61.0%	100.0%

4.2.2 The Experience of the Owner's Staff vs. the Number of Call Backs

Table 4.4 shows the results of a chi-square analysis on the relationship between the experience of the owner's management staff in the field and the number of call backs. The following null hypothesis was tested: There is no relationship or association between the experience of the owner staff in the field and the number of call backs. The alternative hypothesis was: There is an association or relationship between the experience of the owner staff in the field and the number of call backs. Since results of the chi-square test were significant (chi-square=56.062, df= 4, p<.001), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.5) shows that when the owner's management staff experience was low, the number of call backs tended to be high (12 out of 13 or 92.3%), but when the owner's management staff experience was high, the number of call backs tended to be low (34 out of 48 or 70.8%).

Table 4.4 Chi-Square Test (Number of Callbacks)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	56.062(a)	4	.000
Likelihood ratio	53.379	4	.000
Linear-by-linear association	5.379	1	.020
N of valid cases	77.00		

Table 4.5 Experience of owner's management staff in the field by number of call backs

(Crosstab)			number of call backs			Total
			high	average	low	
experience of owner's management staff in the field	low experience	Count	12	1		13
		% within experience of owner's management staff in the field	92.3%	7.7%		100.0%
	high experience	Count	5	9	34	48
		% within experience of owner's management staff in the field	10.4%	18.8%	70.8%	100.0%
	medium experience	Count	3	11	2	16
		% within experience of owner's management staff in the field	18.8%	68.8%	12.5%	100.0%
Total		Count	20	21	36	77
		% within experience of owner's management staff in the field	26.0%	27.3%	46.8%	100.0%

4.2.3 The Experience of the Owner's Staff vs. O&M Cost

Table 4.6 shows the results of a chi-square analysis on the relationship between the experience of the owner's management staff in the field and operation and maintenance cost for building and site. The following null hypothesis was tested: There is no relationship or association between the experience of the owner staff in the field and the operation and maintenance cost for building and site. The alternative hypothesis was: There is an association or relationship between the experience of the owner staff in the field and the operation and maintenance cost for building and site. Since results of the chi-square test were significant (chi-square=34.223, df= 4, p<.001), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.7) shows that when the owner's management staff experience was low, operation and maintenance cost for building and site tended to be high (8 out of 13 or 61.5%), but when the owner's management staff experience was high, operation and maintenance cost for building and site tended to be low (33 out of 48 or 68.8%).

Table 4.6 Chi-Square Test (O&M)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	34.223(a)	4	.000
Likelihood ratio	31.681	4	.000
Linear-by-linear association	4.728	1	.030
N of valid cases	77.00		

Table 4.7 Experience of Owner's Management Staff in the Field by Operation and Maintenance Cost for Building and Site

(Crosstab)			operation and maintenance cost for building and site			Total
			high cost	average cost	low cost	
experience of owner's management staff in the field	low experience	Count	8	4	1	13
		% within experience of owner's management staff in the field	61.5%	30.8%	7.7%	100.0%
	high experience	Count	6	9	33	48
		% within experience of owner's management staff in the field	12.5%	18.8%	68.8%	100.0%
	medium experience	Count	1	11	4	16
		% within experience of owner's management staff in the field	6.3%	68.8%	25.0%	100.0%
Total		Count	15	24	38	77
		% within experience of owner's management staff in the field	19.5%	31.2%	49.4%	100.0%

4.2.4 The Experience of the Owner's Staff vs. Performance of the Envelope

Table 4.8 shows the results of a chi-square analysis on the relationship between the experience of the owner's management staff in the field and quality of performance of the envelope (roof, structure, and foundation). The following null hypothesis was tested: There is no relationship or association between the experience of the owner staff in the field and the quality performance of the envelope. The alternative hypothesis was: There is an association or relationship between the experience of the owner staff in the field and the quality performance of the envelope. Since results of the chi-square test were significant (chi-square= 68.098, df = 4, p<.001), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.9) shows that when the owner's management staff experience was low, quality of performance of the envelope tended to be low (10 out of 13 or 76.9%), but when the owner's management staff experience was high, quality of performance of the envelope tended to be high (41 out of 48 or 85.4%).

Table 4.8 Chi-Square Test (Quality of Performance of the Envelop)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	68.098(a)	4	.000
Likelihood ratio	53.809	4	.000
Linear-by-linear association	9.999	1	.002
N of valid cases	77.00		

Table 4.9 Experience of Owner's Management Staff in the Field by Quality of Performance of the Envelope

(Crosstab)			quality of performance of the envelope			Total
			low	average	high	
experience of owner's management staff in the field	low experience	Count	10	1	2	13
		% within experience of owner's management staff in the field	76.9%	7.7%	15.4%	100.0%
	high experience	Count	1	6	41	48
		% within experience of owner's management staff in the field	2.1%	12.5%	85.4%	100.0%
	medium experience	Count		10	6	16
		% within experience of owner's management staff in the field		62.5%	37.5%	100.0%
Total		Count	11	17	49	77
		% within experience of owner's management staff in the field	14.3%	22.1%	63.6%	100.0%

4.2.5 The Experience of the Owner's Staff vs. Interior Space And Layout Quality

Table 4.10 shows the results of a chi-square analysis on the relationship between the experience of the owner's management staff in the field and interior space and layout quality. The following null hypothesis was tested: There is no relationship or association between the experience of the owner staff in the field and the interior space and layout quality. The alternative hypothesis was: There is an association or relationship between the experience of the owner staff in the field and the interior space and layout quality. Since results of the chi-square test were significant (chi-square=60.919, df = 4, p<.001), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.11) shows that when the owner's management staff experience was low, operation interior space and layout quality tended to be low (10 out of 13 or 76.9 %), but when the owner's management staff experience was high, interior space and layout quality tended to be high (39 out of 48 or 81.3 %).

Table 4.10 Chi-Square Test (Interior Space and Layout Quality)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	60.919(a)	4	.000
Likelihood ratio	48.103	4	.000
Linear-by-linear association	11.735	1	.001
N of valid cases	77.00		

Table 4.11 Experience of Owner's Management Staff in the Field by Interior Space and Layout Quality

(Crosstab)			interior space and layout quality			Total
			low	average	high	
experience of owner's management staff in the field	low experience	Count	10	1	2	13
		% within experience of owner's management staff in the field	76.9%	7.7%	15.4%	100.0%
	high experience	Count	1	8	39	48
		% within experience of owner's management staff in the field	2.1%	16.7%	81.3%	100.0%
	medium experience	Count		9	7	16
		% within experience of owner's management staff in the field		56.3%	43.8%	100.0%
Total		Count	11	18	48	77
		% within experience of owner's management staff in the field	14.3%	23.4%	62.3%	100.0%

4.2.6 The Experience of the Owner's Staff vs. Environmental or Mechanical System

Table 4.12 shows the results of a chi-square analysis on the relationship between the experience of the owner's management staff in the field and environmental or mechanical system quality. The following null hypothesis was tested: There is no relationship or association between the experience of the owner staff in the field and the environmental or mechanical system quality. The alternative hypothesis was: There is an association or relationship between the experience of the owner staff in the field and the environmental or mechanical system quality. Since results of the chi-square test were significant (chi-square=62.146, df = 4, p<.001), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.13) shows that when the owner's management staff experience was low, environmental or mechanical system quality tended to be low (10 out of 13 or 76.9 %), but when the owner's management staff experience was high, environmental or mechanical system quality tended to be high (41 out of 48 or 85.4%).

Table 4.12 Chi-Square Test (Environmental or Mechanical System Quality)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	62.146(a)	4	.000
Likelihood ratio	50.138	4	.000
Linear-by-linear association	9.477	1	.002
N of valid cases	77.00		

Table 4.13 Experience of Owner's Management Staff in the Field by Environmental or Mechanical System Quality

(Crosstab)			environmental or mechanical system quality			Total
			low	average	high	
experience of owner's management staff in the field	low experience	Count	10		3	13
		% within experience of owner's management staff in the field	76.9%		23.1%	100.0%
	high experience	Count	2	5	41	48
		% within experience of owner's management staff in the field	4.2%	10.4%	85.4%	100.0%
	medium experience	Count		9	7	16
		% within experience of owner's management staff in the field		56.3%	43.8%	100.0%
Total		Count	12	14	51	77
		% within experience of owner's management staff in the field	15.6%	18.2%	66.2%	100.0%

4.2.7 The Experience of the Owner's Staff vs. Equipment Quality

Table 4.14 shows the results of a chi-square analysis on the relationship between the experience of the owner's management staff in the field and equipment quality. The following null hypothesis was tested: There is no relationship or association between the experience of the owner staff in the equipment quality. The alternative hypothesis was: There is an association or relationship between the experience of the owner staff in the field and the equipment quality. Since results of the chi-square test were significant (chi-square=38.376, df= 4, p<.001), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.15) shows that when the owner's management staff experience was low, equipment quality tended not to meet expectations (8 out of 13 or 61.5%), but when the owner's management staff experience was high, equipment quality tended to meet expectations (37 out of 48 or 77.1%).

Table 4.14 Chi-Square Test (Equipment Quality)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	38.376(a)	4	.000
Likelihood ratio	29.141	4	.000
Linear-by-linear association	9.445	1	.002
N of valid cases	77.00		

Table 4.15 Experience of Owner's Management Staff in the Field by Equipment Quality

(Crosstab)			equipment quality			Total
			did not meet expectations	met expectations	exceeded expectations	
experience of owner's management staff in the field	low exp.	Count	8	4	1	13
		% within experience of owner's management staff in the field	61.5%	30.8%	7.7%	100.0%
	high exp.	Count	1	37	10	48
		% within experience of owner's management staff in the field	2.1%	77.1%	20.8%	100.0%
	medium exp.	Count		14	2	16
		% within experience of owner's management staff in the field		87.5%	12.5%	100.0%
Total		Count	9	55	13	77
		% within experience of owner's management staff in the field	11.7%	71.4%	16.9%	100.0%

4.2.8 The Experience of the Contractor's Staff vs. the Quality of Facility Startup

Table 4.16 shows the results of a chi-square analysis on the relationship between the experience of the contractor's management staff in the field and the quality of facility startup. The following null hypothesis was tested: There is no relationship or association between the experience of the contractor's management staff in the field and the quality of facility startup. The alternative hypothesis was: There is an association or relationship between the experience of the contractor's management staff in the field and the quality of facility startup. Since results of the chi-square test were significant (chi-square=24.361, df = 4, p<.001), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.17) shows that when the contractor's management staff experience was high, the quality of facility startup tended to be good (36 out of 49 or 73.5%), but when the contractor's management staff experience was low, the quality of facility startup tended to be poor (5 out of 6 or 83.3%).

Table 4.16 Chi-Square Test (Facility Startup)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	24.361(a)	4	.000
Likelihood ratio	22.611	4	.000
Linear-by-linear association	7.114	1	.008
N of valid cases	77.00		

Table 4.17 Experience of Contractor's Management Staff in the Field by Facility Startup

(Crosstab)			facility startup			Total
			poor	average	good	
experience of contractor's management staff in the field	high exp.	Count	3	10	36	49
		% within experience of contractor's management staff in the field	6.1%	20.4%	73.5%	100.0%
	low exp.	Count	5	1		6
		% within experience of contractor's management staff in the field	83.3%	16.7%		100.0%
	medium exp.	Count	6	5	11	22
		% within experience of contractor's management staff in the field	27.3%	22.7%	50.0%	100.0%
Total		Count	14	16	47	77
		% within experience of contractor's management staff in the field	18.2%	20.8%	61.0%	100.0%

4.2.9 The Experience of the Contractor's Staff vs. Number of Call Backs

Table 4.18 shows the results of a chi-square analysis on the relationship between the experience of the contractor's management staff in the field and the number of call backs. The following null hypothesis was tested: There is no relationship or association between the experience of the contractor's management staff in the field and the number of call backs. The alternative hypothesis was: There is an association or relationship between the experience of the contractor's management staff in the field and the number of call backs. Since results of the chi-square test were significant (chi-square= 20.255, df = 4, $p<.001$), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.19) shows that when the contractor's management staff experience was high, the number of call backs tended to be low (30 out of 49 or 61.2%), but when the contractor's management staff experience was low, the number of call backs tended to be high (5 out of 6 or 83.3%).

Table 4.18 Chi-Square Test (Number of Callbacks)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	20.255(a)	4	.000
Likelihood ratio	20.978	4	.000
Linear-by-linear association	10.728	1	.001
N of valid cases	77.00		

Table 4.19 Experience of Contractor's Management Staff in the Field by Number of Callbacks

(Crosstab)			number of call backs			Total
			high	average	low	
experience of contractor's management staff in the field	high exp.	Count	6	13	30	49
		% within experience of contractor's management staff in the field	12.2%	26.5%	61.2%	100.0%
	low exp.	Count	5	1		6
		% within experience of contractor's management staff in the field	83.3%	16.7%		100.0%
	medium exp.	Count	9	7	6	22
		% within experience of contractor's management staff in the field	40.9%	31.8%	27.3%	100.0%
Total		Count	20	21	36	77
		% within experience of contractor's management staff in the field	26.0%	27.3%	46.8%	100.0%

4.2.10 The Experience of the Contractor's Staff vs. O&M Cost

Table 4.20 shows the results of a chi-square analysis on the relationship between the experience of the contractor's management staff in the field and operation and maintenance cost for building and site. The following null hypothesis was tested: There is no relationship or association between the experience of the contractor's management staff in the field and the operation and maintenance cost for building and site. The alternative hypothesis was: There is an association or relationship between the experience of the contractor's management staff in the field and the operation and maintenance cost for building and site. Since results of the chi-square test were significant (chi-square= 15.184, df = 4, $p<.004$), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.21) shows that when the contractor's management staff experience was high, the operation and maintenance cost for building and site tended to be low (31 out of 49 or 63.3%), but when the contractor's management staff experience was low, the operation and maintenance cost for building and site tended to be average (3 out of 6 or 50%).

Table 4.20 Chi-Square Test (O&M)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	15.184(a)	4	.004
Likelihood Ratio	15.345	4	.004
Linear-by-Linear Association	12.883	1	.000
N of Valid Cases	77.00		

Table 4.21 Experience of Contractor's Management Staff in the Field by Operation and Maintenance Cost for Building and Site

(Crosstab)			operation and maintenance cost for building and site			Total
			high cost	average cost	low cost	
experience of contractor's management staff in the field	high exp.	Count	4	14	31	49
		% within experience of contractor's management staff in the field	8.2%	28.6%	63.3%	100.0%
	low exp.	Count	2	3	1	6
		% within experience of contractor's management staff in the field	33.3%	50.0%	16.7%	100.0%
	medium exp.	Count	9	7	6	22
		% within experience of contractor's management staff in the field	40.9%	31.8%	27.3%	100.0%
Total		Count	15	24	38	77
		% within experience of contractor's management staff in the field	19.5%	31.2%	49.4%	100.0%

4.2.11 The Experience of the Contractor's Staff vs. Performance of the Envelope

Table 4.22 shows the results of a chi-square analysis on the relationship between the experience of the contractor's management staff in the field and quality of performance of the envelope (roof, structure, and foundation). The following null hypothesis was tested: There is no relationship or association between the experience of the contractor's management staff in the field and the quality of performance of the envelope. The alternative hypothesis was: There is an association or relationship between the experience of the contractor's management staff in the field and the quality of performance of the envelope. Since results of the chi-square test were significant (chi-square= 13.468, df = 4, p<.009), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.23) shows that when the contractor's management staff experience was high, the quality of performance of the envelope (roof, structure, and foundation) tended to be high (37 out of 49 or 75.5%), but when the contractor's management staff experience was low, the quality of performance of the envelope (roof, structure, and foundation) tended to be low cost (3 out of 6 or 50%).

Table 4.22 Chi-Square Test (Quality of Performance of the Envelope)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.468(a)	4	.009
Likelihood ratio	12.622	4	.013
Linear-by-linear association	6.449	1	.011
N of valid cases	77.00		

Table 4.23 Experience of Contractor's Management Staff in the Field by Quality of Performance of the Envelope

(Crosstab)			quality of performance of the envelope			Total
			low	average	high	
experience of contractor's management staff in the field	high experience	Count	3	9	37	49
		% within experience of contractor's management staff in the field	6.1%	18.4%	75.5%	100.0%
	low experience	Count	3	2	1	6
		% within experience of contractor's management staff in the field	50.0%	33.3%	16.7%	100.0%
	Med. experience	Count	5	6	11	22
		% within experience of contractor's management staff in the field	22.7%	27.3%	50.0%	100.0%
Total		Count	11	17	49	77
		% within experience of contractor's management staff in the field	14.3%	22.1%	63.6%	100.0%

4.2.12 The Experience of the Contractor's Staff vs. Interior Space and Layout Quality

Table 4.24 shows the results of a chi-square analysis on the relationship between the experience of the contractor's management staff in the field and interior space and layout quality. The following null hypothesis was tested: There is no relationship or association between the experience of the contractor's management staff in the field and the interior space and layout quality. The alternative hypothesis was: There is an association or relationship between the experience of the contractor's management staff in the field and the interior space and layout quality. Since results of the chi-square test were significant (chi-square= 14.569, df = 4, p<.006), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.25) shows that when the contractor's management staff experience was high, the interior space and layout quality tended to be high (37 out of 49 or 75.5%), but when the contractor's management staff experience was low, the interior space and layout quality tended to be low (3 out of 6 or 50%).

