KEY PERFORMANCE INDICATORS TO MEASURE DESIGN PERFORMANCE IN CONSTRUCTION

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ABSTRACT

Key Performance Indicators to Measure Design Performance in Construction

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The performance of the design activities for a construction project can have a significant impact on the overall performance and efficiency of the project. Design activities need to be monitored to measure performance of the design process. Performance indicators can be used in this process. The Indicators can: i) measure the degree of success of a project or organization; ii) predict, control and measure the performance of design processes; iii) benchmark performances of different projects within the same company or with other firms; iv) track and demonstrate long-term development and improvement, thereby decreasing design and construction cost and time and increasing the quality of the design product. In the context of Canada, specific construction performance indicators to assess construction project performance across project phases have yet to be formulated and documented. Therefore, there is a need to develop such indicators for the Canadian consulting engineering. From this perspective, the present research introduces practical framework and describes a model that measure the performance of the design activities for Canadian construction projects.

The main objectives of this research are the following: i) to identify key indicators that affect the design performance of construction projects; ii) to develop a model for Key Performance Indicators (KPIs) to measure the performance of design activities in the Canadian construction industry; and iii) to examine the possibility of their use in the construction industry. The methodology adopted for this research is based on review of the existing literature on design processes, review of the existing literature on design performance indicators, questionnaire surveys, interviews with practitioners, and case studies. The questionnaires along with the interviews with designers and managers from the Canadian consulting engineering are mainly conducted to explore and indentify indicators affecting the design performance. The case studies are used to validate and amend the use of these indicators in measuring project performance at the design stage. A web-based questionnaire aimed at design and construction firms was constructed. The significance and the quantification of design performance indicators are determined using a statistical package. The results from the questionnaire were used to develop a generic set of nine groups of design performance indicators for the Canadian consulting engineering. However, this research focuses on the heavy construction sector. The nine groups of indicators have been compared in pairs to identify their level of importance to each other. Experts from heavy construction participated in the pairwise comparisons task.

Built on the results of the survey and experts judgment, a Model for Design Performance Measurement (MDPM) is introduced. The MDPM uses the standard

Analytic Hierarchy Process (AHP) method to assign weights to the scores of the selected indicators, to measure a project performance and to compare projects. The MDPM is tested for small scale heavy constructions. The developed design performance measurement model can 1) predict, track, and control future performance, 2) highlight area/s for future improvement, 3) enable companies to benchmark the performance of different projects from the same or different companies, and 4) document all design performance data.

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I dedicate this thesis to the soul of my father

I really miss you

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CHAPTER 1: INTRODUCTION

1.1 PERFORMANCE MEASUREMENTS

In the construction industry, performance measurement has influenced many construction companies, government sectors, clients, and other project stakeholders. Performance measurements are objective quantitative indicators that are designed to track particular states of performance such as productivity, effectiveness, efficiency, customer satisfaction, quality and cost. In other words, "performance measurement is the regular collecting and reporting information about the inputs, efficiency and effectiveness of construction projects" (Takim et al, 2003). Companies use performance measurements to evaluate their projects by using financial and non financial measures to compare their performance with others in order to improve the efficiency and the effectiveness of their firms. Measuring performance has become critical to business success due to the growth of competitiveness (Bassioni et al, 2004). The measurement of organizational and project performance is very important, however, the measurement of organizational performance is different from the measurement of project performance (Lin and Shen, 2007).

Companies typically measure performance to determine whether objectives or targets are being met. In order to measure particular aspects of a firm's performance, indicators are developed for areas that are to be monitored.

Performance measurements reflect the degree of success, which is the major concern of any business.

Many frameworks have focused on measuring the performance of a project. The unique nature of construction projects makes it difficult to develop a generic framework to measure the performance of various projects. A method does not yet exist to combine the performance and awareness of all participants over all tasks throughout the life of the project (Lin and Shen, 2007).

However, interviews with experts as well as the literature (Love et al 2000, Takim et al 2003, Chan et al 2004) reveal that measurements are needed to track, forecast, and control critical success factors of a project. These are used by construction industry participants, such as decision makers, project managers' designers, and contractors, to meet construction performance targets at project and company levels.

1.2 DESIGN PROCESS PERFORMANCE MEASUREMENTS

Design performance means not only the evaluation of design process outputs themselves but also includes the overall effect of design on the project and company wealth and reputation. "The evaluation of design project performance requires a complete, dynamic, and comprehensive set of factors that influence performance and a complete set of criteria to measure performance," (Fayek, 2001).

Few studies have been carried out on the performance of design activities (Nicholson and Naamani, 1992; Macpherson et al, 1993; Roy and Potter, 1996; Veshosky, 1998). Moreover, the existing methods tend to focus more on product and less on process and design, (Takim et al, 2003).

Design performance is subject to change from project to another according to the project condition and the execution strategies. A little research on design performance measurement has been carried out in the construction sector. By contrast, in the manufacturing sector more research has been reported in the literature. Construction firms exert great effort to find appropriate performance indicators, (Torbett et al, 2001).

At present, "the measures used to assess design are based on the financial performance of a project rather than other important objectives of the design process," (Salter et al 2003 and Torbett et al 2001). For the design stage, as well as all other project stages, subjective measure along with objective measures should be used to measure the design stage performance.

1.3 AIM AND OBJECTIVES

The main aim of the present research is to provide a framework for measuring design performance in the Canadian Construction Industry. Further, to introduce key performance indicators to assess this performance.

The sub-objectives of the research are:

- Identifying key factors required to measure performance of the design activities.
- Generating a new list of design indicators.
- Developing a model for design performance measurements.
- Test and validate the design indicators model as a performance measurement tool for the design and construction companies.

1.4 METHODOLOGY

In order to achieve the stated aim, the research methodology followed consists of a number of steps:

i) investigate how Canadian firms currently measure the performance of design activities at both company and project levels; ii) develop a set of key performance indicators to measure the performance of the design activities in the Canadian construction industry; iii) examine their applicability in the same industry, and iv) develop a model to measure, document, and predict performance of the design stage using design KPIs. This enables companies to benchmark the performance of design activities at the company level and the project level.

From this perspective, the overall methodology of the present research is divided into three stages: investigation, synthesis, and application phase, (see Table 1.1)

Table 1. 1 Research Methodology

Sub-Objective	Work tasks		Methodology Stage	Method
(1) Identify Key issues required to measure performance of the design activities	Explore how Canadian construction practices measure performance	INVESTIGATION	Preliminary data collection	Literature Reviews and Interviews
	Find the most suitable design model.			
(2) Review Construction Key Performance Indicators (KPIs)	List of design indicators were identified	SYNTHESIS	Secondary data collection	Literature Reviews Interviews , Questionnaires, and Observations
	Survey to validate and amend this list were prepared			
(3) Analyize data	Analysis of Gathered Data & Generating a new list of Indicators		- Results of data collection - Developing Ideas	Observations
(4) Develop a model for design performance measurements	Develop a model		Proposal	Modeling, Survey, Observations,
	Test and Validate the Model		Validation	Analysis
(5) Implement the developed model with in a primary case study	Expert Opinions	APPLICATION	Implementation and Validation	Observations
	Case Studies			
	Reviews the Effectiveness of the Model		Advantages and limitations	

1) The investigation phase is concerned with gathering data from literature. Relevant knowledge is presented to acquire a good understanding of design and construction performance measurements. This stage explored how Canadian construction practices measure performance and find the most suitable design model. The design model is to clarify what would and what would not be addressed by the study in order to approach the development of effective design performance indicators. At this phase, interviews were carried out with a number of leading design and construction companies in Quebec.

2) Synthesis phase: A comprehensive literature review of performance indicators for construction in general and for design in particular is the main objective of this stage. From literature, list of design indicators was identified. In order to validate and amend this list, a web-based survey was conducted. The survey aimed at stakeholders, such as design firms, contractors, clients, and sponsors. Based on the results of surveys and the analysis of the results, a set of design performance indicators is introduced and ready to be tested by the industry.

3) Application phase: Experts opinions were gathered and case studies were examined in order to validate the developed model and to demonstrate the application of key design performance indicators.

1.5 THESIS ORGANIZATION

This thesis is organized to have seven chapters. Chapter 2 is divided into two parts. The first part represents an overview of the design stage and of existing construction design models. It focuses on searching the available literature for a proper design model that can be adopted. The second part introduces fundamental knowledge related to construction performance indicators and their use in the industry.

The developed methodology and the proposed design performance indicators model structure for the Canadian construction industry are described in Chapter 3. Chapter 4 describes the survey conducted and presents and discusses its main results. Chapter 5 presents the implementation of a model for measuring; documenting and predicting the design performance of construction project/s. Chapter 6 presents five case examples analyzed using the developed model to illustrate its functionality. Chapter 7 includes the research main contribution, presents the work limitation, and highlights recommendation for future research work.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is divided into two parts. Part one focuses on the review of some of the available literature on cost overruns and projects design performance. A brief explanation of the design stage of construction projects and the available design process models is also given. Part two presents a review of the available literature on design performance indicators. Their advantages and disadvantages are highlighted. Their use to benchmark the performance of construction projects and companies is discussed. Benchmarking and the history of performance measurement and performance measurement models are also covered. Based on the literature, this chapter concludes with some findings.

2.2 COST OVERRUNS

The construction industry has been experiencing projects' cost overruns. Most of the cost overruns happen before construction begins. At the end of a project, it is not easy to point out reasons behind the total cost overruns (Eden et al 2005).

A survey results of a study conducted in Zambia by Kaliba et al (2009) reported the major causes of cost overruns and schedule delays in road construction. Changes in drawings, changes in specifications and scope changes were among the major causes in construction projects. In addition, the study specifically noted that "initial estimates modification to reflect more detailed plans and specifications as a project is designed", is one among the identified reasons. Changes of design and specifications, and design solutions that were complicated to produce were also highlighted as a complex and interrelated causes of cost overruns, (Cui et al 2008).

Cost overruns are increasing due to many factors; one of the major reasons for this episode is the design (Jergeas 2008, Dibonwa 2008, CII 1987). However, improper consideration of important factors, such as client contributions, project team, suppliers, innovation risks, etc., during the design stage can lead to cost overruns and project delays, (Jergeas 2008). Hence a proper consideration of such factors in the early stages of a project could help to minimize the chances of cost overruns and delays from happening. Factors that affect the performance of the design should be further investigated.

2.3 DESIGN PERFORMANCE MEAUREMENTS

Design performance does not only mean the evaluation of design process outputs itself, but it also includes the overall effect of design on the project and company wealth and reputation. "The evaluation of design project performance requires a complete, dynamic, and comprehensive set of factors that influence performance and a complete set of criteria to measure performance" (Fayek, 2001).

The measurement of design performance constitutes a big portion of attention (Lin and Shen 2007). This can be attributed to the following:

1- Cost overruns are increasing and design is known to be one of the major causes of that.

2- Construction projects are increasing in complexity.