Table 4.24 Chi-Square Test (Interior Space and Layout Quality)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	14.569(a)	4	.006
Likelihood ratio	13.701	4	.008
Linear-by-linear association	7.696	1	.006
N of valid cases	77.00		

Table 4.25 Experience of Contractor's Management Staff in the Field by Interior Space and Layout Quality

(Crosstab)			interior space and layout quality			Total
			low	average	high	
experience of contractor's management staff in the field	high experience	Count	3	9	37	49
		% within experience of contractor's management staff in the field	6.1%	18.4%	75.5%	100.0%
	low experience	Count	3	2	1	6
		% within experience of contractor's management staff in the field	50.0%	33.3%	16.7%	100.0%
	Med. experience	Count	5	7	10	22
		% within experience of contractor's management staff in the field	22.7%	31.8%	45.5%	100.0%
Total		Count	11	18	48	77
		% within experience of contractor's management staff in the field	14.3%	23.4%	62.3%	100.0%

4.2.13 The Experience of the Contractor's Staff vs. Environmental or Mechanical System

Table 4.26 shows the results of a chi-square analysis on the relationship between the experience of the contractor's management staff in the field and environmental or mechanical system quality. The following null hypothesis was tested: There is no relationship or association between the experience of the contractor's management staff in the field and the environmental or mechanical system quality. The alternative hypothesis was: There is an association or relationship between the experience of the contractor's management staff in the field and the environmental or mechanical system quality. Since results of the chi-square test were significant (chi-square= 14.108, df = 4, p<.007), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.27) shows that when the contractor's management staff experience was high, the environmental or mechanical system quality tended to be high (38 out of 49 or 77.6%), but when the contractor's management staff experience was low, the environmental or mechanical system tended to be low and high (3 out of 6 or 50%).

Table 4.26 Chi-Square Test (Environmental or Mechanical System Quality)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	14.108(a)	4	.007
Likelihood ratio	14.020	4	.007
Linear-by-linear association	8.572	1	.003
N of valid cases	77		

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Table 4.27 Experience of Contractor's Management Staff in the Field by Environmental or Mechanical System Quality

(Crosstab)			environmental or mechanical system quality			Total
			low	average	high	
experience of contractor's management staff in the field	high exp.	Count	3	8	38	49
		% within experience of contractor's management staff in the field	6.1%	16.3%	77.6%	100.0 %
	low exp.	Count	3		3	6
		% within experience of contractor's management staff in the field	50.0%		50.0%	100.0 %
	Med. Exp.	Count	6	6	10	22
		% within experience of contractor's management staff in the field	27.3%	27.3%	45.5%	100.0 %
Total		Count	12	14	51	77
		% within experience of contractor's management staff in the field	15.6%	18.2%	66.2%	100.0 %

4.2.14 The Experience of the Contractor's Staff vs. Equipment Quality

Table 4.28 shows the results of a chi-square analysis on the relationship between the experience of the contractor's management staff in the field and equipment quality. The following null hypothesis was tested: There is no relationship or association between the experience of the contractor's management staff in the field and the equipment quality. The alternative hypothesis was: There is an association or relationship between the experience of the contractor's management staff in the field and the equipment quality. Since results of the chi-square test were significant (chi-square= 33.152, df = 4, p<.001), the null hypothesis was rejected. Examination of the cross-tabulation table (Table 4.29) shows that when the contractor's management staff experience was high, the equipment quality tended to be meet expectations (37 out of 49 or 75.5

%), but when the contractor's management staff experience was low, equipment quality tended not to meet expectations (5 out of 6 or 83.3%).

Table 4.28 Chi-Square Test (Equipment Quality)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	33.152(a)	4	.000
Likelihood ratio	20.815	4	.000
Linear-by-linear association	1.776	1	.183
N of valid cases	77.00		

Table 4.29 Experience of Contractor's Management Staff in the Field by Equipment Quality

(Crosstab)			equipment quality			Total
			did not meet expectations	meet expectations	exceeded expectations	
experience of contractor's management staff in the field	high exp.	Count	2	37	10	49
		% within experience of contractor's management staff in the field	4.1%	75.5%	20.4%	100.0%
	low exp.	Count	5	1		6
		% within experience of contractor's management staff in the field	83.3%	16.7%		100.0%
	Med. Exp.	Count	2	17	3	22
		% within experience of contractor's management staff in the field	9.1%	77.3%	13.6%	100.0%
Total		Count	9	55	13	77
		% within experience of contractor's management staff in the field	11.7%	71.4%	16.9%	100.0%

Based on the above results, it can be concluded that participants were answering related questions in a consistent way. For example, a high level of owner's staff experience was associated with high quality and the same trend was found regarding the contractor's staff experience. These findings support the validity of the survey results and suggest that participants answered the survey in a thoughtful way and that their responses to survey items were meaningful. In section 4.3.5 results that did not support the predicted differences among PDSs with respect to cost, time, quality, and safety will be presented and explained. Although survey data did not provide support for expected differences among PDSs, the results of the chi-square analyses support the use of survey data in developing and testing a model for selection of a PDS.

4.3 Comparison of Project Delivery Systems PDSs

Research questions a, b, c, and d asked about differences in the cost, time, quality, and safety, respectively, of project delivery system methods: design-bid-build (DBB), design-build (DB), and construction management at risk (CM-R). One-way analysis of variance (ANOVA) was used to compare the average cost, time, quality, and safety of projects built under the three PDS methods. Analysis of variance is a statistical technique that compares the variability of the means of the three PDSs (DBB, DB and CM-R) to the variability of data within each PDS, and uses this comparison to test the significance of the differences among the means.

The variance among the sample, means weighted by the numbers in the samples, is given by

$$MST = \frac{n_1(y_1 - \grave{y})^2 + n_2(y_2 - \grave{y})^2 + \ldots\ldots + n_k(y_k - \grave{y})^2}{K - 1}$$

Where:

MST stands for mean square of treatments
n_j = number in sample j
y_j = mean of sample j
y = the grand mean, or the mean of all the data = (sum y)/ n
k = the number of groups, (three PDSs)

The variance within the groups is the weighted mean of the variance of the data in each sample. It is given by

$$MSE = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2 + \ldots + (n_k - 1)S_k^2}{n - k}$$

Where:

MSE stands for mean squared error, and
S_j^2 = variance in group j.

The two variances, MST and MSE, are compared using the ratio F=MST/MSE. If the ratio is big, this indicates a much greater difference among PDS alternatives than within each PDS (DBB, DB, CM-R), but if the ratio is small this indicates very little difference among means compared with the difference among individuals.(17)

4.3.1 Compare the Average Cost

Table 4.30 shows descriptive statistics on mean cost and Table 4.31 shows the results of the ANOVA. As seen in Table 4.30, the means for the three project delivery systems were almost the same. Table 4.31 shows that the results of the ANOVA were not significant ($F(2, 74)=.17$, $p=.847$). These results indicate that there was a large amount of variability within each set of data, where a set of data was made up of the cost of projects performed under the same delivery system, and little variability in cost between the project delivery system alternatives: DBB, DB, and CM-R.

Table 4.30 Descriptive Statistics on Mean Cost by PDS

	N	Mean	Std. Deviation	Minimum	Maximum
DBB	54	1.9658	.31792	1.38	2.62
DB	17	2.0090	.42210	1.38	2.62
CM-R	6	1.9231	.36407	1.62	2.62
Total	77	1.9720	.34240	1.38	2.62

Table 4.31 ANOVA Summary Table for Mean Cost

	Sum of Squares	df	Mean Square	F	Sig.
Between groups	.040	2	.020	.166	.847
Within groups	8.870	74	.120		
Total	8.910	76			

It was predicted that cost should be highest for projects built under the DBB system and lowest for project built under the DB. The observed results did not support this hypothesis. However, the observed results can be explained by the characteristics of the sample, as discussed in section 4.3.5

4.3.2 Compare the Average Time (Duration)

Table 4.32 shows descriptive statistics on mean time and Table 4.33 shows the results of the (ANOVA). As seen in Table 4.32, the means for the three project delivery systems were not equal. Table 4.33 shows that the results of the (ANOVA) were almost significant ($F(2, 74) = 3.058$, $p=0.053$). These results indicate a greater difference among PDS alternatives than within each alternative's sample (project). In other words, there was less variability in the time (duration) of projects within each set of data for PDSs and more variability in time (duration) between the project delivery system alternatives: DBB, DB, and CM-R. It was predicted that project duration would be longest for projects built under the DBB system, and shortest for projects built under the DB system. The observed results support this hypothesis.

Table 4.32 Descriptive Statistics on Mean Time (Duration) by PDS

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
DBB	54	1.6852	.90750	.12349	1.00	3.00
DB	17	2.2941	.91956	.22303	1.00	3.00
CM-R	6	1.8333	.40825	.16667	1.00	2.00
Total	77	1.8312	.90906	.10360	1.00	3.00

Table 4.33 ANOVA Summary Table for Mean Time

	Sum of Squares	df	Mean Square	F	Sig.
Between groups	4.794	2	2.397	3.058	.053
Within groups	58.011	74	.784		
Total	62.805	76			

4.3.3 Compare the Average Quality

Table 4.34 shows descriptive statistics on mean quality and Table 4.35 shows the results of the ANOVA. As seen in Table 4.34, the means for the three project delivery systems were almost the same. Table 4.35 shows that the results of the ANOVA were not significant ($F(2, 74) = 0.84$, $p=.437$). These results indicate that there was a large amount of variability in the quality of projects within each set of data and little variability in quality between the project delivery system alternatives: DBB, DB, and CM-R. It was predicted that quality should be highest for the CM-R method and lowest for projects built under the DB system. The observed results did not support the hypothesis. However, the observed results can be explained by the characteristics of the sample, as discussed in section 4.3.5

Table 4.34 Descriptive Statistics on Mean Quality by PDS

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
DBB	54	2.1439	.38506	.05240	1.08	2.69
DB	17	2.2262	.38603	.09363	1.15	2.92
CM-R	6	1.9872	.50187	.20489	1.23	2.31
Total	77	2.1499	.39340	.04483	1.08	2.92

Table 4.35 ANOVA Summary Table for Mean quality

	Sum of Squares	df	Mean Square	F	Sig.
Between groups	.260	2	.130	.836	.437
Within groups	11.502	74	.155		
Total	11.762	76			

4.3.4 Compare the Average Safety

Table 4.36 shows descriptive statistics on mean safety and Table 4.37 shows the results of the ANOVA. As seen in Table 4.36, the means for the three project delivery systems were almost the same. Table 4.37 shows that the results of the ANOVA were not significant ($F(2, 74) = 2.203$, $p=.118$). These results indicate that there was a large amount of variability in the safety of projects within each set of data and little variability in safety between the project delivery system alternatives: DBB, DB, and CM-R. It was predicted that safety should be highest for projects built under the DBB system and lowest for projects built under the CM-R system. The observed results did not support this hypothesis. However, the observed results can be explained by the characteristics of the sample, as discussed in the following section.

Table 4.36 Descriptive Statistics on Mean Safety by PDS

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
DBB	54	2.1852	.67500	.09186	1.00	3.00
DB	17	2.5294	.62426	.15141	1.00	3.00
CM-R	6	2.0000	.63246	.25820	1.00	3.00
Total	77	2.2468	.67191	.07657	1.00	3.00

Table 4.37 ANOVA Summary Table for Mean Safety

	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1.928	2	.964	2.203	.118
Within groups	32.383	74	.438		
Total	34.312	76			

4.3.5 Explanation for Lack of Significant Findings

In this study, the lack of significant findings may be due to the inexperience of the participants. In addition, the significance may have been affected by the limited breadth of the sample. One reason that owners and contractors may not have made logical choices is that many were only familiar with DBB and had no knowledge of the other delivery systems. Others choose DBB because a number of owners in Saudi Arabia, particularly governments, prefer some kind of competitive bidding (typically the DBB method) and often insist on it. Since the majority of projects included in the sample (77%) were public sector projects, the influence of the government would be considerable. Consistent with these reasons, the majority of projects in the sample (70%) were performed under DBB. Since in the present sample the choice of a PDS was not typically made based on owner needs and project requirements, a model based only on those data might not lead project owners to the best decision regarding a PDS. Therefore, survey data will be supplemented with data from previous studies in testing the model.

4.4 Creating the Decision Framework

This section of the chapter will describe the methods that were used to create the decision framework. Based both on previous studies and survey data from the current study the following elements of the decision framework were identified. Project factors included cost, time, quality and safety. Owner objectives included type of project, size of project, owner capabilities with respect to both finance and experience, contractor capabilities with respect to finance and experience, time consideration, and possibilities of change. Project parameters (key decision points) included owner risks, owner controlling and involvement, transfer technology, owner satisfaction, ease of design, constructability innovation, political consideration and government limitation, ensuring confidentiality, resource availability, well-defined scope, and knowledge of final cost before starting. All of the elements of the decision framework need to be considered in developing a model for decision making.

A model is used to represent a real or planned system. Usually, the model is simpler and easier to understand than the system it represents. A model can be used as an aid in decision making. In the current study, the model was intended to be easy for owners to use and at the same time to provide meaningful results that could be used in selecting the most appropriate project delivery system.

Two methods of building the model were utilized in the present study. Method 1 was the Weighting Factor Estimation Method (WF) and Method 2 was the Analytical Hierarchical Process Method (AHP). In the next two sections (Section 4.4.1 and 4.4.2) the results obtained under WF and AHP, respectively, will be reported. In Section 4.4.3 the results obtained from the two methods will be compared and similarities and differences will be discussed.

4.4.1 Results Obtained Under (WF) (Method 1)

The details of the steps involved in preparing the data for this model were described in Section 3.11. Prior to entering data from the survey into the model, data from previous studies which were used to develop the coding of responses to survey items were entered into the three main matrices, the project factors matrix, the owner objectives matrix, and the project parameters matrix. These matrices are presented below in Tables 4.38, 4.39 and 4.40. These three matrices were then integrated in order to develop the final decision model PDSDF which is shown in Table 4.41.

4.4.1.1 **Model Testing** The three main matrices and the matrix for the final decision model all were tested to investigate their functionality. The testing indicated that the model produced results which were consistent with the hypothesized outcomes as shown below. For example, given the WFs chosen, and based on ideal data, the model would recommend the selection of DB (see Table 4.41).

Table 4.38 Project Factors Matrix Results (Ideal)

Factors	WF To be decided by owner (using Table 25, App. A)	DBB a1	DB a2	CM-R a3
Cost	10	1.0	3.0	2.0
Time/schedule	7	1.0	3.0	2.0
Quality	4	2.0	1.0	3.0
Safety	3	2.0	1.0	3.0
Total (should be transferred to Criteria Results, Table 4.41)		31	58	55

Table 4.39 Owner Objectives Matrix Results (Ideal)

Characteristics	WF To be decided by owner (using Table 24, App. A)	DBB a1	DB a2	CM-R a3
Type of project	6	2.0	1.0	3.0
Size of project $Cost/ ft^2	4	3.0	2.0	1.0
Owner capabilities (financial & experience)	10	3.0	1.0	2.0
Contractor capabilities (financial & experience)	4	1.0	3.0	2.0
Time consideration	9	1.0	3.0	2.0
Possibilities of changes	7	2.0	3.0	1.0
Total (should be transferred to Criteria Results, Table 4.41)		81.0	84.0	75.0

Table 4.40 Project Parameters Matrix Results

Parameters	WF To be decided by owner (using Table 26, App. A)	DBB a1	DB a2	CM-R a3
Owner Risks	5	3	1	2
Owner controlling & involvement	10	2	1	3
Transfer technology (well the project be technologically advanced)	3	1	2	3
Owner satisfaction (Met requirement)	9	2	1	3
Ease of design	6	1	3	2
Constructability innovation	2	2	1	3
Political consideration & government limitation	7	3	2	1
Ensure confidentially	5	3	2	1
Resource availability	4	3	1	2
Well defined of scope	7	3	1	2
Know final cost before starting	10	1	3	2
Total of the mean (should be transferred to Table 4.41)		145	115	148

Table 4.41 Criteria Results of Project Evaluation Matrices of Decision Model (for each project) PDSDF

Owner output (Criteria) (1)	WF To be decided by owner (Ranking importance of criteria from 1 to 10) (2)	DBB a1 (3)	DB a2 (4)	CM-R a3 (5)
Project factors matrix (Questionnaire)	10	31	58	55
Project key consideration matrix (Questionnaire)	5	81.00	84	75
Project parameters (Key decision points) (Previous study)	1	145	115	148
Total points		860.00	1115.00	1073.00
Select maximum			*****	

4.4.1.2 **Preliminary Results** After the model was tested with ideal data from previous studies, the model was developed again using data from the survey. Survey data were entered into Tables 4.42, 4.43, and 4.44. The results of these three tables were then transferred to Table 4.45. As shown in Table 4.45, the model would recommend the selection of DBB.

Table 4.42 Project Factors Matrix Results

Factors	WF To be decided by owner (using Table 25, App. A)	DBB a1	DB a2	CM-R a3
Cost	10	2.0	2.0	1.9
Time	7	2.75	3	2
Quality	4	2.1	2.2	2.0
Safety	3	2.2	2.5	2.0
Total (should be transferred to Criteria Results, Table 4.45)		54.25	57.3	47

Table 4.43 Owner Objectives Matrix Results

Characteristics	WF To be decided by owner (using Table 24, App. A)	DBB (a1)	DB (a2)	CM-R (a3)
Type of project	6	1.8	2.3	2.0
Size of project ($Cost/ ft^2)	4	2.8	2.1	1.2
Owner capabilities (financial & experience)	10	2.5	2.5	2.4
Contractor capabilities (financial & experience)	4	2.5	2.7	2.3
Time consideration	9	1.7	2.3	1.8
Possibilities of changes	7	1.9	1.3	1.2
Total (should be transferred to Criteria Results, Table 4.45)		85.3	87.8	74.6

Table 4.44 Project Parameters Matrix Results

Parameters	WF To be decided by owner (using Table 26, App. A)	DBB a1	DB a2	CM-R a3
Owner risks	5	3	1	2
Owner controlling & involvement	10	2	1	3
Transfer technology (will the project be technologically advanced)	3	1	2	3
Owner satisfaction (met requirement)	9	2	1	3
Ease of design	6	1	3	2
Constructability innovation	2	2	1	3
Political consideration & government limitation	7	3	2	1
Ensure confidentially	5	3	2	1
Resource availability	4	3	1	2
Well defined of scope	7	3	1	2
Know final cost before starting	10	1	3	2
Total of the mean (should be transferred to Table 4.45)		145	115	148

Table 4.45 Criteria Results of Project Evaluation Matrices of Decision Model (for each project) PDSDF

Owner output (Criteria) (1)	WF To be decided by owner (Ranking importance of criteria from 1 to 10) (2)	DBB a1 (3)	DB a2 (4)	CM-R a3 (5)
Project factors matrix (Questionnaire)	10	54.25	57.3	47
Project key consideration matrix (Questionnaire)	5	85.3	87.8	74.6
Project parameters (key decision points) (Previous study)	1	145	115	148
Total points		1574.38	1532.6	1436.2
Select maximum		********		

4.4.1.3 **Summary of WF Method Results** The WFs to be chosen by the decision maker (project owner) were drawn from Tables 24, 25, and 26 which are included in Appendix A. The WFs derived from these were integrated into Column 2 of the three main matrices and into the final decision model. The same owner priorities as reflected in these WFs were assumed both when testing the model with data from previous studies (ideal data) and when testing the model with survey data from the current study. Because the same WFs were assumed, the model was expected to lead project owners to selecting the same PDS with both data sets. However, as has been shown in Tables 4.41 and 4.45, the implementation of the model with the two data sets led to different recommendations to project owners. As can be seen in Table 4.41, the total points were 860.00, 1115.00, and 1073.00 for DBB, DB, and CM-R, respectively. Since the maximum number of points was assigned to DB, the model would recommend the selection of this method, based on owner needs and project requirements. On the other hand, the total points shown in Table 4.45 were 1574.38, 1532.6, and 1436.2 for DBB, DB, and CM-R, respectively. In this case, the maximum number of points was assigned to DBB, and the model would recommend DBB based on owner needs and project requirements. The differences in results can be explained by the characteristics of the survey data. As mentioned earlier in section 4.3.5, for many of the projects included in the present study the decision about a PDS was not based on logical consideration of the strengths and weakness of each PDS. Owners in the sample may not have been very familiar with the DB method and the number of projects in the sample performed with DB (17 projects) was significantly smaller than the number of projects performed with DBB (54 projects).

4.4.2 Results Obtained Under (AHP) (Method 2)

Developed by Thomas Saaty, AHP provides a proven, effective means to deal with complex decision making and can assist with identifying and weighting selection criteria, analyzing the data collected for the criteria and expediting the decision-making process. The importance of AHP is to help capture both subjective and objective evaluation measures, providing a useful mechanism for checking the consistency of the evaluation measures and alternatives and thus reducing bias in decision making.

AHP is used to assist decision-makers arrive at complex decisions involving multiple criteria. In order to apply AHP, the broad overall goal is decomposed into narrower and more specific objectives. As expressed by Zeleny M., criteria are "the rules, measures, and standards that guide decision makers."(18) In other words, when making decisions, decision-makers consider key attributes, objectives, or variables and these become the criteria. Given the number of factors that interact in today's society, most important decisions such as the selection of a PDS are made on the basis of more than one criterion in order to achieve the goal. Only relatively unimportant decisions can be made using only one criterion.

The Super Decisions software which was developed by William J. Adams of Embry Riddle Aeronautical University, Daytona Beach, Florida, who worked with Rozann W. Saaty, is used to build the AHP model, which finally represents the PDSDF. The model included the following steps (as shown in Figure 4.4):

4.4.2.1 Identifying project evaluation criteria and sub-criteria;

4.4.2.2 Collecting the data and rescaling them;

4.4.2.3 Building a hierarchy model using decision software:

A. Assessment/Pairwise comparisons;

B. Estimating the relative priorities of the decision criteria and alternatives;

C. Checking inconsistency;

D. Modifying the judgments to improve the inconsistency, if needed;

E. Developing the rank of alternatives by putting the list of priorities together.

4.4.2.4 Determining the best PDS.

4.4.2.1 **Identifying Project Evaluation Criteria and Sub-Criteria** Some criteria are well defined and quantitative, such as project cost, size of the project, etc. Other criteria may be less well defined and more qualitative, such as owner satisfaction with the performance of the project. According to Munif it is important for decision-makers to consider both quantitative and qualitative criteria in order to make the best decision.(19) Even when a criterion can be easily measured, for example, project cost, different decision-makers may attribute different degrees of importance to the criterion. For example, the owners of different projects may have different needs and therefore not attribute the same degree of importance to project cost. Finding a way of quantifying the relative importance of criteria is very difficult.

Based on the results of previous studies, major criteria that impact on owners' decisions were identified. These criteria were conceptualized as comprising the following three groups: project factors, owner objectives, and project parameters. The criteria and sub-criteria are shown in Table 4.46.

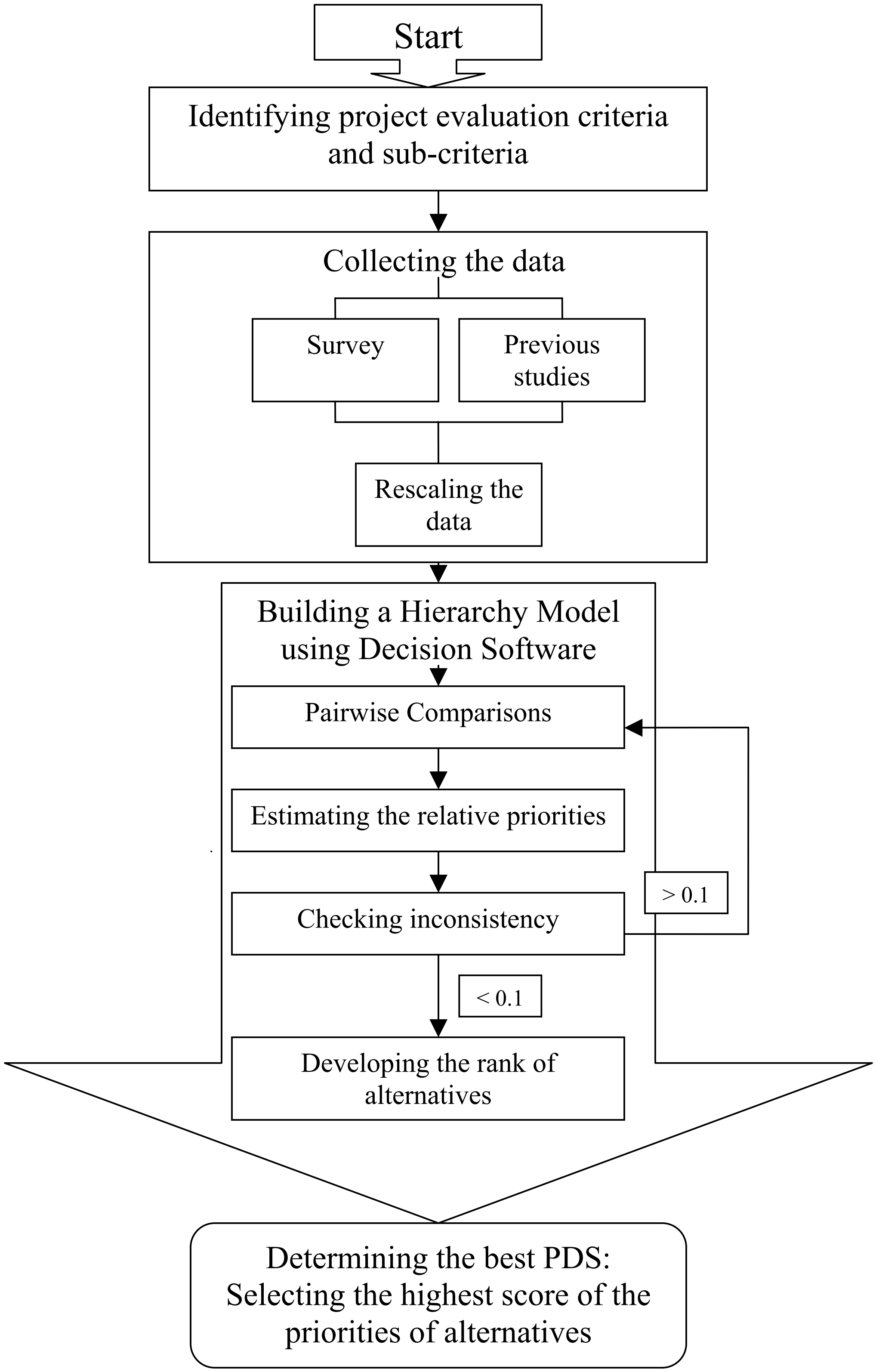

Figure 4.4 Research model by using AHP

Table 4.46 Criteria and Sub-Criteria of the PDSDF

Criteria	**Sub-Criteria**
Project Factors	
	Cost
	Time (duration)
	Quality
	Safety
Owner objectives (key consideration points)	
	Type of project
	Size of project
	Owner capabilities (financial and experience)
	Contractor capabilities (financial and experience)
	Time consideration
	Possibilities of changes
Project Parameters (key decision points)	
	Owners risks
	Owner controlling and involvements
	Transfer technology
	Owner satisfaction
	Ease of design
	Constructability innovation
	Political consideration and government limitation
	Ensure confidentially
	Resource availability
	Well defined of scope
	Know final cost before starting

AHP works well when the number of requirements is small [20]. When the number of requirements is large, it is necessary to divide requirements into groups and to apply the technique for each group. In the present study, the set of 11 project parameters shown in Table

4.46 (key decision points) was grouped into three sets: owner requirements, project needs, and scope requirements (see Table 4.47).

Table 4.47 Project Parameter Criteria

A- Owner requirements
1. Owner risks 2. Owner controlling & involvement 3. Owner satisfaction (met requirements) 4. Political consideration & government limitation
B- Projects needs
1. Transfer technology (well the project be technologically advanced) 2. Constructability innovation 3. Ensuring confidentiality 4. Resource availability
C- Scope requirements
1. Ease of design 2. Well defined of scope 3. Knowledge of final cost before starting

4.4.2.2 **Collecting the Data and Rescaling Them** Data were collected from two major sources to be applied in the step of pairwise comparisons/assessment of alternatives in the AHP. In this step the importance of each criterion in relation to the other criteria was identified. The first of these sources was the data collected from a survey administered to the owners, contractors, and engineers of selected projects. Data on project factors and owner objectives were drawn from this source. After assigning numerical values to qualitative responses from the surveys, data were entered into the tables shown in Appendix A, following the steps outlined below:

- Procedure for deriving the importance of the criteria and sub-criteria of the project factors by using the survey data

Step 1

Fill out Tables 7, 8, 9 and 10 (Appendix A) for each project, based on project owner's response to survey items. Data from each project were entered for only one PDS as reported by the owner in survey item III, 9.

Step 2

Calculate mean for each factor (time, cost, quality and safety) for each project.

Step 3

Transfer means for Tables 7, 8, 9 and 10 to Tables 3, 4, 5 and 6 (Appendix A) respectively, for each project.

Example: mean for project ID 1 would be entered in row 1, etc.

Step 4

After Tables 3, 4, 5 and 6 (Appendix A) have been completed for all projects, calculate the mean for each PDS for that factor; for example, Table 3 for cost, Table 4 for time, etc.

Step 5a

Transfer the means that have been calculated in Step 4 to Table 2 (Appendix A)..

Step 5b

The weight (rank) for each factor should be decided by the owner in Table 25 (Appendix A). The owner gives qualitative answers. For example, the options cost and time are very important to not important. The options for quality are exceeded expectations, met expectations, or did not meet expectations. For safety, the options are high level, acceptable level, or low level. The qualitative responses were converted to quantitative responses in Table 25. The quantitative information in Table 25 was transferred to the weighting factor column of Table 2 for each factor. The researcher assumed the ranking of each sub-criterion to build the AHP.

Step 6

Data in Table 2 were used as a basis of comparing the importance of the sub-criteria with respect to the alternatives.

Step 7

Rescale the data presented in Table 2 from a scale of 1 through 3 to a scale of 2 through 8 (see Table 4.48) to match the scale that was developed by Saaty, as illustrated in Table 3.1.

- <u>Procedure for deriving the importance of the criteria and sub-criteria of the project owner objectives (key consideration points) by using the survey data.</u>

Step 1

Fill out tables 18, 19, 20, 21, 22 and 23 (Appendix A) for each project, based on project owner's response to survey items. Data from each project were entered for only one PDS as reported by the owner in survey item III, 9.

Step 2

Calculate mean for each owner objective, key consideration point (type of project, size of project, owner capabilities, etc.) for each project.

Step 3

Transfer means for Tables 18, 19, 20, 21, 22 and 23 to Tables 12, 13, 14, 15, 16 and 17, respectively, for each project.

Example: mean for project ID 1 would be entered in row 1, etc.

Step 4

After Tables 12, 13, 14, 15, 16 and 17 (Appendix A) have been completed for all projects, calculate the mean for each PDS for that owner's objectives, key consideration points; for example, Table 12 for type of project, table 13 for size of project, etc.

Step 5a

Transfer the means that have been calculated in Step 4 to Table 11: Owner objectives, Key consideration points, matrix.

Step 5b

The weight (rank) for each owner objective (key consideration point) should be decided by the owner in Table 24 (Appendix A). The owner gives qualitative answers. The response options vary across the key consideration points. For example, for type of project, the options are more complex and unique (more control), medium control, or less complex and unique (less control). The qualitative responses were converted to quantitative responses in Table 24 and the quantitative information in Table 24 was transferred to the Weighting Factor column of Table 11. The researcher assumed the ranking of each sub-criterion to build the AHP and carry out analyses.

Step 6

Data in table 11 were used as a basis of comparing the importance of the sub-criteria with respect to the alternatives.

Step 7

Rescale the data presented in table 11 from a scale of 1 through 3 to a scale of 2 through 8 (see Table 4.48) to match the scale that was developed by Saaty, as illustrated in Table 3.1.

Table 4.48 Correspondence between Survey Scale and Saaty Scale

Survey Scale	Saaty Scale
1.0	2.0
1.1	2.3
1.2	2.6
1.3	2.9
1.4	3.2
1.5	3.5
1.6	3.8
1.7	4.1
1.8	4.4
1.9	4.7
2.0	5.0
2.1	5.3
2.2	5.6
2.3	5.9
2.4	6.2
2.5	6.5
2.6	6.8
2.7	7.1
2.8	7.4
2.9	7.7
3.0	8.0

The second source of input into the AHP model was the results of previous studies that had been done in this area. Data on project parameters were drawn from this second source.

- <u>Procedure for deriving the importance of the criteria and sub-criteria of the project parameters (key decision points) by using the data from previous studies</u>

Step 1

The weight (rank) for each parameter should be decided by the owner in Table 26 (Appendix A). The owner gave qualitative answers. The response options vary across the parameters. For example, for owner risk, the options were high risk, medium risk, or low risk. The qualitative responses were converted to quantitative responses in Table 26 and the quantitative information in Table 26 was transferred to the Weighting Factor column of Table 27. The researcher assumed the ranking of each sub-criterion to build the AHP.

Step 2

Data in table 27 were used as a basis of comparing the importance of the sub-criteria with respect to the alternatives.

Step 3

Rescale the data presented in table 27 from a scale of 1 through 3 to a scale of 2 through 8 (see Table 4.48) to match the scale that was developed by Saaty, as illustrated in Table 3.1.