3- Other sectors are having rapid development of performance measurement.

4- The construction industry is composing a large sector of the economy and the design is critical to its performance.

5- Most construction costs are fixed by the design features of the project. Making changing in the early design phase requires the least amount of effort therefore demands more attention in order to reduce overall project costs, (Fayek and Sun 2001).

At present, "the measures used to assess design in construction are based on the financial performance of a project rather than other important objectives of the design process" (Salter et. al 2003 and Torbett et.al 2001). The industry needs to develop a better understanding of the processes of design in order to measure its performance.

A tool is required to measure and assess engineering performance among different projects in order to have an efficient control system (Georgy 2005). Such a tool would enable managers to track performance, detect project positive and/or negative factors, and take corrective actions for improvement. The question is how to assess the design performance in construction projects.

Current construction industry practices measure engineering and design performance during the detailed design stage of the project (see Figure 2.1 and

2.2). The production (the ratio of design work-hours per drawing) of design documents and the performance against schedule (the level of commitment in timely release of design documents) are the most common indicators used industry wide. They have been in existence for many years (Eldin 1991; Chang . 2001; and Georgy 2005). Traditional measures are historic in nature, i.e. they do not provide the opportunity to change, and they are classified as lagging measures. Therefore lagging measures are needed.

Design has a great influence on all of the project life specially the construction stage, (Jergeas 2008), not only in monetary term but also on time. Cavanaph et al , 1978, indicated that making changes in early stages of the design phase require the least amount of time, cost and effort, . Therefore the design phase requires more attention, (see Figure 2.1).

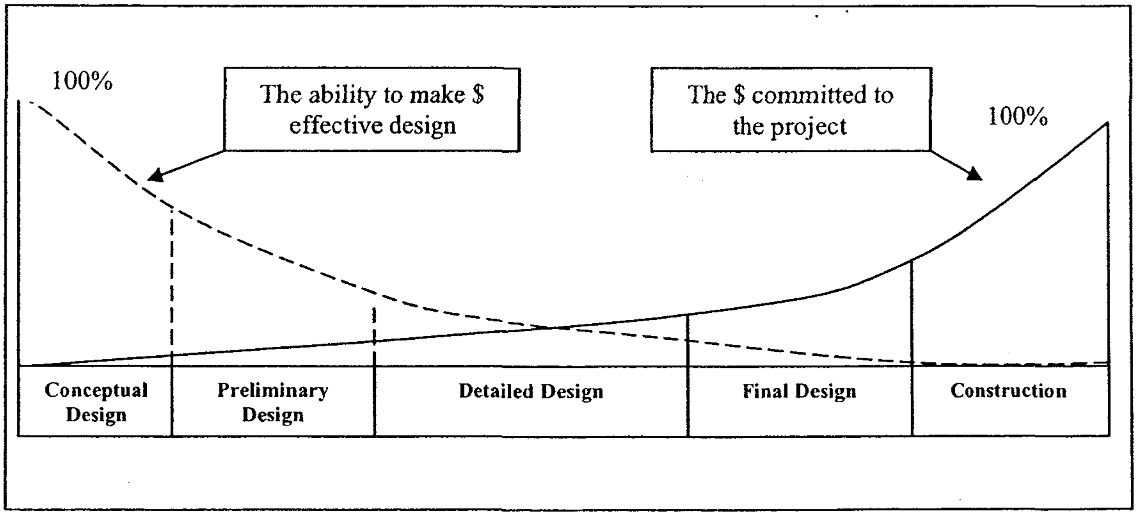


Figure 2.1 Design Stage of a Project (Source Cavanaph et al 1978)

Design performance is subject to change from one project to another according to the project condition and execution strategies. So far as the design performance measurement in construction is concerned, little research has been done compared to manufacturing (Nicholson and Naamani, 1992; Macpherson , 1993; Roy and Potter, 1996; Veshosky, 1998). Firms exert great effort to find appropriate performance indicators, (Torbett 2001).

2.3.1 Literature on Design Performance Measurements (DPMs)

The available literature on the performance of design activities can be placed into one of two groups: 1) Emphasis on input and output criteria or, 2) Emphasis on other objectives and/or subjective measurements.

2.3.1.1 DPMs Emphasis on Inputs and/or Outputs

Design inputs defined as any action that affects design effectiveness. Inputs to design occur at any phase from conceptual until the project execution and prior or during the detailed design. Its major impact occurs during the conceptual phase of the project. On the other hand, output information becomes available at or near the end of the project. At that point the ability to take action to improve the process has passed.

Fayek (2001) introduced a model for the factors used to evaluate design performance using a fuzzy expert system. The following three groups of factors were produced: context variables, input factors, and output factors. Context variables are used to classify design projects into similar groups. Input factors describe the project, its environment, and its participants. These factors vary from project to another. Output factors are used to measure the performance of the design in terms of the following three criteria: cost, time, and quality. The output factors can only be known once the construction is complete. Table 2.1 summarizes the inputs factors that impact the design performance and outputs factors used to measure design performance.

Although the model provides a framework of factors that affect design project performance, it does not take into consideration other important factors such as understanding client needs, integration of design team, risks, innovations, etc. Another limitation is that the model attained a low success rate for numerical prediction because of the roughness of the membership functions and the limited data with which to generate the expert rules.

The Construction Industry Institute (CII) Design Task Force in 1986, 1987 has produced wide research in evaluating design effectiveness. The CII acknowledged a number of input variables impacting design effectiveness and output criteria for measuring effectiveness. These include:1) Accuracy of Design Documents, 2) Usability of Design Documents, 3) Cost of design, 4) Constructability, 5) Economy of design, 6) Performance Against Schedule, 7)

Ease of Start-Up, 8) Security. The input and output criteria, were not combined for the evaluation of design performance.

Table 2.1 Input and out puts factors that impact and used to measure design performance

N	Input factors	Output factors
1	Overall size of design firm	Level of performance against cost of design
2	Level of competition in the market	Level of performance against schedule for design
3	Overall quality of design firm	Level of accuracy of design documents
4	Size of design contract	Completeness of design
5	Continuity of man-hour commitment for project	Re-work
6	Level of scope definition	
7	Complexity of project function	
8	Complexity of design process	
9	Complexity of project conditions (i.e., types of problems – number and magnitude)	
10	Quality of owner's profile	
11	Quality of primary vendors profiles	
12	Complexity of tendering process for construction	
13	Complexity of construction process	
14	Economic (market) conditions	

(source: Fayek 2001 and Jergeas 2008)

2.3.1.2 DPMs emphasis on objective and/or subjective factors

Wuellner (1990) built up a checklist for consulting engineering firms to measure engineering performance in a project. The checklist measures professional image, quality of design/service, dependability to schedule and budget, client satisfaction, and so on. Performance of engineering and design activities was also measured in quality terms by Fergusson and Teicholz (1996).

The literature shows that many indicators are needed in order to develop a certain degree of satisfaction or dissatisfaction with the overall design performance in the project, (Georgy et at, 2005). However Design performance involves the overall outcome of design activities that at the end satisfies or dissatisfies the customers. Owners' satisfaction with engineering and design activities outcome throughout the entire project process is a major tool for assessment of engineering performance (Chalabi 1987; Chang 2001).

Hyun et al in 2008 evaluated the level of design performance to conduct a quantitative evaluation on the performance quality. The paper analyzed the impact of delivery methods on design performance. The Delphi and AHP methods were used to develop objective standards for evaluating the design performance. Based on the developed evaluation standard, the study examined the design performance of public multifamily housing projects in Korea. The authors suggested that their method could be used to evaluate other project types. This study considered the quality as a measure of design performance, while other measures if added could give completely different results.

A study by Georgy et al (2005) introduced a utility function model for predicting the engineering performance in a construction project. The model is on the basis that engineering contributes certain values to each project stage for example detailed design value may be evaluated through measures such as design document release commitment, detailed design cost overrun, and so forth. The literature shows some shortcomings in using the design document only as a measurement for the engineering and design performance. Among these shortcomings is the difficulty to obtain accurate work-hour data and the inconsistency of document content and format among projects, (Chang 2001).

Torbett in (2001) had examined the use of design performance measurements in the construction industry and compared it to manufacturing. The study showed that a few design performance measurements do exit and they focus on cost. Other measures such as quality, client satisfaction, and innovation are needed in order to address the non- routine nature of construction design. A guide on how to 1) integrate design into wider business process; 2) identify key design indicators; 3) use design performance measurements to provide a balanced score card for design performance. According to this study, two set related to design performance measurements were introduced. These are the following: 1) Firm level design performance measurements and 2) Project level design performance measurements. Both of them should address company objectives through the key performance areas.

The Construction Industry Research and Information Association (CIRIA) in 1998 investigated key issues relating to performance measurement of design activities carried out by the UK construction companies. Eleven leading design consultants and contractors in the UK participated in the study. Eight groups of indicators, each group consists of number of sub- indicators as follows: A) Understanding client needs, B) Design process, C) Integration of design with supply chain, D) Internal cost and time management, E) Risk, F) Re-use of design experience, G) Innovation, and H) Client / user satisfaction. These Indicators are being in use by the UK the construction industry for at least five years.

Thomas (1999) conducted a research in measuring the productivity of design during the contract document phase. A model that relies on the measurement of design output was introduced.

2.3.2 Design Stage of Construction Project

Design is a very difficult process to manage. Some of causes of that difficulty derive from the large numbers of decisions, sometimes over a short period of time, the numerous interdependencies and the high uncertainty environment. A large number of personnel are involved, such as architects, civil engineers; mechanical and electrical engineers and marketing consultants; each of these has a different background and style of working.

Engineering and design work are critical links in a project's life cycle. They translate the owners' objectives and requirements into engineering documents that can be used by all other participants in the project. Design is a hierarchical activity, defined as a set of plans and a process (how those plans will be achieved). In large and complex projects, there are a large number of intermediate design tasks. Some of the design activities may not be performed in parallel (one activity cannot be done before another). Suppliers may not be able to share common information and focus on their particular areas, if discrete components are designed independently of each other. This means that sub-systems need to be designed concurrently and in relation to each other (Torbett et al 2001).

"Design is highly organized mental process capable of manipulating many kinds of information, blending them all into a coherent set of ideas and finally generating some realization of those ideas," (Lawson 1980). In the design phase, the needs stated in the Program stage are translated into plans and specifications (Charette et al 1999). The main objective of the design stage is to produce a design consistent to the content, time, and cost criteria in the project brief (Public Works Canada, 1982). Understanding the process of design is of great help in selecting the right set of indicators for design.

2.3.2.1 Concept design sub-phase

The Conceptual Design, as described in Public Works Canada (PWC), is the Design Team's responsibility in close contact with the Project Manager. It defines the organization of the site, location of the building on the site, massing of the construction, location of major group spaces, sections, elevations, perspectives circulation, etc. This stage also includes concept estimating of construction costs, concept design report production (Baldwin et al1999). At this stage about 5% of the total design work should be produced.