- Executing the model

After the three main matrices representing the three major criteria, project factors, owner objectives, and project parameters were completed (see Table 2, Table 11, and Table 27 in Appendix A), the data from these matrices were integrated to form the AHP model which led to the PDSDF illustrated in Tables 4.49 and 4.50. The relative importance of these major criteria had to be evaluated by the decision-maker using the scale of 1 to 9 specified by Saaty (see Table 3.1)   For the purpose of testing the model, it was necessary for the researcher to make assumptions about the relative importance of the three major criteria.

4.4.2.3 **Building a Hierarchy Model Using Decision Software** In its simplest form, the structure applied in AHP was made up of a goal, criteria, and alternative choices. The structure of the AHP model in the present study is illustrated in Figure 4.5. Details about the steps involved in developing the AHP model for the present study were presented earlier in Section 3.16.

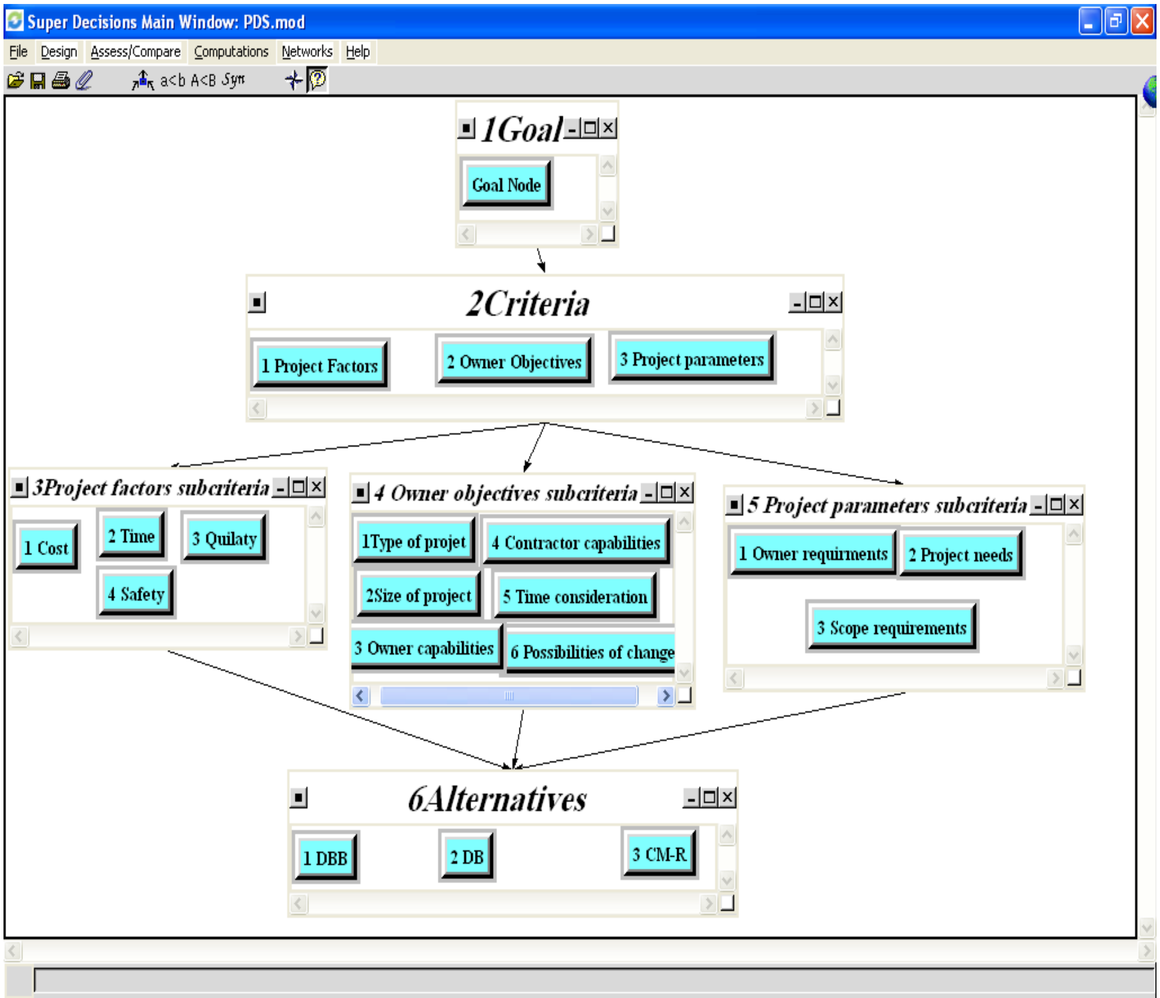

Figure 4.5 Hierarchy Structure of Selecting Best PDS

A. Assessment/Pairwise comparisons.

Details about the steps involved in pairwise comparisons were presented earlier in Section 3.14. Relational data for comparing the alternatives was generated (as described below in step

B). Super Decision software was used by the researcher to generate the comparisons between the criteria and sub-criteria that was needed in order to reach a final decision.

The AHP process required the decision maker (analyst) to make pairwise comparisons among criteria and sub-criteria with respect to the alternatives, each level relative to each activity at the next higher level in the hierarchy. Saaty developed an intensity scale to be applied in these pairwise comparisons which is shown in Table 3.1. An example of the screen for pairwise comparisons in Super Decision software is shown in Figure 4.6 below. The pairwise comparisons were evaluated using two data sources. Both data from previous studies and survey data were used to test the model.

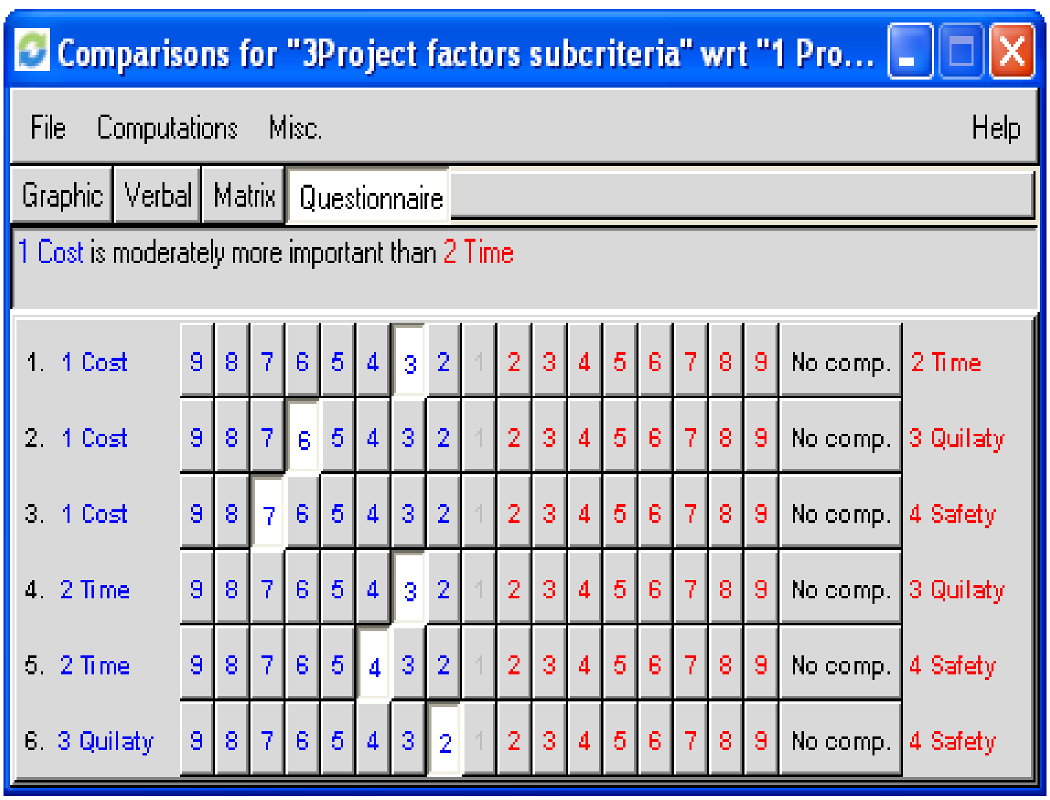

Figure 4.6 Pairwise Comparisons

B. Estimating the relative priorities of the decision criteria and alternative.

An example of the screen in super decision software is shown below in Figure 4.7

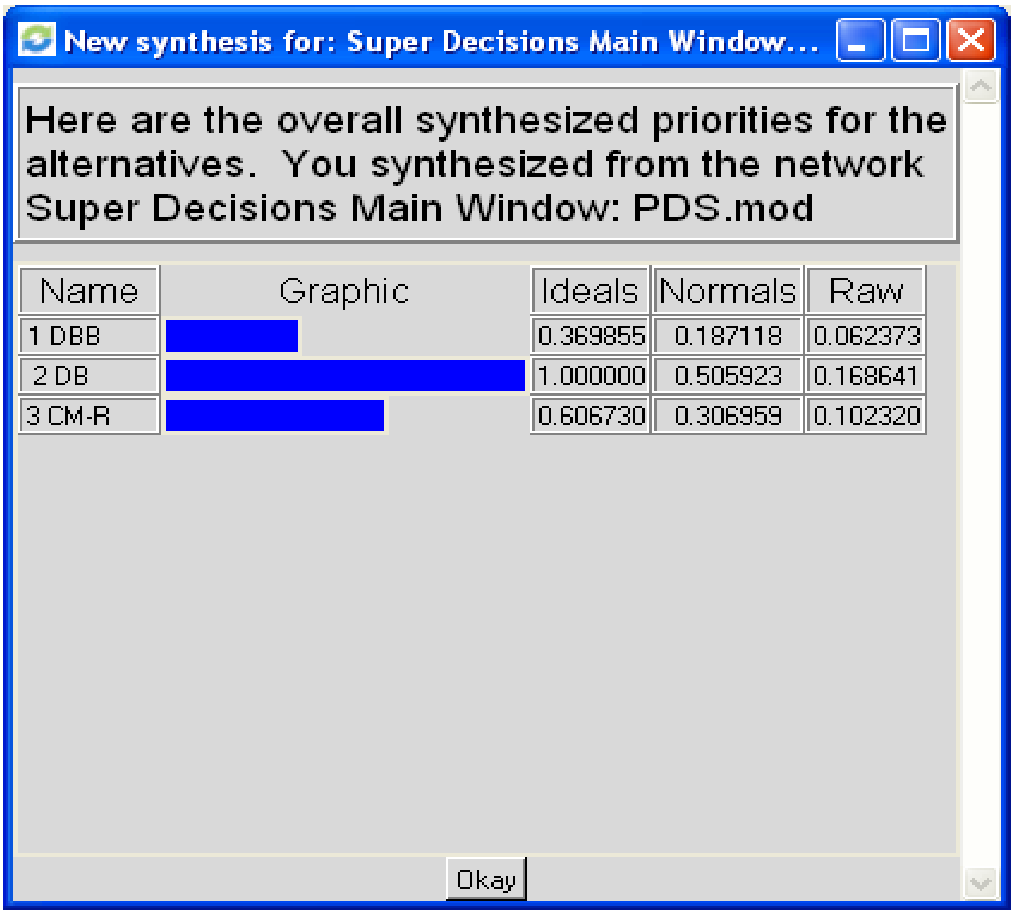

Figure 4.7 Synthesized Priorities

C. Checking inconsistency.

As presented earlier in section 3.15, the inconsistency measure was useful for identifying possible errors in judgment as well as actual inconsistencies in the judgments themselves. In general, the inconsistency ratio should be less than 0.1 or so to be considered reasonably consistent.

D. Modifying the judgments to improve the inconsistency, if needed.

E. Deriving the rank of alternatives by integrating the criteria in order to produce a list of priorities.

4.4.2.4 **Determining the Best PDS** After running the analysis by using the Super Decision software, the delivery system with the highest priority score was selected as the best PDS, as illustrated in section 4.4.2.5.1.

The next section will present the results of testing the AHP model both with data from previous studies (ideal) and survey data based on actual completed projects.

4.4.2.5 **Preliminary Results** A) Synthesis, The results for the alternative were obtained with the synthesis as shown in Figure 4.7 above. The "Normal" column presents the results in the form of priorities where the highest priorities score was the best PDS that was recommended to the decision-maker (project owner). The "Ideals" column was obtained from the "Normals" column by dividing each of its entries by the largest value in the column. Super Decision software obtained the "Raw" column by reading directly from the limit supermatrix. In a hierarchical model such as this one, the rankings of alternatives in the "Raw" column and the "Normals" column are the same.

These results show that the DB would be the best choice for the decision- maker. The "Ideal" column shows the results divided by the largest value so that the best choice has a priority of 1.0. The others were in the same proportion as in "Normals" and were interpreted this way: CM-R was 60.67 percent as good as DB and DBB was 36.99 percent as good as DB. This answer reflected the needs of the project owner who made the judgments, incorporating their project requirements.

B) Sensitivity

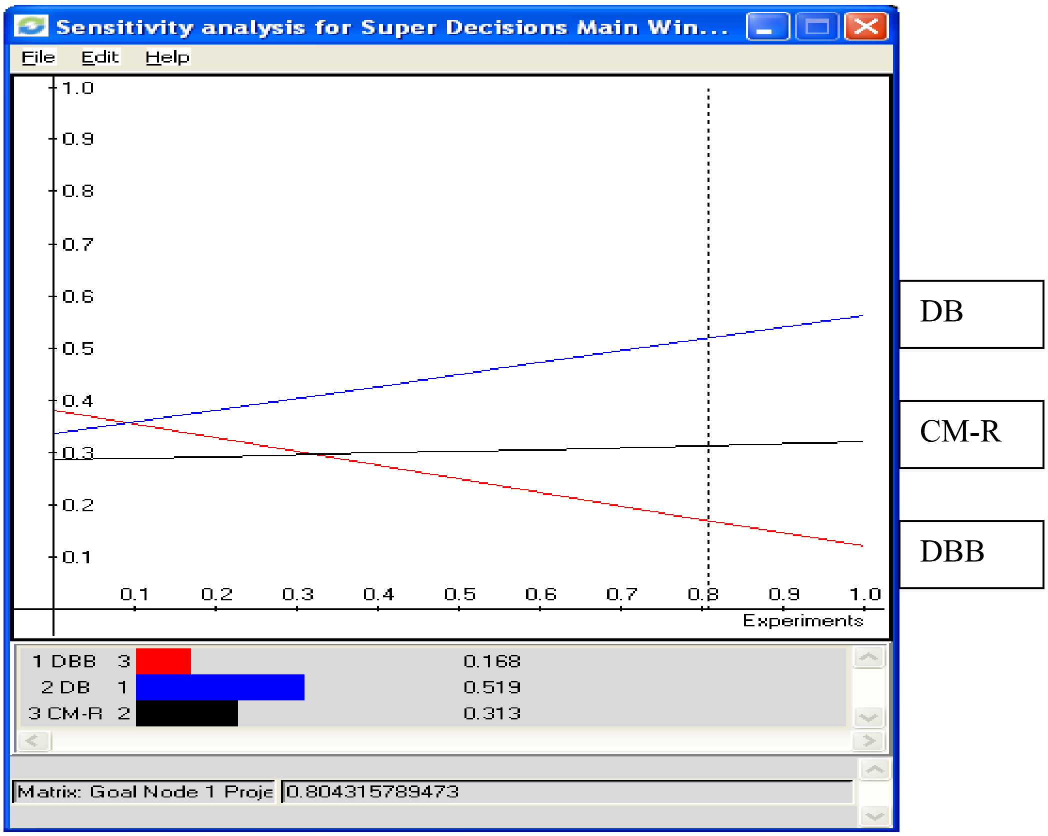

Figure 4.8 Sensitivity of the Outcome to Change in Criteria Weight (Project Factors)

The outcome of the results presented above was highly dependent on the hierarchy structured by the decision-makers (project owners) and on the relative judgments made about the various factors of the project. Changes in the hierarchy or the judgments could lead to changes in the outcome.[21] In Figure 4.8, the priority of factors is plotted on the x axis and the priorities of the alternatives are plotted on the y axis which shows the sensitivity of the outcome to change in criteria (factors and parameters) weight. At the point weight = 0.8, DB is about 0.52, CM-R is about 0.313, and DBB is about 0.17. What this graph is indicates is that if the weight is greater than about 0.32, DB becomes the best PDS, and CM-R the second best. If the weight is less than about 0.1, DBB becomes the best choice. Before changing the relative importance of the factors the DB is the best alternative.

Further testing of the sensitivity is shown in Figures 4.9 and 4.10 below. While Figure 4.8 represented project factor criteria, Figure 4.9 represents owner objective criteria and Figure 4.10 represents project parameter criteria.