2.3.2.2 Scheme design sub-phase

The main product of this phase is the design and its documentation in compliance with the project brief. After a schematic proposal is produced, it should be approved by the senior manager and by the client as well. This stage includes: site investigation, project outline, project specifications, revise cost estimation, scheme structural design, scheme service design, external works scheme design, scheme drainage design, scheme architectural design (Baldwin et al 1999), this sub-phase about 15% of the design work should be produced.

2.3.2.3 Detailed design sub-phase

This stage includes detail and complete architectural design, civil design, structural design, mechanical design, electrical design, (Austin et al 2002). This stage organizes design team, completes user studies, reviews cost plan (Hughes 2003). The working Drawing and detailed specifications produced in this stage, which reflects about 40% of the total design work, commence the construction stage. This stage ends with client approval of the plans, cost, and schedule.

2.3.2.4 Construction documents sub-phase

Once the final evaluation is completed, the design is documented and presented for external approval and Issued for Construction (IFC), (Jergeas, 2008). Final plans and construction specifications are provided to bidders, and contracts are awarded (Charette and Marchall, 1999).

Broaddus (1991) described the process from the beginning to end as shown in Figure 2.2. The main steps of the process where design activities included are in Phases I through V. It is important to understand where the inputs and outputs of design occur in the process. According to Broaddus (1991), the most significant design inputs with broad applicability to the industry are the following: **1)** scope definition, **2)** owner profile and participation, **3)** pre-project planning, **4)** project objectives and priorities, **5)** basic design data, **6)** selection and qualification of designer, **7)** qualification of project manager, **8)** construction input, **9)** type of contract, and **10)** equipment source. The study also stated that the impact of those inputs on outputs is defined as the best measures of design effectiveness.

Design effectiveness can be measured by design outcome parameters. Eight parameters have been identified by Construction Industry Institute (1986). These are the following: **1)** final project schedule, **2)** constructability, **3)** quality of design, **4)** final project cost, **5)** plant start-up, **6)** performance, **7)** safety, and **8)** security.

2.3.3 Design Models

Adopting a design model is an essential step in the development of design performance indicators. The purpose of the design model is to clarify what would and would not be addressed by the study in order to approach the development of effective performance indicators.

The Literature shows a variety of design models. The major models among them are the Royal Institute of British Architect (RIBA) 1973, Public Work Canada (PWC) 1982, and Construction Industry Research and Information Association (CIRIA) 2001.

2.3.3.1 Royal Institute of British Architect (RIBA) 1973

In this model the design process is divided into four phases:

Phase one: assimilation, which represents all the general information specifically related to the problem at hand.

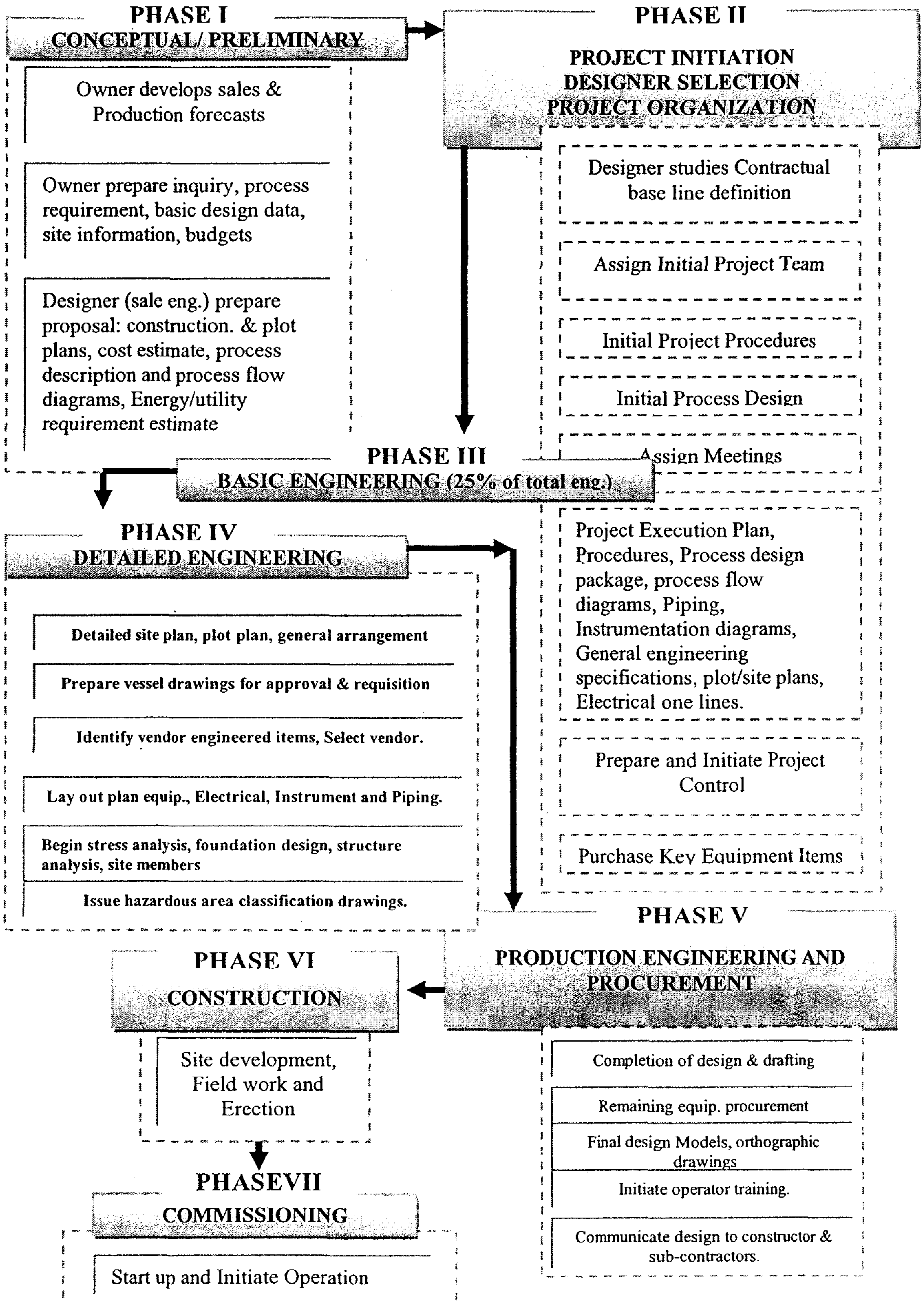


Figure 2. 2 Construction Project Flow chart Adopted and modified from Broaddus (1991)

Phase two: General study that investigates the nature of the problem and its possible solutions.

Phase three: development of isolated solution or solutions from phase two.

Phase four: The communication of the solutions to people inside and outside the design team.

The RIBA design model forms the tasks to be performed by different design personnel during each stage but does not model the relationships between tasks (Austin et al 1999).

2.3.3.2 Public Works Canada (PWC), 1982

PWC developed a process network for the design stage of constructions. It is composed of two phases: **1)** Development of a concept proposal and **2)** Development of Design. The Process network as defined in PWC is a schematic representation of 25 activities that make up the design stage of a project. The process network as shown in Figure 2.3 aims to illustrate the sequence, interrelationships and decision points in the design process.

1- Concept Proposal activities; for example, compliance with the project brief is achieved, and at certain defined points the involving concept proposal is submitted to the departmental approving authority for review.

2- Design Activities: it is the design up to the point at which working drawings and detailed specifications can begin.

This is considered a good representation for design activities, but does not give a clear representation for the inputs and the outcome of design, on the one hand. On the other hand, the relationships between the internal and external environment is not clear enough in this process.

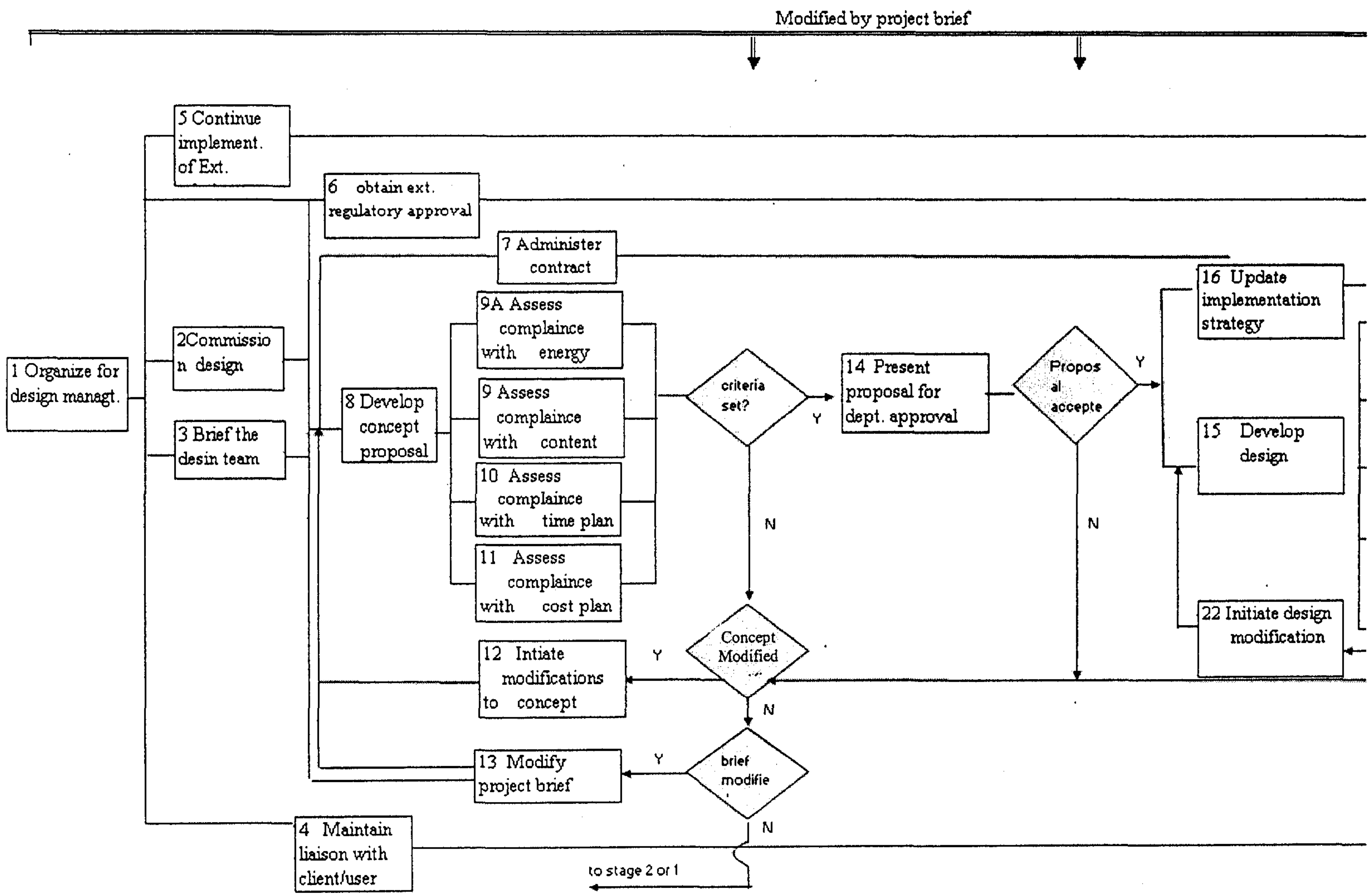


Figure 2.3 Process Network, Design (Source PWC 1982)