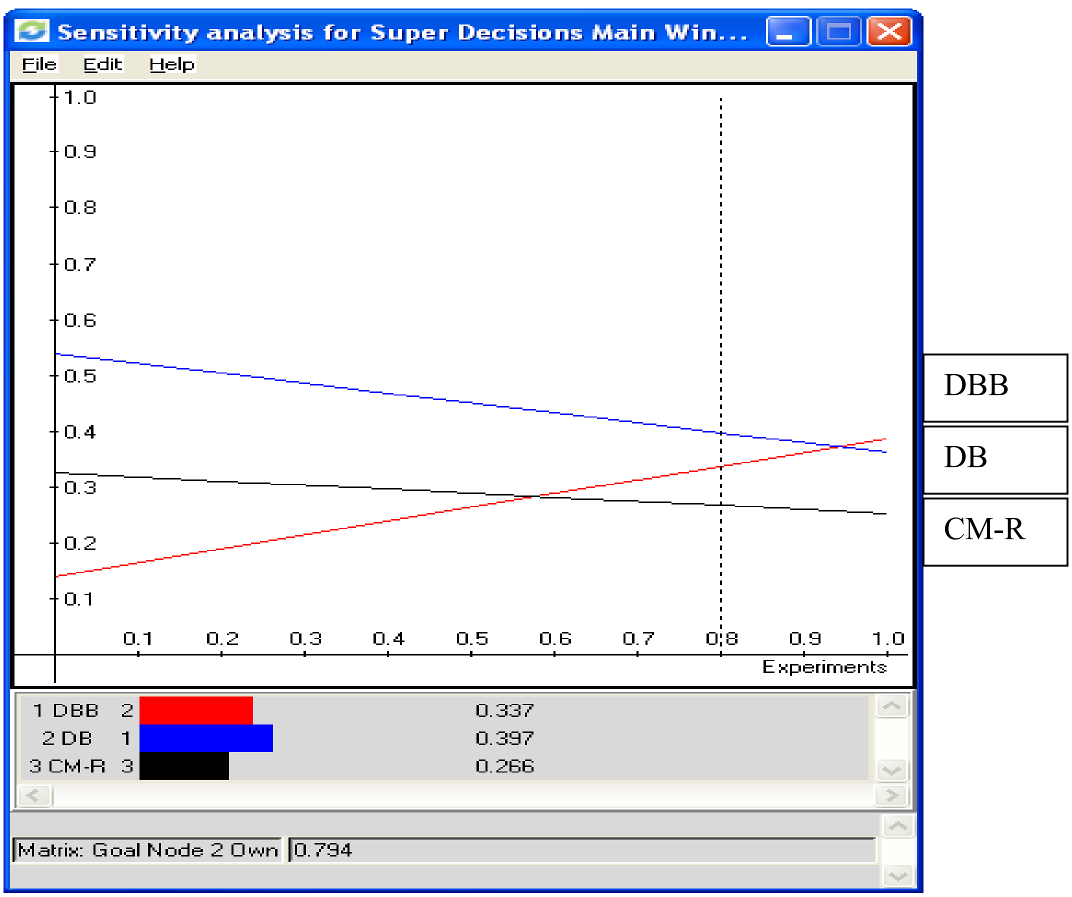

Figure 4.9 Sensitivity of the Outcome to Change in Criteria Weight (Owner Objectives)

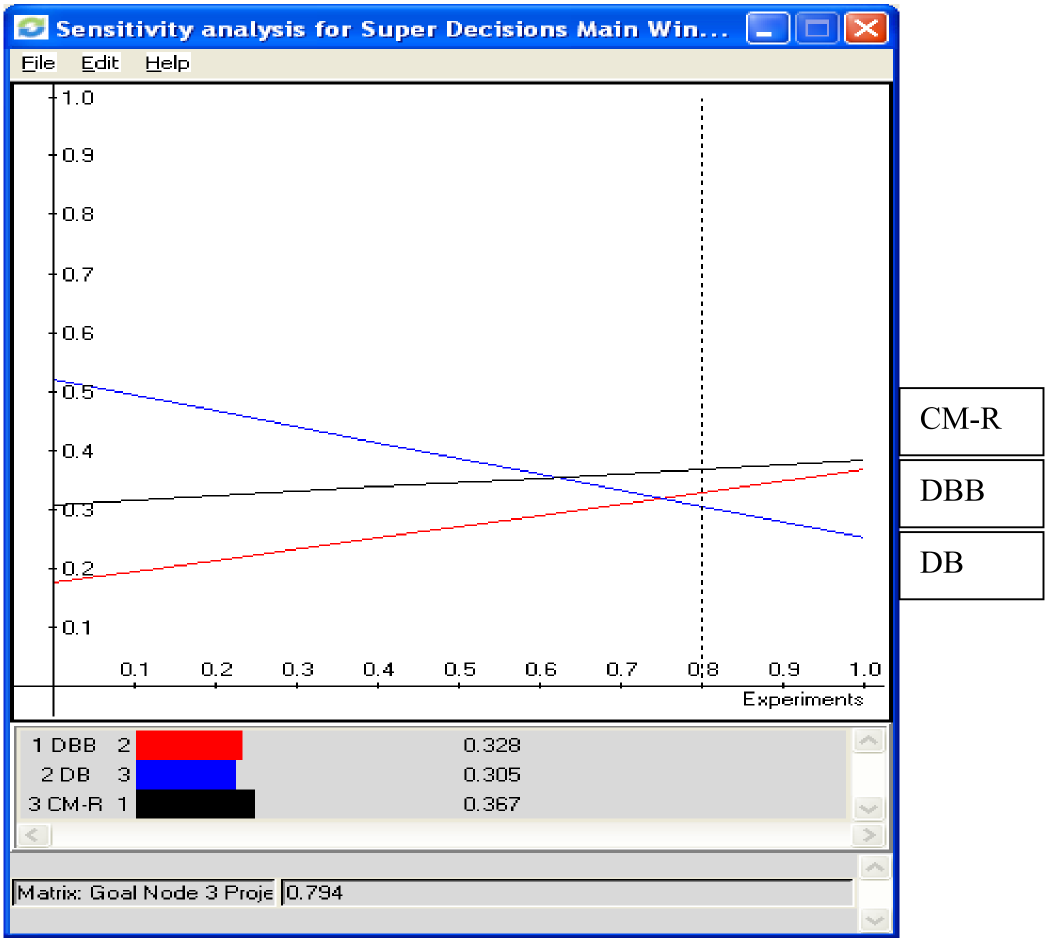

Figure 4.10 Sensitivity of the Outcome to Change in Criteria Weight (Project Parameters)

C) The Supermatrices

Results are shown in Tables 4.49 and 4.50. The final priorities for the alternatives are in the column under the Goal.

4.4.2.6 **Summary of AHP Method Results** The AHP report summarizing the results for testing the model with ideal data is shown in Table 4.51. As seen in the Alternative Ranking section at the end of Table 4.51, the highest priority was assigned to DB (.1686), the second to

CM-R (.1023) and the third to DBB (.0624). The Alternative Ranking section of the same report for testing the model with survey data is shown in Table 4.52. The highest priority was again assigned to DB (.1493), but the second priority was assigned to DBB (.1202), while the third highest priority was assigned to CM-R (.0632). The reversal in priorities of DBB and CM-R may have arisen because of two factors. One, the mathematical issue entailed by rescaling, and two the fact that project owners' selection of a PDS in the survey was not based on a logical consideration of the strengths and weaknesses of each PDS.

Table 4.49 Preliminary Results AHP (Ideal Data)

		1Goal	2Criteria			3Project factors sub criteria			
		Goal node	1 Project factors	2 Owner objectives	3 Project parameters	1 Cost	2 Time	3 Quality	4 Safety
1Goal	**Goal node**	0	0	0	0	0	0	0	0
2Criteria	**1 Project factors**	0.247622	0	0	0	0	0	0	0
	2 Owner objectives	0.064627	0	0	0	0	0	0	0
	3 Project parameters	0.021084	0	0	0	0	0	0	0
3Project factors sub criteria	**1 Cost**	0.145523	0.293841	0	0	0	0	0	0
	2 Time	0.0612	0.123576	0	0	0	0	0	0
	3 Quality	0.025004	0.050489	0	0	0	0	0	0
	4 Safety	0.015894	0.032094	0	0	0	0	0	0
4 Owner objectives sub criteria	**1Type of project**	0.006025	0	0.046617	0	0	0	0	0
	2Size of project	0.003413	0	0.026409	0	0	0	0	0
	3 Owner capabilities	0.0253	0	0.195738	0	0	0	0	0
	4 Contractor capabilities	0.003413	0	0.026409	0	0	0	0	0
	5 Time consideration	0.016709	0	0.129276	0	0	0	0	0
	6 Possibilities of changes	0.009765	0	0.075551	0	0	0	0	0
5 Project parameters sub criteria	**1 Owner requirements**	0.009371	0	0	0.222222	0	0	0	0
	2 Project needs	0.002343	0	0	0.055556	0	0	0	0
	3 Scope requirements	0.009371	0	0	0.222222	0	0	0	0
6Alternatives	**1 DBB**	**0.062**	**0.057902**	**0.194519**	**0.183918**	**0.095**	**0.088**	**0.2426**	**0.2109**
	2 DB	**0.168**	**0.282274**	**0.179812**	**0.124319**	**0.655**	**0.669**	**0.0879**	**0.0841**
	3 CM-R	**0.103**	**0.159824**	**0.12567**	**0.191763**	**0.25**	**0.243**	**0.6694**	**0.7049**

Table 4.49 (Cont.)

1Type of project	2Size of project	3 Owner capabilities	4 Contractor capabilities	5 Time consideration	6 Possibilities of changes	1 Owner requirements	2 Project needs	3 Scope requirements	1 DBB	2 DB	3 CM-R
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0.242637	**0.669417**	**0.669417**	**0.087946**	**0.095338**	**0.262753**	**0.558425**	**0.4**	**0.169205**	**0**	**0**	**0**
0.087946	**0.242637**	**0.087946**	**0.669417**	**0.654807**	**0.65863**	**0.121957**	**0.2**	**0.387479**	**0**	**0**	**0**
0.669417	**0.087946**	**0.242637**	**0.242637**	**0.249855**	**0.078617**	**0.319618**	**0.4**	**0.443316**	**0**	**0**	**0**

Table 4.50 Preliminary Results AHP (Survey Data)

		1Goal	2Criteria			3Project factors sub criteria			
		Goal node	1 Project factors	2 Owner objectives	3 Project parameters	1 Cost	2 Time	3 Quality	4 Safety
1Goal	**Goal node**	0	0	0	0	0	0	0	0
2Criteria	**1 Project factors**	0.247622	0	0	0	0	0	0	0
	2 Owner objectives	0.064627	0	0	0	0	0	0	0
	3 Project parameters	0.021084	0	0	0	0	0	0	0
3Project factors sub criteria	**1 Cost**	0.145523	0.293841	0	0	0	0	0	0
	2 Time	0.0612	0.123576	0	0	0	0	0	0
	3 Quality	0.025004	0.050489	0	0	0	0	0	0
	4 Safety	0.015894	0.032094	0	0	0	0	0	0
4 Owner objectives sub criteria	**1Type of project**	0.006025	0	0.046617	0	0	0	0	0
	2Size of project	0.003413	0	0.026409	0	0	0	0	0
	3 Owner capabilities	0.0253	0	0.195738	0	0	0	0	0
	4 Contractor capabilities	0.003413	0	0.026409	0	0	0	0	0
	5 Time consideration	0.016709	0	0.129276	0	0	0	0	0
	6 Possibilities of changes	0.009765	0	0.075551	0	0	0	0	0
5 Project parameters sub criteria	**1 Owner requirements**	0.009371	0	0	0.222222	0	0	0	0
	2 Project needs	0.002343	0	0	0.055556	0	0	0	0
	3 Scope requirements	0.009371	0	0	0.222222	0	0	0	0
6Alternatives	**1 DBB**	**0.1202**	**0.179681**	**0.18112**	**0.183918**	**0.4**	**0.32**	**0.29696**	**0.2385**
	2 DB	**0.15**	**0.233848**	**0.224148**	**0.124319**	**0.4**	**0.558**	**0.53962**	**0.625**
	3 CM-R	**0.0632**	**0.086471**	**0.094732**	**0.191763**	**0.2**	**0.122**	**0.16342**	**0.1365**

Table 4.50 (Cont.)

Cont. 2 of 2

4 Owner objectives sub criteria						5 Project parameters sub criteria			6Alternatives		
1Type of project	**2Size of project**	**3 Owner capabilities**	**4 Contractor capabilities**	**5 Time consideration**	**6 Possibilities of changes**	**1 Owner requirements**	**2 Project needs**	**3 Scope requirements**	**1 DBB**	**2 DB**	**3 CM-R**
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0.1365	**0.669417**	**0.4**	**0.238487**	**0.1365**	**0.725848**	**0.558425**	**0.4**	**0.169205**	**0**	**0**	**0**
0.625013	**0.242637**	**0.4**	**0.625013**	**0.625013**	**0.172118**	**0.121957**	**0.2**	**0.387479**	**0**	**0**	**0**
0.238487	**0.087946**	**0.2**	**0.1365**	**0.238487**	**0.102034**	**0.319618**	**0.4**	**0.443316**	**0**	**0**	**0**

Table 4.51 The AHP Report (Summary of the Results by Involving the Ideal Data) **1 of 2**	
Alternative(s):	• 1 DBB • 2 DB • 3 CM-R

Clusters/Nodes	• **1Goal:** *This is the goal cluster, the top level in a hierarchical model*
	  o **Goal Node:** *Selecting the best PDS for the owner*
	• **2Criteria:** *Criteria for selecting a PDS*
	  o **1 Project Factors:** *the data were provided by the survey*
	  o **2 Owner Objectives:** *the data were provided by the survey*.
	  o **3 Project parameters:** *the data were provided by the previous studies*.
	• **3Project factors sub criteria:** *Sub criteria for selecting a PDS*
	  o **1 Cost:** *The amount of money paid by the owner for a facility. Costs are limited to the design and construction of the facility and do not include owner costs.*
	  o **2 Time:** *The time taken by the facility team to design and construct the facility, measured in months or days.*
	  o **3 Quality:** *The degree to which the facility meets the specified facility requirements.*
	  o **4 Safety:** *Project safety in which all aspects of the project are safe, including labor, equipment, and project facilities.*
	• **4 Owner objectives sub criteria:** *description*
	  o **1Type of project:** *level of complexity and uniqueness of the project, and the corresponding appropriate level of control.*
	  o **2Size of project:** *the more complex and costly ($/ft2) a project, the greater the need for professional management and advice.*
	  o **3 Owner capabilities:** *the owner should determine his capabilities to adopt any PDS in relation to his financial position and experience.*
	  o **4 Contractor capabilities:** *the owner also, should find out what are the contractor's capabilities to adopt any PDS in relation to his financial position and experience.*
	  o **5 Time consideration:** *if the project needs to be constructed within severely compressed time limits, methods adaptable to DB construction should be considered. However, the owner must weigh the need for a*

compressed time limit against the increased risk of DB.
    - **6 Possibilities of changes:** *usually the DBB method leads to change orders and a high probability of change; while the CM-R method limits changes in the scope of the work (mostly scope changes are difficult).*
- **5 Project parameters sub criteria:** *description*
    - **1 Owner requirements:** *1. Owner risks 2. Owner controlling & involvement 3. Owner satisfaction (Met requirements) 4. Political consideration & government limitation*.
    - **2 Project needs:** *1. Transfer technology (will the project be technologically advanced) 2. Constructability innovation 3. Ensuring confidentiality 4. Resource availability.*
    - **3 Scope requirements:** *1. Ease of design 2. Well defined of scope 3. Knowledge of final cost before starting.*
- **6Alternatives:** *Alternatives PDS (DBB, DB and CM-R)*
    - **1 DBB:** *Design-Bid-Build, a delivery system where the owner or owner's agent contracts separately with a designer and a constructor.*
    - **2 DB:** *Design-Build, a project delivery system where the owner contracts with a single entity to perform both design and construction under a single design-build contract.*
    - **3 CM-R:** *Construction Management at Risk, a delivery system where the owner contracts separately with a designer and a contractor. The owner contracts with a design company to provide a facility design. The owner selects a contractor to perform construction management services and construction work, in accordance with the plans and specifications, for a fee.*

Report for top level

This is a report for how alternatives fed up through the system to give provide synthesized values.

Alternative Rankings

Graphic	Alternatives	Total	Normal	Ideal	Ranking
	1 DBB	0.0616	0.1847	0.3659	3
	2 DB	0.1683	0.5048	1.0000	1
	3 CM-R	0.1035	0.3104	0.6149	2

Table 4.52 The AHP Report (Summary of the Results by Involving Survey Data)

Alternative Rankings

Graphic	Alternatives	Total	Normal	Ideal	Ranking
	1 DBB	0.1202	0.3605	0.8009	2
	2 DB	0.1500	0.4501	1.0000	1
	3 CM-R	0.0632	0.1895	0.4210	3

Additional Testing

Because the results of the two methods (WF and AHP) did not match perfectly when testing the PDSDF with survey data, it was considered advisable to conduct an additional testing of the PDSDF with ideal data. Additional testing of the PDSDF with both WF and AHP models was carried out for the purpose of seeing whether these models would lead a project owner to a PDS that was best suited to his needs and the project requirements.

As the first test of the PDSDF with WF, the researcher input data in Column 2 (which required input from the owner) of the matrices shown in Tables 4.53 to 4.56. A scale of 1 to 10 was used to represent the weighting factors of criteria. Scale values for criteria were chosen in such a way as to reflect the needs of a project owner whose requirements were as follows:

- Owner is willing to carry high risk
- Owner wishes to have major involvement in decisions at every phase of project development
- Owner expects to be highly satisfied with project activities
- Furthermore the owner needs to meet government requirements
- Owner is concerned about the confidentiality of the design and construction of the project
- Owner is able to clearly define the scope of the work
- Owner needs to know the final cost before construction is begun
- Time and cost are not primary concerns

Logically, given these conditions, the model should lead the project owner to the selection of DBB. As shown in Table 4.56, the total points were highest for DBB (1933), second for CM-R (1890), and third for DB (1577).

Table 4.53 Project Factors Matrix Results (Ideal)

Factors	WF To be decided by owner (using Table 25, App. A)	DBB a1	DB a2	CM-R a3
Cost	5	1.0	3.0	2.0
Time/schedule	3	1.0	3.0	2.0
Quality	8	2.0	1.0	3.0
Safety	10	2.0	1.0	3.0
Total (should be transferred to Criteria Results, Table 4.56)		44	42	70

Table 4.54 Owner Objectives Matrix Results (Ideal)

Characteristics	WF To be decided by owner (using Table 24, App. A)	DBB a1	DB a2	CM-R a3
Type of project	8	2.0	1.0	3.0
Size of project \$Cost/ ft^2	4	3.0	2.0	1.0
Owner capabilities (financial & experience)	7	3.0	1.0	2.0
Contractor capabilities (financial & experience)	4	1.0	3.0	2.0
Time consideration	3	1.0	3.0	2.0
Possibilities of changes	7	2.0	3.0	1.0
Total (should be transferred to Criteria Results, Table 4.56)		70.0	65.0	63.0

Table 4.55 Project Parameters Matrix Results

Parameters	WF To be decided by owner (using Table 26, App. A)	DBB a1	DB a2	CM-R a3
Owner Risks	10	3	1	2
Owner controlling & involvement	8	2	1	3
Transfer technology (well the project be technologically advanced)	3	1	2	3
Owner satisfaction (Met requirement)	9	2	1	3
Ease of design	6	1	3	2
Constructability innovation	2	2	1	3
Political consideration & government limitation	7	3	2	1
Ensure confidentially	4	3	2	1
Resource availability	8	3	1	2
Well defined of scope	10	3	1	2
Know final cost before starting	10	1	3	2
Total of the mean (should be transferred to Table 4.56)		171	127	158

Table 4.56 Criteria Results of Project Evaluation Matrices of Decision Model (for each project) PDSDF

Owner output (Criteria) (1)	WF To be decided by owner (Ranking importance of criteria from 1 to 10) (2)	DBB a1 (3)	DB a2 (4)	CM-R a3 (5)
Project factors matrix (Questionnaire)	8	44	42	70
Project key consideration matrix (Questionnaire)	4	70	65	63
Project parameters (Key decision points) (Previous study)	4	171	127	158
Total points		1933.00	1577.00	1890.00
Select maximum		*****		

Following the same principle, to test the PDSDF with AHP, the researcher input data into Super Decision Software reflecting the same assumptions about the project owner's priorities to make pairwise comparisons of the criteria with respect to the goal. The results are shown in Figure 4.11. Consistent with the results provided by the WF method, the results of AHP led to the selection of DBB. As shown in Figure 4.11, the highest priority was assigned to DBB, with

CM-R second and DB third. The ranking of the three project delivery systems that was consistent for WF and AHP reflects the strengths and weaknesses of the delivery systems.

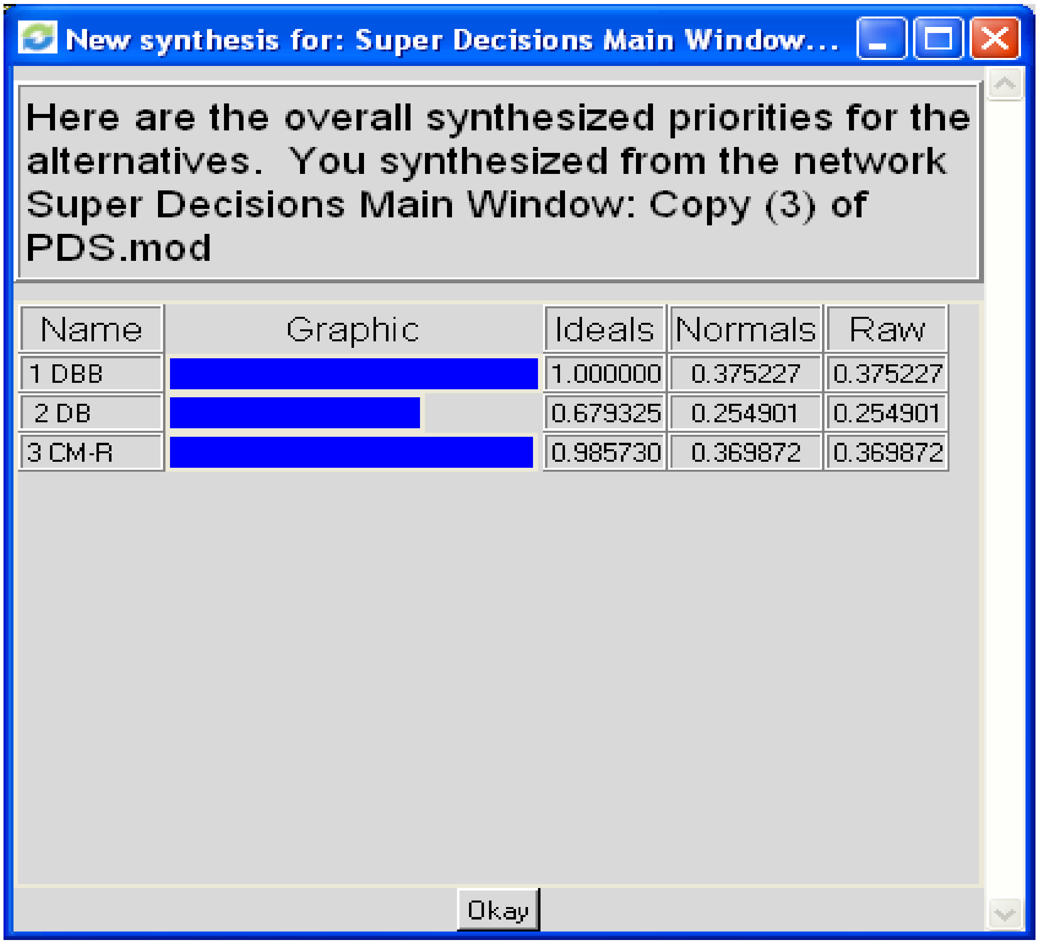

Figure 4.11 Synthesized Priorities (DBB)

As a second test of the PDSDF with WF, the researcher input a second set of assumed data in Column 2 (which required input from the owner) of the matrices shown in Tables 4.57 to 4.60. Scale values for criteria were chosen in such a way as to reflect the needs of a project owner whose project was complex and unique and who placed high priority on quality. For example, in Table 57 the researcher assumed that the owner would assign a weight of 10 to quality since this was the highest priority. Logically, in this case the model should lead this project owner to the selection of CM-R. As shown in Table 4.60, the total points were highest for CM-R (1380), second for DB-B (1196), and third for DB (1048).

Table 4.57 Project Factors Matrix Results (Ideal)

Factors	WF To be decided by owner (using Table 25, App. A)	DBB a1	DB a2	CM-R a3
Cost	5	1.0	3.0	2.0
Time/schedule	3	1.0	3.0	2.0
Quality	10	2.0	1.0	3.0
Safety	7	2.0	1.0	3.0
Total (should be transferred to Criteria Results, Table 4.60)		42	41	67

Table 4.58 Owner Objectives Matrix Results (Ideal)

Characteristics	WF To be decided by owner (using Table 24, App. A)	DBB a1	DB a2	CM-R a3
Type of project	8	2.0	1.0	3.0
Size of project $Cost/ ft^2	4	3.0	2.0	1.0
Owner capabilities (financial & experience)	7	3.0	1.0	2.0
Contractor capabilities (financial & experience)	4	1.0	3.0	2.0
Time consideration	3	1.0	3.0	2.0
Possibilities of changes	7	2.0	3.0	1.0
Total (should be transferred to Criteria Results, Table 4.60)		70.0	65.0	63.0

Table 4.59 Project Parameters Matrix Results

Parameters	WF To be decided by owner (using Table 26, App. A)	DBB a1	DB a2	CM-R a3
Owner Risks	5	3	1	2
Owner controlling & involvement	10	2	1	3
Transfer technology (well the project be technologically advanced)	3	1	2	3
Owner satisfaction (Met requirement)	9	2	1	3
Ease of design	6	1	3	2
Constructability innovation	2	2	1	3
Political consideration & government limitation	7	3	2	1
Ensure confidentially	5	3	2	1
Resource availability	4	3	1	2
Well defined of scope	7	3	1	2
Know final cost before starting	10	1	3	2
Total of the mean (should be transferred to Table 4.60)		145	115	148

Table 4.60 Criteria Results of Project Evaluation Matrices of Decision Model (for each project) PDSDF

Owner output (Criteria) (1)	WF To be decided by owner (Ranking importance of criteria from 1 to 10) (2)	DBB a1 (3)	DB a2 (4)	CM-R a3 (5)
Project factors matrix (Questionnaire)	8	42	41	67
Project key consideration matrix (Questionnaire)	4	70	65	63
Project parameters (Key decision points) (Previous study)	4	145	115	148
Total points		1196.00	1048.00	1380.00
Select maximum				*****

As was done for the first test, the researcher input data into Super Decision Software reflecting the same assumptions about the project owner's priorities to make pairwise comparisons of the criteria with respect to the goal. The results are shown in Figure 4.12. Consistent with the results provided by the WF method, the results of AHP led to the selection of CM-R. As shown in Figure 4.12, the highest priority was assigned to CM-R, with DBB second and DB third. The ranking of the three project delivery systems that was consistent for WF and AHP reflects the strengths and weaknesses of the delivery systems.

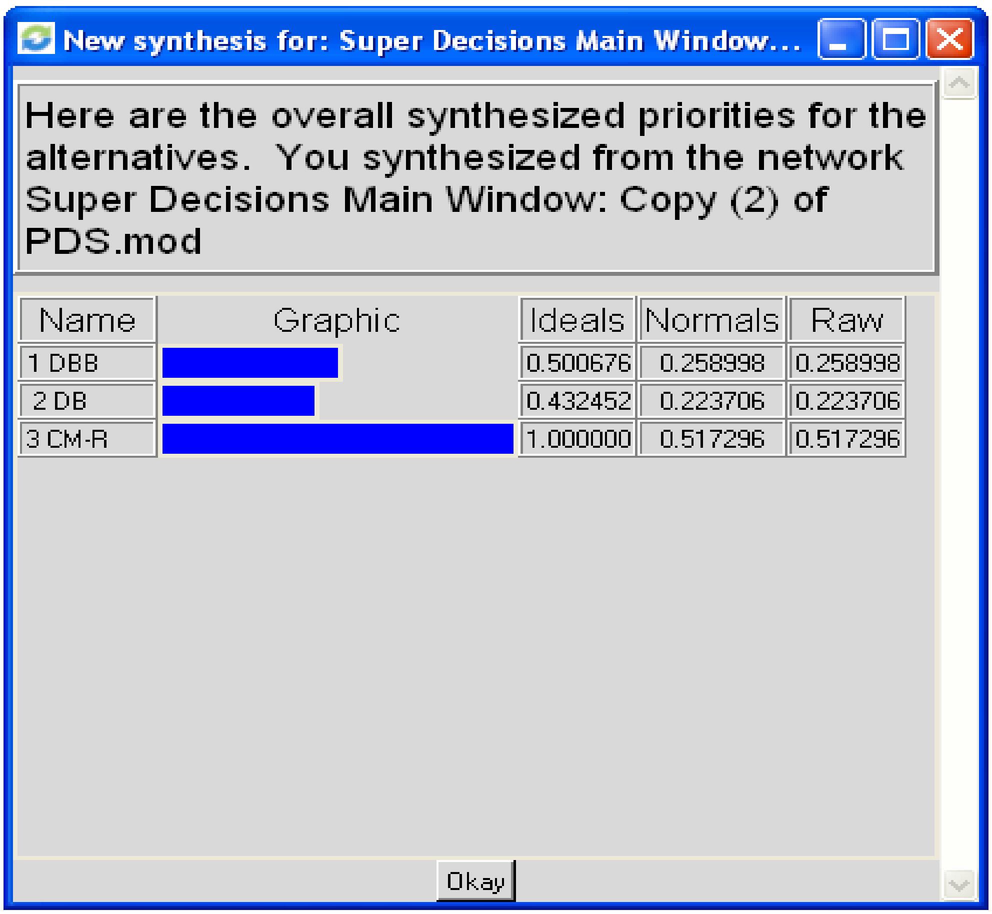

Figure 4.12 Synthesized Priorities (CM-R)

The results of this additional test provided evidence of the functionality of the PDSDF, both with WF and AHP. In the two cases described above, the researcher first input data reflecting the needs and requirements of a project owner which would best be met by DBB, and then input data reflecting needs and requirements which would best be met by CM-R. In both cases the PDSDF provided meaningful results.

4.4.3 Conclusion and Comparison of Results of WF with Results of AHP

When the two methods (WF and AHP) were tested using data from previous research (ideal data), the results matched. These data were considered to be ideal because the selection of a PDS was based on consideration of the strengths and weaknesses of each delivery system: DBB, DB, and CM-R. Both methods would direct a project owner to the same decision: choosing the same system. In these ideal data, the researcher filled in the column where the owner assigned rankings from 1 to 9 to represent the relative importance of the criteria and sub-criteria. The researcher assigned rankings based on assumptions about owner requirements and project needs. Based on these rankings, the choice of PDS was a logical one because the method would best suit the owner requirements and project needs that were assumed by the researcher. However, when the two methods were tested using survey data, the results did not match. In the case where DB should have been preferred the WF method would direct a project owner to choose the DBB system. AHP, however would direct a project owner to choose the DB system. Several factors can explain this lack of agreement between the two methods. First, in the WF results the total points for DBB were only slightly higher than the total points for DB (see Table 4.45). In the AHP results, the priority assigned to DB was .45 compared to .37 for DBB, which, again, was a small margin. The reversed priorities for DB and DBB may have arisen because of a mathematical issue. As previously described in Section 4.4.2.2, it was necessary to rescale the survey data so that they would fit the scale developed by Saaty on which AHP is based. To accomplish the rescaling, decimals needed to be rounded to the nearest whole number and this resulted in a lack of precision during the pairwise comparison stage of the AHP method.

5.0 CONCLUSIONS AND FUTURE STUDY

5.1 Conclusions

Both the WF and AHP methods are effective in building a PDSDF to help decision makers (project owners) select the best PDS to meet their needs and project requirements. The results produced by the two methods agreed when the PDSDF was tested with ideal data (data obtained from the findings of previous studies).

Some discrepancy between the two methods occurred when the PDSDF was tested with data collected in the survey associated with this research.. One factor that contributed to this discrepancy was the characteristics of the survey data; for many of the projects the selection of a PDS was not based on logical consideration of the strengths and weaknesses of the three delivery systems. Another reason for the discrepancy was that the scale of 1 to 3 used in the survey needed to be converted to a scale of 1 to 9 in order to make use of AHP as implemented in the Super Decision Software.

When project owners are in a position to select among alternative PDSs based on logical consideration of the strengths and weaknesses of each delivery system, a PDSDF can be a helpful tool. The results of a PDSDF are likely to lead project owners to select the delivery system that is the best alternative in their circumstances.

The results of testing the WF and AHP methods with both ideal data and survey data showed that the AHP method was very sensitive to small changes in judging the relative importance of criteria and sub-criteria. On the other hand, the WF method was seen to be less sensitive to small changes. The sensitivity of the AHP method was due in part to the use of means from survey data in completing the matrices. Only small differences between means of factors and parameters with respect to the three delivery systems were observed.

Because of the greater sensitivity of the AHP method to small changes in judgment, the researcher concluded that the WF method might be more useful to project owners. In the WF method the relative ranking of alternatives would not be likely to change as a result of small changes in judgment. Previous research has shown that an individual's judgments are not perfectly stable but fall within a certain range. A method that is less sensitive to such small changes in judgment might provide results that are a better reflection of the owner's priorities. However, it is necessary to keep in mind that both methods provided meaningful results.

5.2 Limitations of the Research

The owners of the projects targeted by the survey were often only familiar with one delivery system, DBB. Therefore, they were not in a position to consider other the alternatives and make a reasoned decision based on strengths and weaknesses of alternatives.

It was noted that approximately 77 percent of the projects on which data were obtained were in the public sector and under the influence of government policy. The government in Saudi Arabia usually prefers some kind of competitive bidding, typically DBB, and often insists on such a method. These circumstances led to an unbalanced representation of the three delivery systems in the present sample, namely, that projects were predominantly built under DBB. The relatively small number of projects built under DB and CM-R could have led to a lack of accuracy in testing the model. In addition, the differences between means of factors were very small, possibility as a result of the unbalanced representation of the three delivery systems in the present sample.