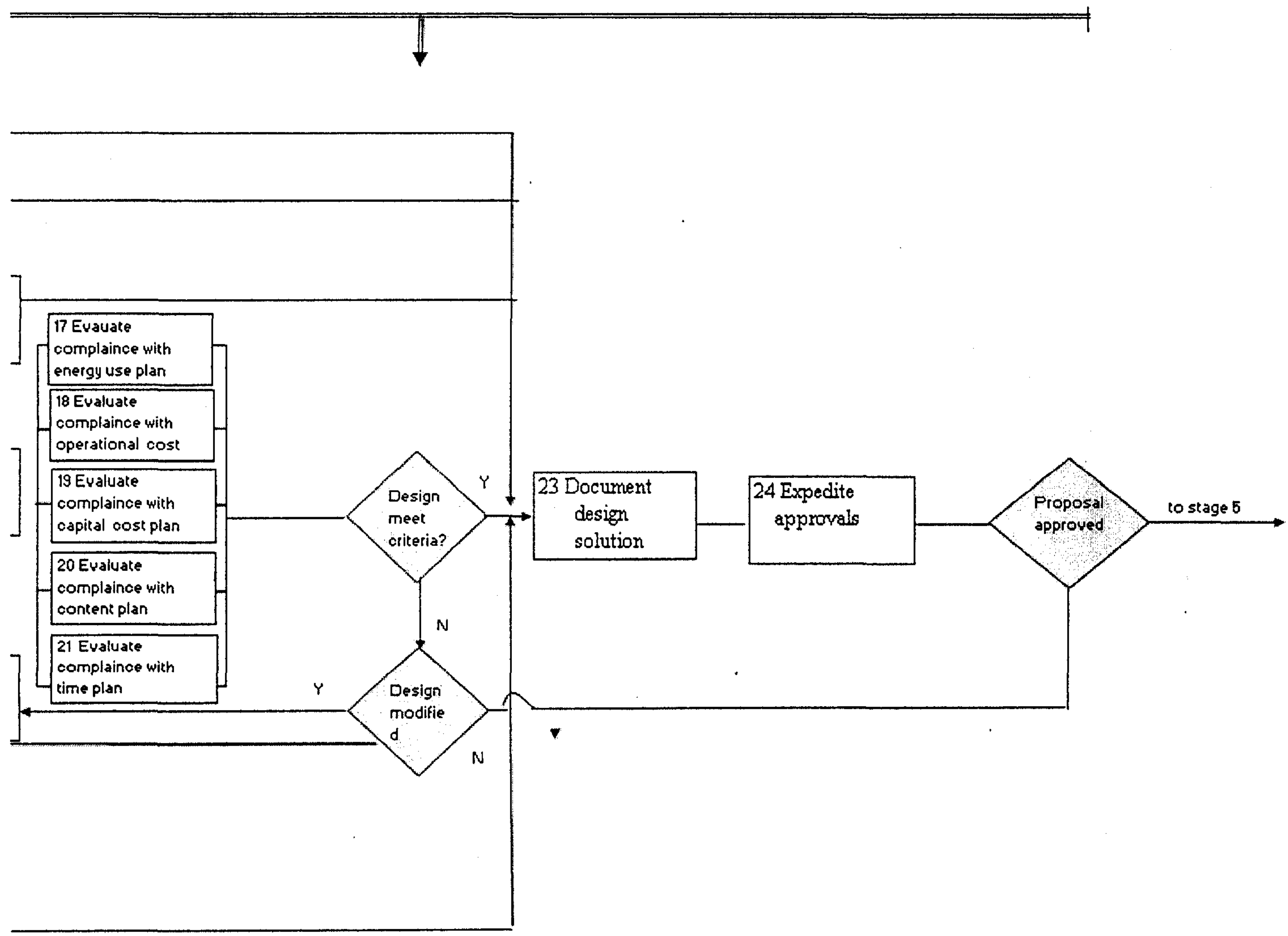


Figure 2.3 Process Network, Design (Source PWC 1982), (continued)

2.3.3.3 The Construction Industry Research and Information Association (CIRIA)

CIRIA developed a model of design activities in order to build up a set of Design Key Performance Indicators. The model considered being indicators related to costs of realization of design and value of the outcome or product, Figure 2.4 The model proposes that design consists of two elements: Process and Outcome

The design process consists of:

1- Conception activities: including activities such as identification of needs and development of brief
2- Development activities: such as design schedule development, detailed design, estimating time and cost, design review.

Design outcome consists of:

1. Realization of the design: This is usually the construction phase. Indicators measurement includes construction costs at planning stage, number of change orders, and safety during construction, environmental impact and waste.
2. Satisfaction with the design: that includes client brief satisfaction, end user satisfaction and client satisfaction.

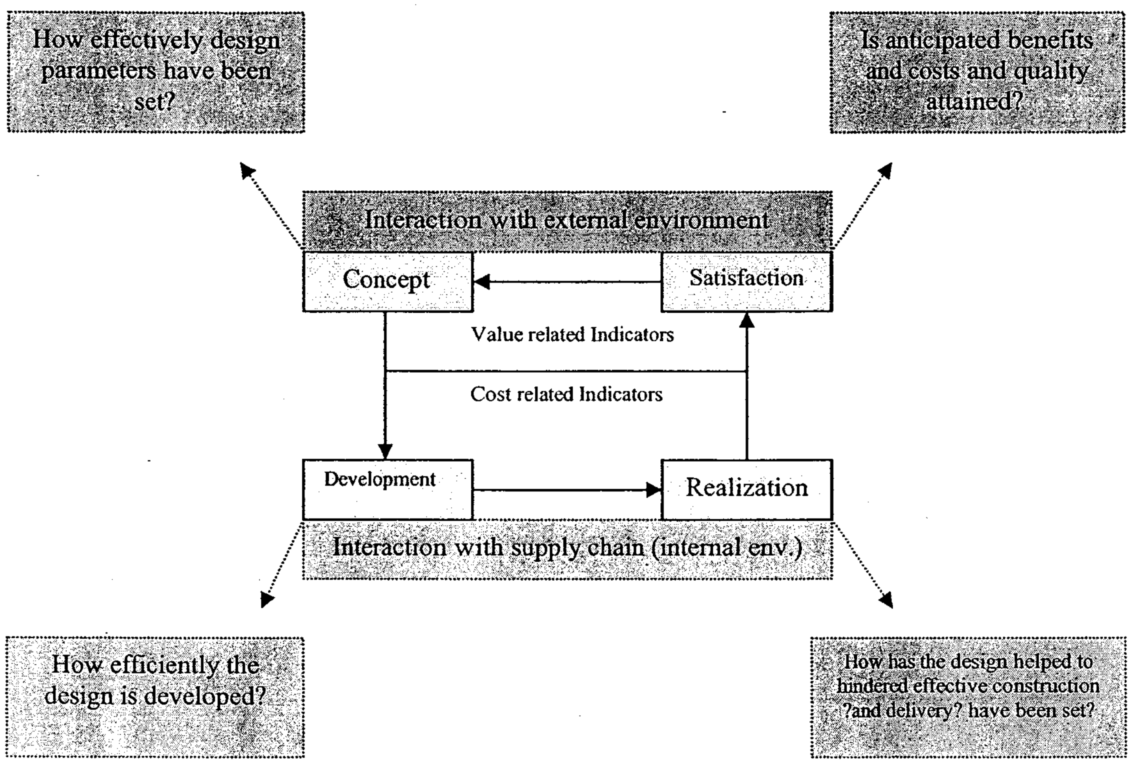


Figure 2. 4 CIRIA 2001, Model of Design Activities(Source: Dent, R. J and Alwanti-Starr, G, 2001)

A model proposed by Carlos (1998) consists of general plan of the design process. The design process is divided into seven stages. The protocol consists of six elements, which are the following: the main activities content, their precedence relationships, the main inputs and outputs of each activity, tools supporting the execution of each activity, role and responsibilities of different actors, and a model of information flow. The developed model is divided into three stages, which are the following: Preliminary investigation, Design model, and Design manual. Carolos uses two tools for modeling. The first is the flowchart, which represents the seven design stages, for each stage a flowchart of activities and a flow chart of operations for the most complex activities. The second tool is the input-output charts, where the details for all activities are presented.

Austin (1999) used an analytical design planning technique (AdePT) to program and manage the design phase of complex projects. The methodology of this model consists of three stages: 1) a model of the building design process, which represents design activities and their information requirements, 2) The information of this model are linked to a dependency structure matrix through a dependency table. 3) Based on the optimized process sequence, a design program is generated.

Aken (2005) raises questions about what will happen if company A uses the same design process that company B successfully used. Would it also be as successful in company A?

What are the performance indicators for judging the success of a design process? How do the various design models score on these performance indicators? The author emphasized the need for further research in what he calls "design process design".

Table 2.3 is a list of design models where authors and the main element are mentioned Aken (2005), and Evbuonwan (1996).

Table 2. 2 Design Models and Design Process Main elements

Author	Design process elements
Marples	designing is a sequence of decisions, starting from the original statement of (functional) requirements and ending by the (technical) specifications of the artifact to be produced. These decisions are represented in a 'Marple tree', with the functional specification as starting mode and then branching out via subsequent levels of sub-decisions.
Asimow	feasibility study phase, preliminary design phase, detailed design phase.
Watts	cycles of analysis, synthesis and evaluation, moving through design decisions from abstract levels to ever more concrete ones.
Archer	six stages, viz. programming, data collection, analysis, synthesis, development, communication, with iterations between the stages where necessary.
French	conceptual design, development of the generated schemes, detailing
Jones	three stages, viz. analysis, synthesis and evaluation
Pahl and Beitz	clarification of the task, conceptual design, embodiment design and detail design.
Cross	six stages, three decomposing the overall problem into sub problems, viz. clarifying objectives, establishing functions, setting requirements, and three stages synthesizing the overall solution, viz. generating alternatives, evaluating alternatives, improving details.
Roozenburg and Eekels	four basic steps, viz. analysis, synthesis (of the solution to the design problem), simulation (prediction of the properties of the new artifact), evaluation (overall assessment), with possible iterations between the steps
Reymen	organize the overall design process in a sequence of design sessions, each starting with planning and ending with reflection

2.3.4 Summary of Design Literature

This chapter covered the available literature on design performance measurements for the construction industry, the Design stage of a project, and Design models. However, few studies have been carried out on the performance of design activities. The literature can be listed to one of two groups: 1) Emphasis on inputs and outputs criteria, and 2) Emphasis on other objective and/or subjective measurements. The current industry practices measure engineering and design during the detailed design stage of the project, the production (the performance ratio of design work-hours per drawing) of design documents and the performance against schedule. The literature confirmed that the construction industry needs to develop a better understanding of the processes of design in order to measure its performance.