A total of 77 usable surveys were received out of 150 that were sent out. The response rate was lower than ideal distribution because of the timing of the survey distribution. Surveys reached project owners in August which is the most common time for vacations.

5.3 Contribution of the Research

Several features of the present study enhanced its contribution. Unlike many previous studies, the present study made use of data from actual completed projects in Saudi Arabia. Therefore, its results can be generalized to project owners in Saudi Arabia and are meaningful in that context. The comparison of two methods of building a PDSDF, Weighting Factors (WF) and Analytical Hierarchy Process (AHP), was another strength of the present study. Furthermore, both of these methods were applied to data from previous studies in addition to survey data so that the two methods could be tested with data from both sources.

This research should make it possible for project owners and project engineers in Saudi Arabia to select the project delivery system that best meets their needs. Based on review of the literature, most studies on the selection of project delivery systems have been carried out on projects in the United States. Because of government constraints, it is necessary to collect data from a sample of Saudi Arabian projects in order to develop a model that will provide meaningful results that can be generalized to that population.

5.4 Recommendations for Future Studies

Surveys that are designed for future studies should allow project owners to directly assign quantitative ratings of the relative importance of criteria and sub-criteria. These ratings should be based on the 1 to 9 the scale designed by Saaty so that rescaling is not necessary in order to use Super Decision software. This will improve the accuracy of the results produced by AHP.

To build on the present study, a future study should be designed in which project owners are given the opportunity to use the PDSDF to help them select a delivery system. Project owners could be surveyed again following the completion of the projects to learn how successful the implementations were. The ultimate goal of a PDSDF is to help the project owner select the method that will lead to the most successful outcome. Learning about project owners' perceptions of success could be used to improve the functioning of the model.

In the present study, survey projects were randomly sampled from a listing of projects completed within the last 15 years and there was unequal representation of the three delivery systems. Specifically, the majority of projects in the sample (70%) were performed under DBB. It is recommended that in future studies the sample should include an equal number of projects built under each delivery system to improve the functioning of the PDSDF.

In the procedure testing of the model, the relative ranking of the importance of criteria and sub-criteria were assumed by the researcher instead of an actual project owner. Stronger evidence of the functionality of the PDSDF could be gained by testing the model with data supplied by actual decision-makers (project owners.)

APPENDICES

APPENDIX A

Tables of 1 to 27

Table 1. Summary Results of Project Evaluation Matrices of Decision Model (for each project)

Owner Output (1)	WF To be decided by the owner (2)	DBB (a1) (3)	DB (a2) (4)	CM-R (a3) (5)
Project Factors Matrix (Questionnaire)				
Owner Objectives (Key Consideration Points) Matrix (Questionnaire)				
Project Parameters (Key Decision Points) (Previous Study)				
Total Points				
Select Maximum Score				

Table 2. Project Factors Matrix

Factors	WF To be decided by Owner	DBB (a1)	DB (a2)	CM-R (a3)
Cost				
Time/schedule				
Quality				
Safety				
Total, (Should be transferred to Table 1).				

Table 3. Cost (for all projects)

	PDS		
Project ID	DBB	DB	CM-R
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
Mean (Should be transferred to Table 2).			

Table 4. Time (for all projects)

	PDS		
Project ID	DBB	DB	CM-R
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
Mean (Should be transferred to Table 2).			

Table 5.Quality (for all projects)

	PDS		
Project ID	DBB	DB	CM-R
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
Mean (Should be transferred to Table 2).			

Table 6. Safety (for all projects)

	PDS		
Project ID	DBB	DB	CM-R
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
Mean (Should be transferred to Table 2).			

Table 7. Cost (for one project e.g., Project ID # 1)

	PDS		
Items	DBB	DB	CM-R
I5			
I6			
II6			
III 7.1			
III 7.2			
III 7.3			
III 7.4			
III 7.5			
III 8			
III 11			
III 14-a			
III 14-b			
Mean (Should be transferred to Table 3).			

Table 8. Time (for one project e.g., Project ID # 1)

	PDS		
Items	DBB	DB	CM-R
III 12			
Mean (Should be transferred to Table 4)			

Table 9. Quality (for one project e.g., Project ID # 1)

	PDS		
Items	DBB	DB	CM-R
I3			
I4			
I5			
II2			
II3			
II4			
III 13-a1			
III 13-a2			
III 13- a3			
III 13-b1			
III 13-b2			
III 13-b3			
III 13-c			
Mean (Should be transferred to Table 5).			

Table 10. Safety (for one project e.g., Project ID # 1)

	PDS		
Items	DBB	DB	CM-R
III 15			
Mean (Should be transferred to Table 6).			

Table 11. Owner Objectives (Key Consideration Points) Matrix

Characteristics	WF To be placed by Owner	DBB (a1)	DB (a2)	CM-R (a3)
Type of project				
Size of project				
Owner capabilities (Financial & Experience)				
Contractor capabilities (Financial & Experience)				
Time Consideration				
Possibilities of Changes				
Total (Should be transferred to Summary Results Table 1)				

Table 12. Type of Project (Means) (for all projects)

	PDS		
Project ID	DBB	DB	CM-R
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
Mean (Should be transferred to Table 11)			

Table 13. Size of Project (Means) (for all projects)

	PDS		
Project ID	DBB	DB	CM-R
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
Mean (Should be transferred to Table 11)			

Table 14.Owner Capabilities (Means) (for all projects)

	PDS		
Project ID	DBB	DB	CM-R
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
Mean (Should be transferred to Table 11)			

Table 15. Contractor Capabilities (Means) (for all projects)

	PDS		
Project ID	DBB	DB	CM-R
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
Mean (Should be transferred to Table 11)			

Table 16. Time Consideration (Means) (for all projects)

	PDS		
Project ID	DBB	DB	CM-R
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
Mean (Should be transferred to Table 11)			

Table 17. Possibilities of Activities Changes (Means) (for all projects)

	PDS		
Project ID	DBB	DB	CM-R
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
Mean (Should be transferred to Table 11)			

Table 18.Type of Project (for one project e.g., Project ID # 1)

	PDS		
Items	DBB	DB	CM-R
III 5			
Mean (Should be transferred to Table 12)			

Table 19. Size of Project (for one project e.g., Project ID # 1)

	PDS		
Items	DBB	DB	CM-R
III 4			
III 11			
Mean (Should be transferred to Table 13)			

Table 20. Owner Capabilities (for one project e.g., Project ID # 1)

	PDS		
Items	DBB	DB	CM-R
I 3			
I 4			
I 5			
I 6			
Mean (Should be transferred to Table 14)			

Table 21. Contractor Capabilities (for one project e.g., Project ID # 1)

	PDS		
Items	DBB	DB	CM-R
I 3			
I 4			
I 6			
Mean (Should be transferred to Table 15)			

Table 22. Time Consideration (for one project e.g., Project ID # 1)

	PDS		
Items	DBB	DB	CM-R
III 12			
Mean (Should be transferred to Table 16)			

Table 23. Possibilities of Change (for one project e.g., Project ID # 1)

	PDS		
Items	DBB	DB	CM-R
III 11			
Mean (Should be transferred to Table 17)			

Table 24. Owner Objectives, Key Consideration Points
(Owner Decision Matrix)

Characteristics			
Type of project	1 (Less Complex & Uniqueness) less control	5	10 (more control) more complex & uniqueness
Size of project	10 Low $Cost/ ft^2	5	0 High $Cost/ ft^2
Owner capabilities (Financial & Experience)	1 Limited	5 Reasonable	10 Adequate
Contractor capabilities (Financial & Experience)	10 adequate	5 Reasonable	1 Limited
Time Consideration	10 Very Critical (limited , Rigid)	5 critical but has some flexibilities	1 Flexible (not critical)
Possibilities of Changes	10 high probability of change	5	1 low (Most Difficult), (Scope changes are difficult)

Table 25. Project Factors Matrix (Owner Decision Matrix) WF Measurement

Factors			
Cost	10 Very Important (low Cost)	5	1 Low Important (High Cost)
Time	10 Short (very Important)	5	1 (Long ,Low)
Quality	1 Low	5 Met Expectation	10 Exceeded Expectation
Safety	1 Low	5 Acceptable	10 High level

*(According to the point of view of the owner and project needs, The owner should determine the WF level of the above factors)

Table 26. Project Parameters, Key Decision Points (Owner Decision Matrix)

Parameters			
Owner Risks	10 High Risk	5	1 Low Risk
Owner Controlling & Involvement	10 High Involvement	5	1 Low
Transfer Technology (will the project be technologically advanced)	10 (required) Highly Advanced	5	1 (Not required) Not advanced
Owner Satisfaction (Met Requirement)	10 Satisfied	5	1
Ease of Design	10 Easy	5	1 Difficult
Constructability Innovation	10 Early	5	1 Late
Political Consideration & Government Limitation	1 Limited & Not Allowed	5	10 Flexible & Preferred
Ensure Confidentially	1 high confidentially	5	10 Low
Resource Availability	10 Available	5	1 Not available
Well defined of scope	10 well defined	5	1 Not well defined
Know final cost before starting	1 Don't know	5	10 Know

*(According to the point of view of the owner and project needs,
The owner should determine the WF level of the above parameters)

Table 27. Project Parameters Matrix (Key Decision Points)

			PDS	
Parameters	WF from table 26	DBB (a1)	DB (a2)	CM-R (a3)
Owner Risks		3 (high) Contractor takes risk for construction only	1 (low) Single of responsibilities (Sole source of responsibilities)	2
Owner Controlling & Involvement		2 The involvement is not on a day-to-day basis and is not present in all the decisions	1 - Fewer checks and balances - Reduced owner representation - Minimize owner's role in managing design and construction	3 -The owner on the project team may retain most, if not all, the decision power - Promote greater owner involvements in detailed design and construction
Transfer Technology (will the project be technologically advanced)		1	2 Need Special Designer and contractor	3 Highly Advanced
Owner Satisfaction (Met Requirements)		2	1 Less satisfied due to the poor involvement for the owner during the construction	3 Owner mostly satisfied
Ease of Design		1	3 because the design and construction is provided by or through one contractor (single responsibilities)	2
Constructability Innovation		2	1 limit the construction knowledge	3 Introduce Construction knowledge into design early in the process
Political Consideration & Government Limitation		3 mostly preferred	2	1

Table 27. (cont.)

Parameters	WF from table 26	DBB a1	DB a2	CM-R a3
Ensure Confidentially		3 Protect secrecy of business objectives and proprietary technology.	2	1
Resource Availability		3 Usually by selecting this method, it's assumed that the most of resources are available	1 Not available	2
Well defined of scope		3 Well defined	1	2
Know final cost before starting		1 the owner doesn't the final cost due to change orders as a result of design ambiguous and contractors climes	3 the contract usually been signed as fixed price contract	2
Total of the Mean (should be transferred to Table 1)				

APPENDIX B

Data Coding

PROJECT FACTORS MATRIX (WF)

Cost

Q I 5 Level of staffing (# of people)

	DBB	DB	CM-R
	High Level	Low Level	Med. Level
Coding #	1	3	2

Q I 6 Financial Position (Owner)

	DBB	DB	CM-R
	Excellent	Poor	Good
Coding #	1	3	2

Q II 6 Financial Position (Contractor)

	DBB	DB	CM-R
	poor	Excellent	Good
Coding #	1	3	2

Q III 7 Project Category or Division:

Q III 7.1 Project typical (Owner)

	DBB (No)	DB (Yes)	CM-R
	Not typical	Typical	Mixed
Coding #	1	3	2

Q III 7.2 Project typical (Contractor)

	DBB (No)	DB (Yes)	CM-R
	Not typical	Typical	Mixed
Coding #	1	3	2

Q III 7.3 special characteristics that made it unusual

	DBB	DB (No)	CM-R (Yes)
	have some	doesn't have S.C	S.C
Coding #	1	3	2

Q III 7.4 Element of the project been used on a previous project by the owner

	DBB	DB	CM-R
	No	Yes	
Coding #	1	3	2

Q III 7.5 Element of the project been used on a previous project by the contractor

	DBB	DB	CM-R
	No	Yes	
Coding #	1	3	2

Q III 8 The project have repetitive major activities

	DBB	DB	CM-R
		Yes	No
Coding #	2	3	1

Q III 11 The project cost

	DBB	DB	CM-R
	Med cost	low cost	High cost
Coding #	2	3	1

Q III 14.a Advanced or unusual materials used in the project

	DBB	DB	CM-R
		No	Yes
Coding #	2	3	1
		low cost	

Q III 14.b Advanced or unusual construction processes used in the project

	DBB	DB	CM-R
	Yes	No	
Coding #	1	3	2
		low cost	

Time

Q III 12 Project Schedule

	DBB	DB	CM-R
	Flexible	Limited	Critical but has some flexibility
Coding #	1	3	2

Quality

Q I 3 Owner's support staff experience

	DBB	DB	CM-R
	High exp.	Low Exp.	Med. Exp.
Coding #	2	1	3

Q I 4 Owner's field management staff experience

	DBB	DB	CM-R
	High exp.	Low Exp.	Med. Exp.
Coding #	2	1	3

Q I 5 Level of staffing (# of people)

	DBB	DB	CM-R
	High Level	Low Level	Med. Level
Coding #	2	1	3

Q II 2 Is the contractor

	DBB	DB	CM-R
	G.C	G.C.	CM & S.C.
Coding #	2	1	3

Q II 3 Contractor's support staff experience

	DBB	DB	CM-R
	Low exp.	High Exp.	Med. Exp.
Coding #	2	1	3

Q II 4 Contractor's field management staff experience

	DBB	DB	CM-R
	Low exp.	High Exp.	Med. Exp.
Coding #	2	1	3

III 13 Project quality
III 13-a Turnover quality
III 13-a-1 Facility startup

	DBB	DB	CM-R
	Poor	Average	Good
Coding #	1	2	3

III 13-a-2 The number of call back

	DBB	DB	CM-R
	high number	Average #	Low #
Coding #	1	2	3

III 13-a-3 The operation and maintenance cost for building /site

	DBB	DB	CM-R
	high Cost	Average cost	Low Cost
Coding #	1	2	3

III 13-b System Quality Measures

III 13-b-1 Performance of the envelope

	DBB	DB	CM-R
	Low	Average	High
Coding #	1	2	3

III 13-b-2 The Interior space and layout

DBB	DB	CM-R
Low	Average	High
1	2	3

III 13-b-3 Environmental or mechanical systems

	DBB	DB	CM-R
	Low	Average	High
Coding #	1	2	3

III 13-c Equipment Quality

DBB	DB	CM-R
Did not meet expectation	met expectation	Exceeded expectation
1	2	3

Safety

Q III 15 Project Safety

	DBB	DB	CM-R
	Acceptable	Poor	High Level
Coding #	2	1	3

OWNER OBJECTIVES (KEY CONSIDERATION POINTS)

Q III 5 Project Type

	DBB	DB	CM-R
		less Complex & control over the end product	More Complex
Coding #	2	1	3

Owner Capabilities

Q I 3 Owner's support staff experience

	DBB	DB	CM-R
	High exp.	Low Exp.	Med. Exp.
Coding #	3	1	2

Q I 4 Owner's field management staff experience

	DBB	DB	CM-R
	High exp.	Low Exp.	Med. Exp.
Coding #	3	1	2

Q I 5 Level of staffing (# of people)

	DBB	DB	CM-R
	High Level	Low Level	Med. Level
Coding #	3	1	2

Q I 6 Financial Position (Owner)

	DBB	DB	CM-R
	Excellent	Poor	Good
Coding #	3	1	2

Contractor Capabilities

Q II 3 Contractor's support staff experience

	DBB	DB	CM-R
	Low exp.	High Exp.	Med. Exp.
Coding #	1	3	2

Q II 4 Contractor's field management staff experience

	DBB	DB	CM-R
	Low exp.	High Exp.	Med. Exp.
Coding #	1	3	2

Q II 6 Financial Position (Contractor)

	DBB	DB	CM-R
	poor	Excellent	Good
Coding #	1	3	2

Time Consideration

Q III 12 Project Schedule

	DBB	DB	CM-R
	Flexible	Limited	Critical but has some flexibility
Coding #	1 Need Longer time than other method	3 To be constructed in a severely compressed time limit	2

Possibilities of Change

Q III 11 The project cost

	DBB	DB	CM-R	
	High Possibilities	Med.	Most difficult of change	
Coding #	2 High cost Growth	3 Med cost Growth	1 Low cost Growth	Cost Growth

APPENDIX C

Questionnaire

APPENDIX C1

English Questionnaire

Project Delivery Systems Selection Model (PDSSM)

Instruction:

Please note the following:

- To answer multiple choice questions, put an X in the box next to your answer.
- At the end of the survey is a sheet of general definitions of terms that may be useful in answering some of the questions.
- There are three sections to the questionnaire: 1) Owner, 2) Contractor, and 3) General Project Information.
- All respondents should answer all sections.