Some of the design models presented in this literature review are based on a synthesis of case-studies; others are based on the experience of famous designers. The practical basis of other models is unclear (Akin 2005). The previously mentioned design models address design activities with different representations; however, they suffer from one or more of the following shortcomings:

1- Do not model the relationships between tasks.

2- Do not give a clear representation for the inputs and the outputs of design.

3- Do not clearly show the relationships between the internal environment, e.g. the supply chain and the external environment or the client and the end user.

2.4 BACKGROUND TO KEY PERFORMANCE INDICATORS

A key performance indicator (KPI) is a parameter for benchmarking projects in order to achieve good performance. A key performance indicator as defined by Constructing Excellence (2007) is a measure of a factor to success. According to Takim and Akintoye (2002), "Performance indicators specify the measurable evidence necessary to prove that a planned effort has achieved the desired result."

Key performance indicators are the UK construction industry's reaction to Egan's report to measure project performances, (Egan 1998). To improve the performance of the construction industry in UK, the government formed a task force headed by Egan, who published a report named "Rethinking Construction" in 1998. The report identified the need to focus on the client in order to improve the quality and efficiency of construction performance. This report identified the following five key drivers of change (Kagioglou et al, 2000):

1. committed leadership;
2. focus on the customer;
3. integrated processes and teams;
4. quality-driven agenda; and
5. commitment to people.

Clients need their projects delivered on time, on budget, free from defects, efficiently, right the first time, safely and by a profitable company that has respect for the environment and people. The KPIs enable both clients and suppliers to measure project performances, based on ten critical factors. These parameters consist of seven project performance indicators and three company performance indicators. Project performance indicators are: 1) construction cost, 2) construction time, 3) cost predictability (design and construction), 4) time predictability (design and construction), 5) defects, 6) client satisfaction with the product, and 7) client satisfaction with the service. The company performance indicators are: 1) safety, 2) profitability, and 3) productivity.

The main objectives of key performance indicators are as following:

1) to enable measurement of project and organizational performance throughout the construction industry (The KPI working Group 2000);

2) to provide a method of benchmarking companies performance against others from the same industry; and

3) to track and demonstrate long term developments and improvements in performance (Constructing Excellence 2007).

The publication of the first set of construction industry KPIs was followed by Respect for People KPIs in 2002 and the Environmental KPIs in 2003. Gradually, the major sectors of the construction industry published KPIs for their specific areas of activity. The major sets of performance indicators are divided into two groups: headline KPIs and specialist KPIs and summarized hierarchically as follows, Figure 2.5.

2.4.1 Head Line Performance Indicators

1) Economic key performance indicators: measure economic issues at project level, such as client satisfaction, predictability, construction cost and time, etc., and company level, profitability, productivity and safety. The economic KPIs are published as wall-charts. The wall-chart includes data from all the major construction industry sectors excluding construction product suppliers.

2) Social (Respect for People) key performance indicators measure issues of critical importance to companies wishing to do extremely well in people management. The social KPIs are presented on the wall-chart and they include employee satisfaction, staff turns over, safety, sickness absence, training, etc.

3) Environment key performance indicators: reducing the impact of construction on the environment is very important for the industry. These indicators reflect economic and environment benefits. The economic benefits come from the efficient use of energy and transport, which can lead to significant cost savings and the reduction of the company's overhead cost. Environmental benefits include energy efficiency, which reduces $CO2$, fossil fuel, and waste going to landfill.

2.4.2 Specialist Key Performance Indicators

These are the following: 1) Construction consultant KPIs, 2) Mechanical and Electrical contractors KPIs, and 3) construction products KPIs. Additional KPI graphs were produced to be used to: 1) establish a basic performance measurement system within a firm, 2) measure performance of firms against other specialist sectors, 3) demonstrate past projects and track the performance of new projects.

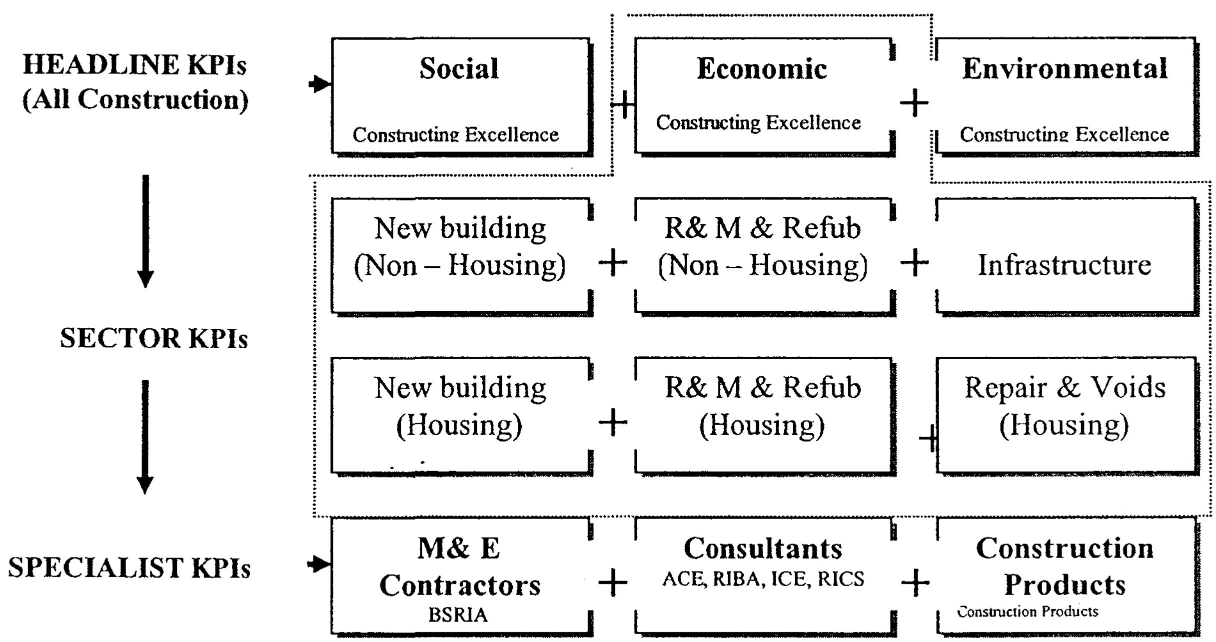


Figure 2. 5 Set of KPIs Hierarchy
(source Constructing Excellence2007)

All the six sets of KPIs use subjective measures, applying a scale of 1 to 10. Scale 1 always denotes the worst possible score and 10 is the best possible score. According to the KPI report for the Minister of construction (UK), the project life is divided into the following stages (see Figure 2.6): (A) Commit to

Invest, (B) Commit to Construct, (C) Available for Use, (D) End of Defect Liability Period, and (E) End of Life Time of Project.

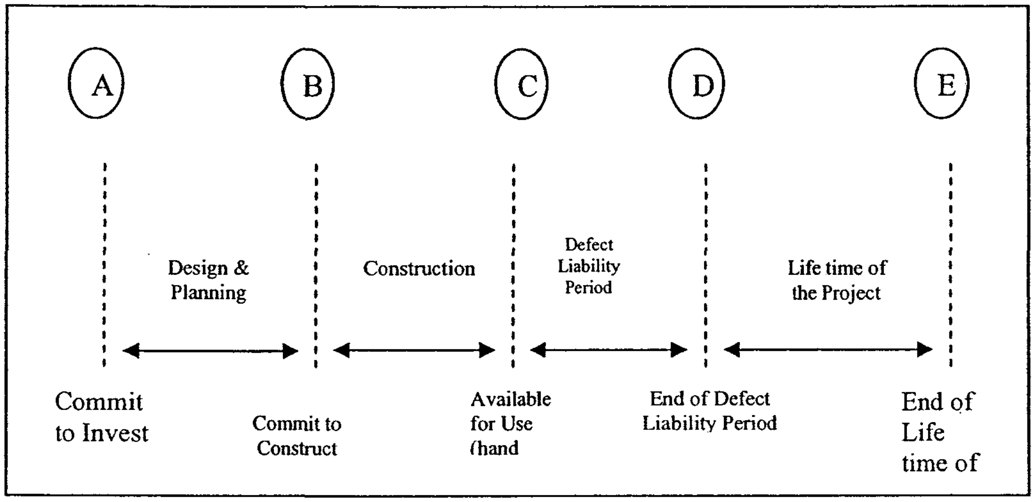


Figure 2. 6 Project Life Time (source The KPI Working group, 2000)

As a part of the KPIs, industry performance graphs are provided to allow analysis to be made by companies. Companies provide their own results and compare them with others. In the example shown in Figure 2.7, when the performance score is 4 out of 10, the benchmark score reading is 12%. This benchmark score is plotted on the radar chart. The nearer the plotted line is to the outer parameter of the chart the highest the overall performance. This means that 12% of the industry is achieving a lower or equal performance, and 88% is achieving a higher performance than the company.

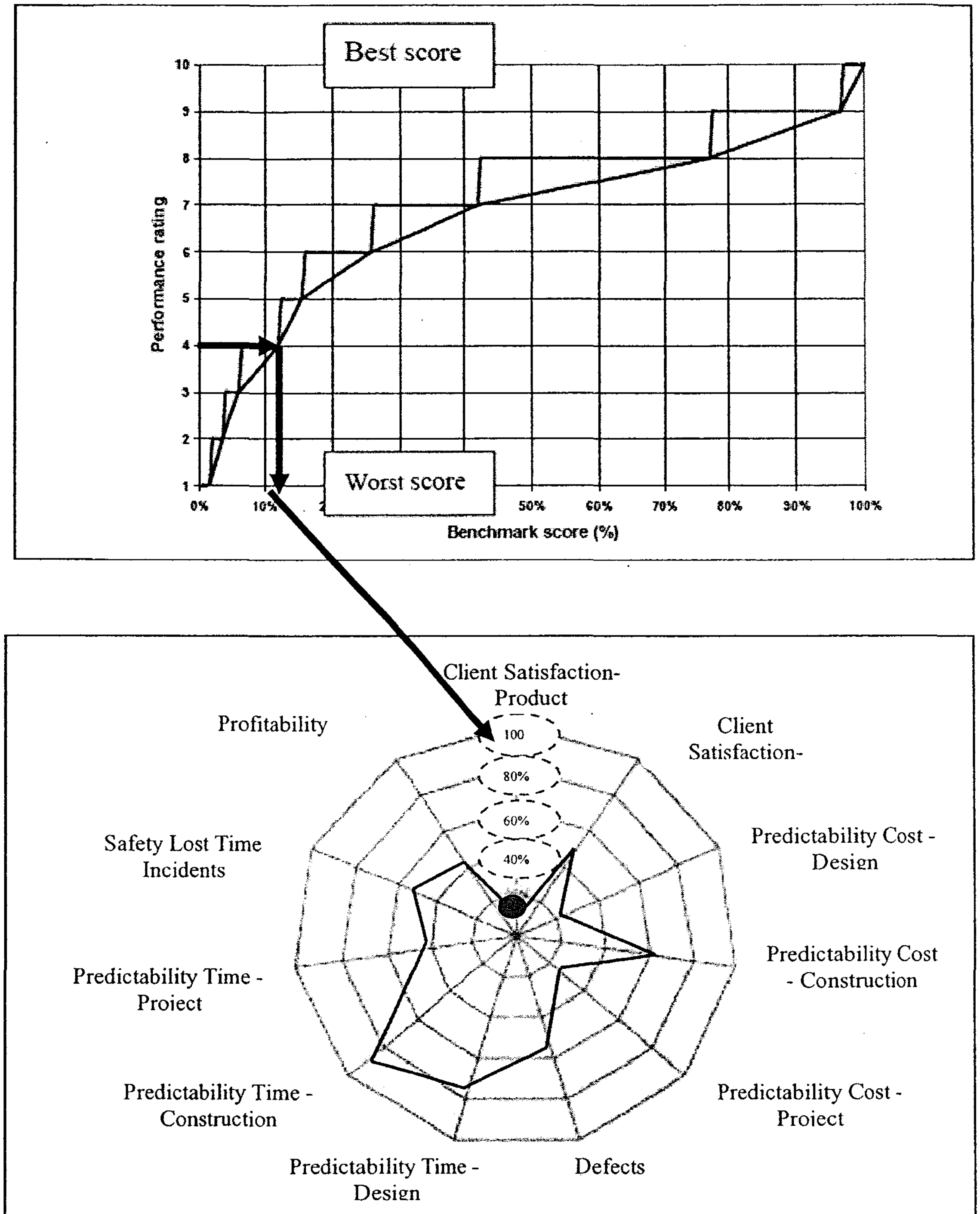


Figure 2.7 KPI Reading Rule Example
(Source Worldwide KPIs 2003)

2.5 LITERATURE ON CONSTRUCTION PERFORMANCE INDICATORS

2.5.1 General

Key performance indicators are well established and well used by the construction industry, therefore Literature on the construction KPIs were reviewed so lessons may be learned. Recently, the area of construction performance measurement attracted the interest of researchers. However, the number of papers on this subject has increased significantly during last few years. Some reasons behind that increase are the following, (Lin and Shen 2007).

1. The continuation of the rapid development of performance measurement in other sectors during the1990s.
2. The increasing complexity of construction projects that require appropriate measurement tools to improve performance.
3. The development of construction project management as well as building technology.

2.5.1.1 Organizational Performance Measurement

The construction industry has inherent problems with its complexity and fragmentation, which have inhibited its performance. The fragmentation occurs within and between the different stages in the construction process (Egan 1998, and Beatham 2004). As a result of these, the construction industry faces numerous problems. Competitive pressures in the political and economic sphere, as well as other considerations, are now forcing the industry to improve performance of the construction industry. The construction industry is highly inefficient in terms of profit, litigation, accident record, and investment in training compared to other industry sectors. Improvement and innovation are slow to spread.

In Canada, Value Improving Practices (VIP) and Best Practices (BP) are two techniques that had been developed to improve the project performance.

The VIPs were developed by a private organization named the Independent Project Analysis Inc. (IPA) in 1987. It is specialized in project evaluation and benchmarking. They recommended using the VIPs through the early stages of a project to improve the design process, (Lozon and Jergeas 2008, IPA 2009). The elected VIPs are as following: 1) Class of plant quality, 2) Constructability reviews, 3) Customized standard specifications, 4) Design to Capacity, 5)Energy optimization, 6) predictive maintenance, 7) Process reliability modeling, 8) Process simplification, 9) Technology selection, 10) Traditional value engineering, 11) waste minimization, and 12) 3D CAD.

The BPs were developed by the Construction Industry Institute (CII) in 1983. The best practices as listed by the CII are as following: 1) Alignment, 2) Benchmarking and matrices, 3) Change management, 4) Constructability reviews, 5) Design effectiveness, 6) Dispute prevention and resolution, 7)

Implementation of products, 8) Materials management, partnering, 9) Planning for start up, 10) Pre project planning, 11) Quality management, 12) Team building, and 13) zero accident techniques, (CII 2009).

A study made by Lozon and Jergeas in 2008 analyzed the impact of Value Improving Practices (VIP) and Best Practices (BP) on large construction projects. A survey was conducted in this study to determine which practices are being used. The study found that about 50 % of the participant were not familiar with the CII BP and VIPs, 42% of the participants whose were not familiar were engineers, and 59% were contractors. The study recommended further investigation to quantify the impact of using the VIPs and BPs on the performance of projects.

Jergeas (2005) used a tool that consists of four areas to evaluate team performance. These are: 1) Communication: including communication level of difficulty, information flow, and time line of information , 2) Working relationships: including cooperation between parties, issues and concerns, responses to issues, disputes, and the responsible personnel to resolve problems, 3) Technical requirements including: safety performance, overall quality, and value of money: , 4) Stakeholders and external issues. These evaluation areas act as a team self-evaluation to uncover problems on an ongoing basis and take corrective basis. The tool asks each team member to evaluate team performance/ success in those areas using a scale 1 to 5.

Performance below 3 requires follow up by the project Manager. This tool has been applied to more than 20 projects in Alberta.

In the UK, the Construction task force charged two organizations; Movement for Innovation (M4i) and the Construction Best Practice Program (CBPP), with delivering improvements within the industry. The M4I specified the requirement needed for improvement (see Figure 2.8).

The CBPP introduced 10 headline Key Performance Indicators (KPIs) in 1998. These KPIs were criticized for being focused on financial lagging measures which cannot offer the opportunity to change, (Beatham 2003, Ghalayini and Noble 1969). Financial measures are useful, but they tend to measure the past. Neely (1999) stated that these types of measures are criticized because they: 1) lack strategic focus and fail to provide data on quality, responsiveness and flexibility, and 2) do not encourage continuous improvement.

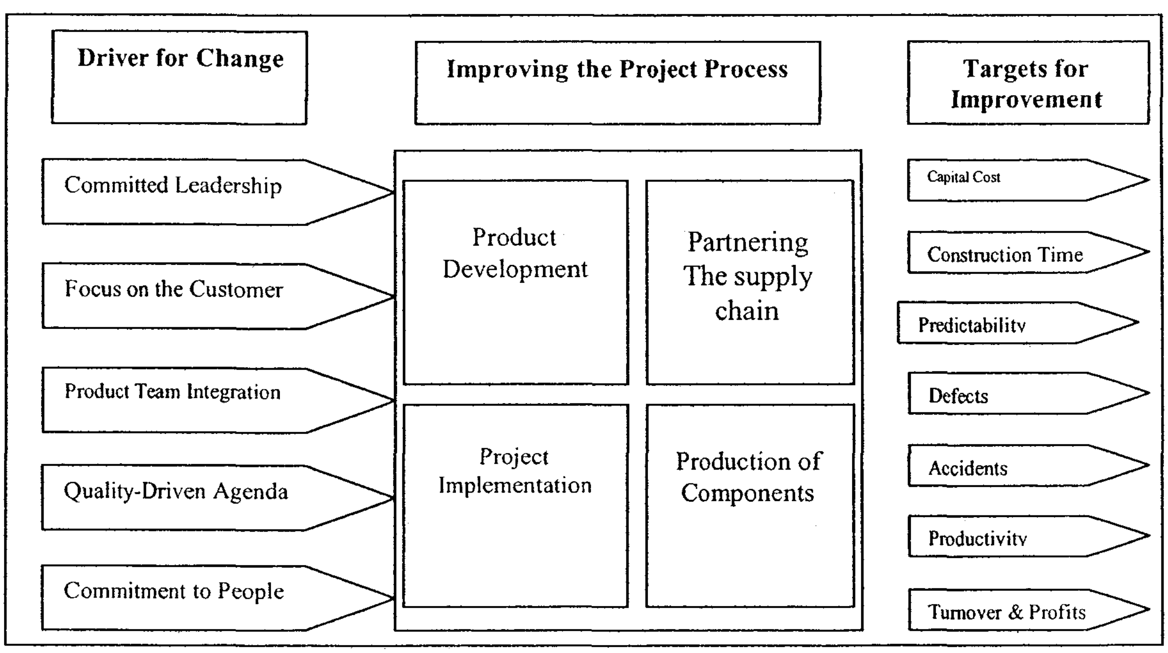


Figure 2.8 M4i Improvement Requirements (Source: Beatham 2003)

Continuous research efforts have been undertaken in the area of performance measurement. Quite a number of these studies emphasized KPIs and their measurement and implementation in the construction industry.

The UK KPIs working group in 2000 presented a KPI framework that consists of seven main groups: 1) Time, 2) Cost, 3) Quality, 4) Client satisfaction, 5) Client changes, 6) Business performance, and 7) Health and safety. Three levels of KPIs were introduced: 1) Headline indicators provide a measure of the overall firm health, 2) Operational indicators focus on specific aspects of a firm's activities, and 3) Diagnostic Indicators provide information changes and why they occurred in the headlines or operational indicators.Table 2.3 summarizes a range of indicators for the UK construction industry from different construction task forces (Takim and Akintoye 2002).

Table 2. 3 Performance Indicators for UK Industry Measures

Latham (1994)	**Egan (1998)**	**Constr. Productivity Network (1998)**	**Construction Industry Board (1998)**
Client satisfaction	Construction Cost	People	Capital Cost
Public Interest	Construction Time	Process	Construction Time
Productivity	Defects	Partners	Time predictability
Project Performance	Client satisfaction (product)	Products	Cost Predictability
Quality	Client satisfaction (Service)		Defects
Research & Development	Profitability		Safety
Training and Recruitment	Productivity		Productivity
Financial	Safety		Turnover & profitability
	Cost predictability (const.)		Client satisfaction
	Time Predictability (Constr.)		
	Cost predictability (design)		
	Time predictability (design)		

Source: (Takim and Akintoye 2002). Adopted from Mbugua et al., (1999).

Yeuing et al (2008) introduced seven most important KPIs for measuring the partnering performance of construction projects in Hong Kong. The KPIs are including: (1) time performance; (2) cost performance; (3) top management commitment performance; (4) quality performance; (5) trust and respect performance; (6) effective communications performance; and (7) innovation and improvement performance. Quantitative indicators (QIs) and Quantitative ranges (QRs) were used to measure, evaluate and improve the existing performance of their partnering projects.