Thank you

I) Owner / Client:

1. Owner Name: ____

2. Is the owner:
   ☐ Public sector
   ☐ Private sector

3. How would you characterize the construction experience of the owner's support staff on this particular project?
   ☐ Low
   ☐ Medium
   ☐ High

4. How would you characterize the construction experience of the owner's field management staff on this particular project?
   ☐ Low
   ☐ Medium
   ☐ High

5. What was the owner's level of staffing (# of people)?
   ☐ Low
   ☐ Medium
   ☐ High

6. What was the owner's financial position?
   ☐ Poor
   ☐ Good
   ☐ Excellent

II) Contractor

1. Name of the contractor. ____

2. Is the contractor:
   ☐ Specialty contractor
   ☐ General contractor
   ☐ Other, (please specify) ____

3. How would you characterize the construction experience of the contractor's support staff on this particular project?
   ☐ Low
   ☐ Medium
   ☐ High

4. How would you characterize the Construction experience of the contractor's field management staff on this particular project?
   ☐ Low
   ☐ Medium
   ☐ High

5. Please indicate the percentage of the contract equipment that was rented and owned (if none, please specify 0 %):
   ______% Owned
   ______% Rented

6. What was the contractor's financial position:
   ☐ Poor
   ☐ Good
   ☐ Excellent

7. Cost of the majority of past projects:
   SR Million
   ☐ SR 00 – SR 10
   ☐ SR 11 – SR 30
   ☐ SR 31 - SR 60
   ☐ More than SR 60

III) General Project Information:

1. Project Name: ____

2. Project Location:

____
(address)

______________________ ______________ ______________________
(City) (State) (Country)

3. Year Built: __________

4. Size of the Project (total building floor area only).
______________ m^2 OR ____________ ft^2

5. Project Type (check all that apply):
☐ Multistory Dwelling
☐ Light Industrial
☐ Simple Office
☐ Complex Office
☐ Heavy Industrial
☐ High Technology
☐ Other, (Please specify) ______________________________________

6. Project Status.
☐ New project
☐ Renovation project

7. Project Category or Division;

7.1 Was this project typical of the type of work for the owner?
☐ No
☐ Yes

7.2 Was this project typical of the type of work for the contractor?
☐ No
☐ Yes

7.3 Did this project have any special characteristics that made it unusual?
☐ No
☐ Yes, please specify ________________________________
____

7.4 Have elements of this project been used on a previous project by the owner?
☐ No
☐ Yes, please specify ________________________________
____

7.5 Have elements of this project been used on a previous project by the contractor?
- ☐ No
- ☐ Yes, please specify ____
____

8. Does this project have repetitive major activities?
   - ☐ No
   - ☐ Yes, please give some examples, and indicate below the percentage of the project that involved repetitive activities

     ____
     ____

     - ☐ 25% or less
     - ☐ 26% to 50%
     - ☐ More than 50%

9. What was the Project Delivery Method?
   - ☐ Traditional Method, Design-Bid-Build (DBB)
   - ☐ Design Build Method (DB)
   - ☐ Construction Management at Risk Method (CM-R)
   - ☐ Other, please specify ____
     ____

10. What was the payment method?
    - ☐ Lump sum
    - ☐ Unit price
    - ☐ Fixed price plus percentage of the total cost
    - ☐ Fixed price plus fixed amount

11. What was the project cost during each of the following stages (check all that apply)?

	Cost (SR)
☐ Estimated cost	____________
☐ Bid cost	____________
☐ Contract cost	____________
☐ Actual cost	____________

Check all of the items included in the actual project cost and indicate the cost of each?

Cost (SR)

- ☐ Pre-design ___________
- ☐ Design ___________
- ☐ Construction ___________
- ☐ Operation and maintenance ___________
- ☐ Handover the project ___________
- ☐ All of above ___________
- ☐ Other, please specify ____
____

12. What was the duration of the project schedule as determined in the following stages?

Days

- ☐ Estimated duration in design stage ______________
- ☐ Estimated duration in bid stage ______________
- ☐ Estimated duration in contract stage ______________
- ☐ Actual duration at completion ______________

Which of the following characterizes the project schedule?

- ☐ Limited (rigid) schedule
- ☐ Flexible schedule
- ☐ Critical but had some flexibility for unforeseen circumstances

13. Project Quality:

a) Turnover quality:

a-1. Facility startup:

☐ Poor ☐ Average ☐ Good

a-2. Number of call backs:

☐ Low (0 – 1) ☐ Average (2 – 4) ☐ High (4 and more)

a-3. Operation and maintenance cost for building / site:

☐ Low ☐ Average ☐ High

b) System Quality Measures:

	Low	Average	High
b-1. Performance of the envelope (roof, structure, foundation)	☐	☐	☐
b-2. The interior space and layout..........................	☐	☐	☐
b-3. Environmental or mechanical systems	☐	☐	☐

c) Equipment Quality;

- ☐ Did not meet expectations
- ☐ Met expectations
- ☐ Exceeded expectations

14. Advanced Technology and Materials:
a) Were advanced or unusual materials used in the project?

☐ No
☐ Yes, please specify ____
____

b) Were advanced or unusual construction processes used in the project?

☐ No
☐ Yes, please specify ____
____

15. Project Safety (Labor, Equipment, and Project Facilities)

☐ Poor, or did not meet the requirements
☐ Acceptable
☐ High level of safety

APPENDIX C2

Arabic Questionnaire

"أختيار الطريقه المثلى لتنفيذ المشاريع آلأنشائيه"

إستماره الإستبانه

ـــ تعليمات

أرجو ملاحظه التعليمات التاليه للأجابه على الأسئله:

- ❖ ضع العلآمه X أمام الآجابه التي تختارها
- ❖ الأستيان مقسم الى ثلاث اجزاء ١- المالك (عام او خاص)
  ٢ – المقاول المنفذ
  ٣ – الأستشاري او المهندس
- ❖ أمل من الجميع الأجابه على جميع الأسئله باجزائها الثلاثه, فمثلاً إن كان المجيب يمثل الجهه المالكه للمشروع فعليه ان يجيب عن ما يخص المالك وكذلك ما يتعلق بالأطراف الأخرى للمشروع من مقاول او إستشاري من وجهه نظره. و كذلك العكس فان كان المجيب يمثل المقاول المنفذ للمشروع فعليه الأجابه فيما يخصه والأطراف الأخرى من مالك واستشاري من وجهه نظره, و هكذا.
- ❖ في نهايه الأستبيان يوجد بعض التعريفات العامه لبعض المصطلحات, امل الأطلاع عليها عند الحاجه.

أولاً: المالك أو من يمثله:

١- اسم المالك: ________________________________

٢- هل المالك:

☐ عام (حكومي)
☐ خاص

٣- كيف تصف او تقيم الخبره الفنيه الأنشائيه لطاقم العمل المساند لهذا المشروع (المتواجد عاده بالمركز الرئيسي) والخاص بالمالك ؟

☐ ضعيفه
☐ متوسطه
☐ عاليه

٤- كيف تصف او تقيم الخبره الفنيه الأنشائيه لطاقم العمل والخاص بالمالك والمتواجد بموقع العمل للأشراف والمتابعه لهذا المشروع ؟

☐ ضعيفه
☐ متوسطه
☐ عاليه

٥- ما مستوى الهئيه الأشرافيه للمشروع والخاصه بالمالك مقارنه بعدد العاملين بطاقم العمل ؟

☐ ضعيفه
☐ متوسطه
☐ عاليه

٦- ما هو تقيمك للوضع المالي للمالك لهذا المشروع ؟

- ☐ ضعيف
- ☐ جيد
- ☐ ممتاز

ثانيًا: المقاول المنفذ:

١- اسم المقاول المنفذ: ______________________________

٢- هل المقاول:

- ☐ مقاول متخصص
- ☐ مقاول عام
- ☐ غير ذلك(أ رجو التحديد): ______________________________

٣- كيف تصف او تقيم الخبره الفنيه الأنشائيه لطاقم العمل المساند لهذا المشروع (المتواجد عاده بالمركز الرئيسي) والخاص بالمقاول المنفذ ؟

- ☐ ضعيفه
- ☐ متوسطه
- ☐ عاليه

٤- كيف تصف او تقيم الخبره الفنيه الأنشائيه لطاقم العمل والخاص بالمقاول المنفذ والمتواجد بموقع العمل للتنفيذ و للأشراف والمتابعه لهذا المشروع ؟

- ☐ ضعيفه
- ☐ متوسطه
- ☐ عاليه

٥- الرجاء توضيح نسبه المعدات المستآجره والمملوكه من قبل المقاول المنفذ بالمشروع(في حاله انعدام احدهما يوضع صفر امام الفراغ المخصص له) ؟

________ % مملوك

________ % مستآجر

٦- ما هو تقيمك للوضع المالي للمقاول المنفذ لهذا المشروع ؟

- ☐ ضعيف
- ☐ جيد
- ☐ ممتاز

٧- أين تنحصر تكاليف المشاريع المنفذه من قبل المقاول في الفتره السابقه لتنفيذ هذا المشروع ؟

من الى

- ☐ ٠٠،٠٠٠،٠٠٠ ريال سعودي الى ١٠،٠٠٠،٠٠٠ ريال سعودي
- ☐ ١١،٠٠٠،٠٠٠ ريال سعودي الى ٣٠،٠٠٠،٠٠٠ ريال سعودي
- ☐ ٣١،٠٠٠،٠٠٠ ريال سعودي الى ٦٠،٠٠٠،٠٠٠ ريال سعودي
- ☐ أكثر من ٦٠،٠٠٠،٠٠٠ ريال سعودي

ثالثًا: معلومات عامه عن المشروع:

١- اسم المشروع : ________________________

٢- موقع المشروع :

____

العنوان

________ ________ ________

المدينه المنطقه الدوله

٣- عام التنفيذ : ________ هجري ________ ميلادي

٤- مساحه المشروع (مساحه المباني المنفذه بالمشروع)

________ متر مربع ________ قدم مربع

٥- نوع المشروع (ضع علامه X امام الأجابات الممكنه في حاله ان المشروع يشمل اكثر من اجابه):

- ☐ مباني سكنيه (وتشمل جميع المباني السكنيه سواء كانت تشمل دور واحد او اكثر وكذلك العنابر والمساكن العسكربه).
- ☐ منشآت صناعيه (وتشمل مستودعات ومخازن, ورش صناعيه, منشآت مدنيه خفيفه) وهذه المنشآت تشمل اعمال كهربائيه وميكانيكيه خفيفه.
- ☐ مكاتب مبسطه
- ☐ مكاتب مركبه (وهي عباره عن مكاتب تحتوي علىمستوى عالي من التقنيه مثل مراكز المعلومات , المكتبات, المراكز الطبيه)
- ☐ منشآت ذات تكنولوجيا عاليه مثل (المستشفيات, مباني المشبهات , المباني التي تحتوي علي اجهزه ذات تقنيه الكترونيه عاليه)
- ☐ غير ذلك, (أرجو التحديد): ________________________

____

٦- حاله المشروع :

- ☐ جديد
- ☐ ترميم

٧- فئه المشروع :

١-٧ هل يعتبر المشروع نموذجي (مكرر) بالنسبه لأعمال المالك ؟

- ☐ لا
- ☐ نعم

٧-٢ هل يعتبر المشروع تموذجي (مكرر) بالنسبه لأعمال المقاول المنفذ ؟

☐ لا
☐ نعم

٧-٣ هل يشمل المشروع على صفات مميزه مما يجعله مشروع غير اعتيادي ؟

☐ لا
☐ نعم, ارجو تحديد هذه الصفات ان أمكن: ________________

____
____

٧-٤ هل عناصر المشروع سبق ان استخدمت بمشاريع سابقه بالنسبه للمالك ؟

☐ لا
☐ نعم,ارجوتحديدهذه العناصر ان أمكن, ________________
____
____

٧-٥ هل عناصر المشروع سبق ان استخدمت بمشاريع سابقه بالنسبه للمقاول المنفذ ؟

☐ لا
☐ نعم,ارجوتحديدهذه العناصر ان أمكن, ________________
____
____

٨- هل المشروع يشمل على أنشطه رئيسيه مكرره ضمن المشروع نفسه ؟

☐ لا
☐ نعم,أمل اعطاء بعض الأمثله مع تحديد نسبتها من كامل المشروع ان أمكن,
____
____
____

☐ ٢٥ % أو اقل
☐ من ٢٦% ألى ٥٠ %
☐ أكثر ٥٠ %

٩- ما نوع الطريقه المستخدمه بتنفيذ المشروع:

☐ الطريقه الأعتياديه (تصميم واعداد الوثائق- طرح المشروع للمتافسه – تنفيذ).

☐ طريقه التصميم والتنفيذ من قبل مقاول واحد

☐ طريقه إدارة التنفيذ مع المسولية المطلقة وهي ان يتعاقد المالك مع مصمم ومقاول منفذ كل على حده, يشارك المقاول المنفذ بابداء الملاحظات والمراجعه على اعمال التصميم ومن ثم يتولى اعمال التنفيذ والأشراف بنفس الوقت حسب المواصفات والمخططات المعتمده.

☐ غير ذلك, (أرجو التحديد): ____
____

١٠- ما هي طريقه الدفع المعتمده للمشروع:

☐ مبلغ مقطوع

☐ بواسطه سعر الوحده وحساب الكميات.

☐ مبلغ ثابت بالأضافه الى نسبه من المبلغ الأجمالي للمشروع.

☐ مبلغ ثابت بالأضافه الى مبلغ مقطوع.

١١- ماذا كانت تكلفه المشروع خلال المراحل التاليه:

	ألتكلفهSR
☐ تقدير التكلفه قبل تقديم العروض و فتح المظاريف	---------
☐ أثنا المنافسه وفتح المظاريف.	---------
☐ تكلفه التعاقد.	----------
☐ التكلفه الفعليه.	----------

ضع علامه X امام العناصر المشموله بالتكلفه الفعليه للمشروع مع توضيح تكلفه كل عنصر ان أمكن:

	ألتكلفهSR
☐ مرحله الدراسات	---------
☐ التصميم	---------
☐ التنفيذ.	---------
☐ التشغيل والصيانة.	---------
☐ التسليم للمشروع	---------
☐ جميع ما ذكر اعلاه	----------
☐ غير ذلك, ارجو الحديد ____________________	---------

١٢- ماهي مدة تنفيذ المشروع خلال المراحل التالية:

يوم

☐ المدة الزمنية المقدرة لتنفيذالمشروع حسب مرحلة التصميم . ---------

☐ المدة الزمنية المقدرة لتنفيذالمشروع حسب العروض المقدمه إثنا فتح المظاريف ---------

☐ المدة الزمنية المقدرة لتنفيذالمشروع والمعتمدة بعقد المشروع. ----------

☐ المدة الزمنيةالفعلية التي تم تنفيذالمشروع خلالها. ----------

اي من الصفات التالية تحدد المدة الزمنية للمشروع

☐ مدة زمنية ثابتة
☐ مدة زمنية مرنة
☐ مدة زمنية حرجة ولكن هنالك بعض المرونة في مدة المشروع لاسباب التاخير الخارجة عن الارادة فقط(كالظروف الجوية وماشابه ذلك).

١٣- جودة تنفيذ المشروع :-

أ - جودة الاعمال اثناء مرحلة التسليم من قبل المهندس المشرف.

أ-١ تشغيل المرفق

☐ ضعيف ☐ متوسط ☐ جيد

أ-٢ عدد مرات استدعاء المقاول للايفاء ببعض الملاحظات على بعض انشطة المشروع المنفذه:-

☐ قليل (من صفر – الى١) ☐ متوسط (٢-٤) ☐ مرتفع (٤ واعلى)

أ-١ تكلفة تشغيل وصيانة المشروع فى مراحلة الاولى بعد التسليم

☐ قليله ☐ متوسطه عاليه

ب- قياس انظمة الجودة :-

	قليل	متوسطه	عاليه
ب – ١ مراعاة جودة تنفيذ الأنشطه الرئسية للمشروع من (قواعد , هيكل انشائي , سقف)	☐	☐	☐
ب – ٢ جودة الفراغات الداخلية والتوزيع	☐	☐	☐
ب – ٣ مراعاة جودة فاعلية الاتظمة البئية والميكانيكية	☐	☐	☐

ج- جودة المعدات المستخدمة بالمشروع:-

☐ لم تفي بالمطلوب

☐ تفي بالغرض

☐ اعلى من المطلوب

١٤-التكنولوجيا المتقدمة والمواد:

أ- هل هناك مواد متقدمة تقنيا او غير اعتيادية استخدمت بالمشروع؟

☐ لا
☐ نعم, ارجو التحديد : ____
____

ب- هل هناك استخدام لطرق تنفيذية متقدمة او غير اعتيادية بالمشروع؟

☐ لا
☐ نعم, ارجو التحديد : ____
____

١٥- الالتزام بعناصر ومتطلبات السلامه اثناء تنفيذ المشروع (عمال , معدات , مرافق المشروع):-

☐ ضعيفة ولم تفي بالمطلوب

☐ مقبولة

☐ ذات مستوى عالى

١٦ - هل هناك نقاط او ملاحظات ترى انها ذات دور في نجاح أو فشل المشروع ترغب أضافتها ولم يتم التطرق لها بالأستبانه؟

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