Ling et al (2008) examined the impact of project management practices of international firms on the performance of their projects in China. This work discussed and applied five performance measures to predicting the success of international projects. However these measures used to examine the extent to which project management practices adopted by international architectural, engineering, and construction companies in China could affect project performance. The five measures are as follow:

1) Cost performance (actual versus budget),

2) Time performance (actual versus plan),

3) Quality performance (e.g., technical quality, workmanship quality),

4) Owner satisfaction (service quality), and

5) Profit margin (profit margin derived from service)

This study found that a firm's response to perceived change orders is the most important project management practice that affects five performance measures.

Chan (2004) discussed KPIs in detail. KPI calculation methods are divided into two groups. The first group is based on mathematical calculation, such as time, cost, value, safety and environment. The second group is based on subjective opinions and personal judgment of stakeholders, such as quality, functionality, and satisfaction level of all project personnel.

Cox et al (2003) reported six indicators, based on a survey carried out to identify a set of commonly perceived KPIs according to construction sector, management level and experience level. However, the research focused on collecting management perceptions of the quantitative and qualitative performance indicators that have been practically used in the construction industry at the project level.. In this study, performance indicators were defined by either the "quantitative" results of a construction process i.e. $/unit, or by qualitative measures such as worker behavior on the job.

Quantitative performance indicators, as they are classified: 1) Unit per man-hour, 2) Dollar per unit, 3) Cost, 4) On time Completion, 5) Resource Management, 6) Quality Control, 7) Percent Complete, 8) Earned Man-hours, 9) Lost Time Accounting and 10) Punch List. Qualitative Performance indicators are as follows: 1) Safety, 2) Turnover, 3) Absenteeism, and 4) Motivation.

The analyses indicated that KPIs vary according to the number of years of experience and the level of management. The total cost indicator was found to have significant differences between those with more than 35 years of experience and all other categories except for those who reported less than 5 years experience. On-Time Completion KPI indicated that there existed a significant difference between managers with less than 5 years experience and managers with 25-30 years experience. This difference may be due to the newer, less experienced managers being exposed to tight field schedules, whereas the more experienced managers have seen that projects almost always get done near the contract completion date.

It was also determined that the higher the levels of self-performed work by a construction company, the greater the importance of the quality control/rework KPI. Contractors self performing 26-50% of their work volume selected Units/MHR as their KPI. Those self-performing 37-75% focused on Safety as their KPI. Contractors with the highest level of self-performed work indicated that Quality control/rework was the most important KPI because when self performing 75-100% of the scope of work, quality control directly affected profitability. The study recommended that more in-depth studies should be performed in establishing the development in KPIs.

Yu et al (2007) developed a model to measure and compare the performance of the Korean construction companies. Qualitative and quantitative analysis is used in order to select the proper KPIs. The study used 12 KPIs to compare 34 Korean construction companies. Each indicator assigned weight using the AHP method. Although this study provided a framework for measuring the overall performance of a construction company, it cannot be used to measure the performance of a company at a project level as more performance data are needed.

A study that reviews KPIs for non financial results made in the UK by Beatham et al (2004), resulted with the observation that the KPIs are being used as a marketing tool and not as an integral part of business management.

Beatham's study differentiates between two types of KPIs: Lagging Measures and Leading Measures.

Lagging measures:

- used to assess completed performance results,
- provide opportunity to change performance,
- alert the results of associated performance, and
- used only as historic review.

Leading Measures:

- offered the opportunity to change
- their result is used to predict future performance of the activity being measured or to enable future decisions to be made on future activities based on the outcome of the previous activities. The study indicated that there is quite a large number of organizations developing their own KPIs. The study also reviewed some of them such as: Construction Best Practices Program

(CBPP) construction industry KPIs, Association of Engineers, (ASE) Consultant KPIs, Respect For People, (RFP) KPIs, Construction Industry Research and Information Association (CIRIA) Design KPIs, Major Contractor Group (MCG) Benchmarking Club, Design Quality Indicators (DQI), and Satisfaction Of Service (SOS) KPIs.

Further the study indicated that the construction industry does not distinguish between the following three types of measures:

- KPIs: indicative (indicative of other problems which need corrective action).
- Key Performance Outcomes (KPOs) results of completed action (do not offer opportunity to change)
- Perception measures used at any stage (can be leading or lagging measures). A framework for the effective use of the three types of measures within the overall performance measurement systems is suggested in the study.

2.5.1.2 Project Performance Measurement

Each construction project is unique. This uniqueness makes it difficult to generate a generic framework to measure the performance of different projects (Lin and Shen 2007). Many papers have focused on measuring the performance of a project, some have focused on measuring one aspect and other have focused on measuring the overall performance of a project.

Takim and Akintoye (2002), proposed a model that helps to identify the performance of the stakeholders involved in a construction project. The paper provided a generic framework criterion for successful construction project performance and presented a review of measurements developed to assess project performance. The paper argued that successful construction project performance can be divided along three orientations: procurement, process and result orientations.

Alarcon et al (1998), classified project performance indicators according to their types as follows:

1) Results indicators: they attempt to measure the level of success a project has achieved at the end of the project. Examples are cost deviation, schedule deviation.

2) Processes indicators: they measure the performance of the most important processes that occur in construction phase, such as, design, construction, planning, and procurement.

3) Variables: decisions, strategies, and others that are not a process but affect the performance of the project. Examples are subcontractor ratio and type of contract. Figure 2.9 shows how measurement and analysis of performance indicators help managers to make more effective decisions.

Alarcon also criticized the traditional performance parameters measured in projects. Costs and schedule are not appropriate for continuous improvement for the following reasons:

- They are not effective in identifying causes of productivity and quality losses.
- They do not provide an adequate vision of the potential for improvement, and the information obtained usually arrives too late to take corrective actions.
- Nearly all non value-adding activities become invisible within traditional control systems since these center their attention in conversion activities and ignore flow activities.

For these reasons, it is important to integrate performance measures that promote continuous improvement in company processes and make visible non value-adding activities.

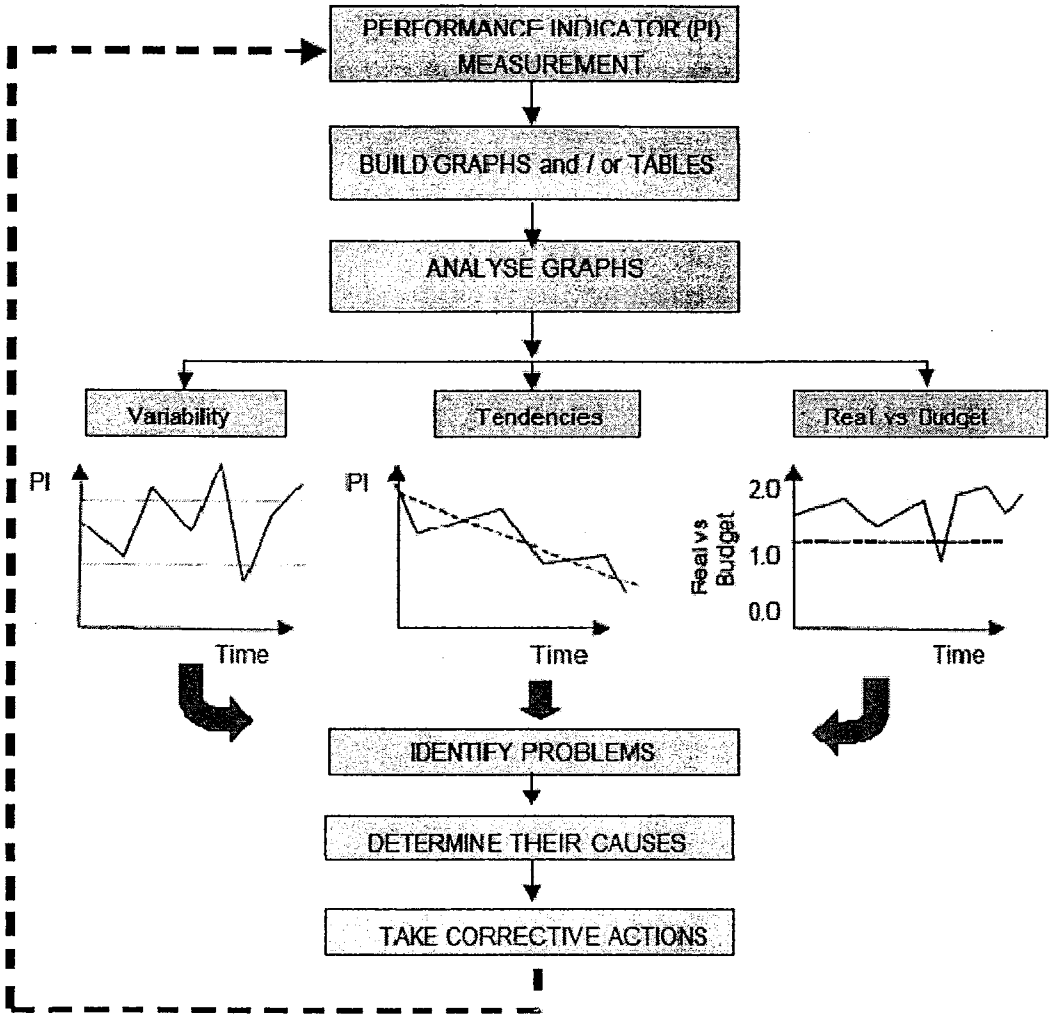


Figure 2.9 How Performance Measurement Support Management Actions
source: Alarcon et al (1998) Adopted from (Grillo 1997)

In Worldwide KPIs and Benchmarking report (2003), an international comparison study has been made. The report looked to "Respect to People issues. Countries covered in the comparison were the following: US, Canada, Member States of the European Union, Switzerland, Norway, Australia, New Zealand, Hong Kong, and Japan. On the one hand, the research showed that the UK has a better safety record than any other country included in their study. On the other hand, the study indicated that Productivity as a headline key indicator has proven to be an recognizable measure. The comparison showed that:

1. The UK lags behind many other countries in certain areas such as site productivity and therefore they have much to learn for improvement from other leading countries.
2. The study showed the possibility to compare different aspects of performance with world class firms overseas, using comparable forms of measurement and definitions.
3. Using world wide KPIs will enable the two way knowledge transfer, and
4. It will improve companies' processes to be activated and maintained, (Worldwide KPIs and Benchmarking 2003).

South Africa and Chile are two countries that have developed their own sets of KPIs. South Africa had national high-level construction industry indicators. The developed indicators are driven by the industry development objectives set in their business plan. Their choice of indicators is based on factors such as international experience, their relevant importance in the South African context, data currently available, and what data can reliably be collected through surveys, Huyssteen, et al (2002). Chile, on the other hand, produced its first set of KPIs in 2002. They adopted the following UK headline KPIs: predictability of cost, predictability of time, safety (accident incidence rate), and productivity.

In 2000, Love underlined the need to focus on stakeholder perspective measurements. The alternative is to consider relations with customers, suppliers, employees, financiers, and wider community as critical for business long term viability. Love criticized traditional performance measurements as narrow, fragmented, and reactive measures. Stakeholder perspective measurements should consider the following three perspectives of the company:

1. As a stakeholder entity reflecting the interests of customers and shareholders (reflected in measures of product/service performance),
2. As a goal-orientated, profit center (reflected by measures of financial performance),
3. As a system that engages in resource garnering, conversion and exchange with the environment (reflected in measures of competitive ability, productivity and quality).

Love concluded that successful business strategies require the adoption of a stakeholder perspective in business measurement, as it can be used to deliver optimal business performance. It is expected that, in the near future, the development of reliable, comprehensive stakeholder relationships will become one of the most important issues for business success.

2.5.2 Advantages of the Key Performance Indicators

The overall strength of the KPIs are that: 1) the overall concepts are easily understood, 2) KPIs are easily implemented, and 3) they can be used by clients, designers, consultants, contractors, sub-contractors and suppliers (Takim and Akintoye (2002).

Ofori (2001) described the advantages of KPIs as the following:

1. KPIs would provide specific targets to be achieved and could be used to measure, systematically, and thus monitor, progress in the effort to improve the industry.
2. They would guide routine activity in the administration of the industry development program and also stimulate innovation during implementation.
3. They would help to identify deficiencies in the program, guide corrective action and indicate additional areas where action could be taken.
4. The indicators could be used to compare the performance of a country's construction industry from one period to another. The efficiency with which the agency administering construction industry development undertakes its tasks could also be monitored.

5. The targets derived from the indicators could be raised over time as the administering agency gains experience, or greater executive capacity; or good progress is made in the industry development effort.
6. Finally, it would be possible to make cross-country and inter-agency comparisons of the nature, extent and pace of achievements in construction industry development.

2.5.3 Disadvantages of the Key Performance Indicators

Chan (2004) highlighted some practical difficulties that may be encountered while applying KPIs. They are as follows:

- Certain project information related to monetary values is sensitive and confidential, so the stakeholders may not be willing to disclose it for analysis.
- The second limitation relates to calculating the accident rate, which relies on an accurate record of the total number of accidents that have occurred and the total number of workers engaged in construction projects in a year. However, the total number of workers is difficult to obtain since there is a complicated sub-contracting system and a rapid flow of labor in the construction industry.
- The calculation of a project's value and profit also involves some problems since it is confidential in nature. Besides, the concept of value and profitability is not appropriate if the project is publicly funded.

Takim et al (2003) indicated these limitations:

- The KPIs are not compartmentalized along project phases. In other words, there is no clear link between the performance indicators measurements based on project phases (e.g., selection phase, execution phase) and the factors that may determine the project performance at completion phase. There is no key factor linking one phase of a project to another.
- There are no suggestions for performance indicators in benchmarking projects at the project selection phase, in which major decisions are made, such as decisions on the project's objectives and planning the project's execution
- Ignoring the performance indicators of the stakeholders that involved in the project.

Ofori (2001) indicated that the problems likely to be encountered in developing and applying indicators for the construction industry development in developing countries would be as follows:

- Developing a realistic and agreed-upon set of indicators would be difficult because of the nature of the construction industry. Construction involves many varied inputs; it produces a range of different outputs. The construction industry also has many complex links with other sectors of the economy. As a result, determining the features of the industry to track would not be easy. Moreover, most of the indicators would relate to items that are directly affected by many factors.
- Collecting and processing the required raw data for estimating the indicators would be difficult in developing countries, which are characterized by poor

information systems and inadequate and inaccurate data, especially those relating to construction activity where indicators are difficult to collect.

- Since the factors relating to construction activity and construction industry development are dynamic, it would be necessary to adjust the indicators for each country over time to ensure their continual appropriateness. This might not be easy to do in all countries.

2.5.4 Benchmarking

"Performance measurement and benchmarking is the cornerstone for challenging any industry to become world class," (Beatham et al. 2004). Construction Best Practice Program (CBPP) defines benchmarking as a systematic process of comparing and measuring the performance of the companies (business activities) against others and of using lessons learned from the best to make targeted improvements. Benchmarking helps companies to systematically and continually discover, analyze, describe and measure best practices, (Ronald et al. 2008).

Benchmarking as defined by CII best practice is " the legal, ethical and confidential venue for owners and contractors organizations to share successful practices and to learn from top performers in the industry with the ultimate aim of improving overall industry efficiency", (Lozon and Jergeas, 2008).

Benchmarking enables an organization to identify its performance gaps and opportunities and to develop continuous improvement programs for all stages of their process. Constructing Excellence (2004) defined benchmarking as "a systematic method of comparing the performance of your organization against others, then using lessons from the best to make targeted improvements". Data need to be compared to something in order to give useful information. The purpose of the benchmarking is to know who is performing better, why they perform better, and how to improve the performance to match or exceed the best practices achievements

Ronald et al. (2008) introduced a tool for cost reduction and performance improvement. This tool is limited to the German mechanical engineering industry, but can be applied to other industries with a little modification. Four stages were suggested in his study. These stages are preparation, analysis, comparison, improvement.

There are different benchmarking models in the literature of benchmarking. Anand, et al (2008) based on his review of the existing benchmarking models, indicated that some models were developed to perform a particular type of benchmarking which can create confusion among the users. A user may find it difficult to choose a best model from the available models, as these models differs in terms of the number of phases involved, number of steps involved, application, etc. Anand et al 2008 developed a conceptual benchmarking model to test the existing benchmarking models.

Georgy et al. (2005) suggested that there are four bases of comparison: 1) current performance against past, 2) actual performance against standards or targets, 3) performance among subunits within an organization or a program, and 4) an organization's or program's performance against other organizations or programs.

According to Constructing Excellence, 2004, there are three levels to benchmarking. Level one named internal benchmarking: it allows the comparison of the progress of project/s and it also allows the comparison between different departments. Level two, Competitiveness Benchmarking: It involves comparison against competitors of specific function, or service, through benchmarking groups. The purpose of the benchmarking clubs is to enable the comparison of data from companies that compete with each other. A number of benchmarking groups exist within the construction industry. Participants submit their performance data to a central data base and receive a report that describes the steps to be followed to compare the data against that of other participants in the club.

Level three Generic Benchmarking: allows the comparison with other industries regardless of the industry sector or location.

Lema and Price (1994) stated that there are basically two types of benchmarking: internal and external. Internal benchmarking is used to compare the performance between units/departments within an organization. External benchmarking can be further categorized into two types: external/competitive and external/generic.

External/competitive is used to compare a specific competitor for the product, service or function of interest, whereas external/generic is a comparison of business functions or processes that are the same, regardless of industry or country. There are many classification of benchmarking on the literature. Anand et al (2008) stated that benchmarking should be classified as internal and external benchmarking and all other cases such as functional and process can be listed under these two categories.

Anderson and Moen (1999) have identified 60 different existing models developed for the purpose of benchmarking. Benchmarking models are not covered on this literature as they are not the main purpose of this study.

Traditionally, performance measures have been compared with previous measures from the same organization at different times. That indicates whether or not the organization is improving its own performance. However, this reflects the rate of improvement within the organization. Benchmarking models are used to determine how well an organization is performing compared with other similar organizations. The following section covers some of methods that have been used for benchmarking purposes.

Generally, the tools for measuring performance are simple and effective. They are computer-generated benchmarking tools used to enable a project team to monitor their construction project processes by measuring performance. The usual method used to give the overall picture of the company's performance is a

Radar chart (Cartlidge, 2006). Its primary objective is to identify the strengths and areas of improvement.

2.5.5 Background of Performance Measurement

There is a distinction between performance indicators, performance measures, and performance measurement. Performance indicators specify the measurable data necessary to verify that a planned effort has achieved the desired result. When indicators can be measured with some degree of accuracy and without ambiguity they are called performance measures. Performance measures are the numerical or quantitative indicators. Performance measurement is a systematic way of evaluating the inputs and outputs in manufacturing operations or construction activity and acts as a tool for continuous improvements (Takim and Akintoye, 2002).

Performance measurement has been traced back to the use of planning and control procedures by U.S. railroads in the 1860s and 1870s (Chandler 1977; Kaplan 1984). "By 1925, many of the financial performance methods and techniques used today such as discounted cash flow, residual income, economic value added and cash Flow return on investment had been developed (Chandler 1977;Kaplan 1984; Neely et al. 2000)" (Bassioni et al 2004).

In 1950, dissatisfaction about financial measurement began to appear on the surface. Its limitations have been discussed and recognized by a number of authors (Kaplan 1984; Eccles 1991; Bourne et al 2000). In 1989 Keegan et al classified the performance measurements into cost and non cost measures. Maskell (1989) used performance measures based on non financial measures such as quality, time, process, and flexibility.

Cross and Lynch (1988–1989) prescribed in a performance pyramid relationships among the basic performance criteria. Those criteria are 1) Quality, delivery, process time, and cost (located at the bottom of the pyramid, 2) Customer satisfaction, flexibility, and productivity, 3) Market measure and financial measure and finally 4) Vision at the top of the pyramid. In the early 1990s, success was related considerably to performance measure.

Project level, time, cost, and quality are the three basic and most important measures. They are recognized and thrashed out in most of the literature related to project success (Chan 2004). It has been suggested that soft measures such as participant satisfactions and project psychological outcomes that refer to satisfaction of interpersonal relations with the project team be added as measures for project success (Pinto and Pinto 1991 and Wuellner 1990 respectively), (Chan 2004).

Dixon et al (1990) developed the performance measurement questionnaire (PMQ) and Brignall et al (1991) applied non financial measurements to the service industry and suggested dividing performance into determinants and results.

Kaplan and Norton (1992, 1993) introduced to performance measurement frameworks the new concept of Balanced Scorecard with four broad perspectives: financial, customer, internal processes, and innovation (Bassioni et al 2004).

In the period from 1994 to 1996, about 3,615 articles were published, and in 1996 a new book came into view on the subject in the United States every two weeks. The U.K has a long track record on the subject of performance measurements. The U.K hosted 23 conferences about performance measurements between the years 1994 and 1999. A number of reports and publications in the performance measurements identified the areas of improvement. Simon in 1944 indicated the need for change and improvement. Egan (1998) highlighted the status of the industry and how to achieve performance improvement (Bassioni et al 2004 and Flapper et al 1996).

Bititci et al (1997), Ghalayani et al (1997), and Medori (1998) developed performance measurement frameworks that have design and implementation features. A new perspective for performance measurements was presented in

2001 by Neely and Adams. They argued that performance measurement should focus first on measuring stakeholders' needs and contributions and then on the required strategies, processes, and capabilities. Table 2.4 is a summary of the history of performance measurements.

Table 2.4 Performance Measurement History

Year	History of Performance measurement	Country
1860s-1870s	use of planning and control procedures	US
1989	classified the performance measurements into cost and non cost measures	
1989	Use of performance measures based on non financial measures such as quality ,time, process, and flexibility.	
1992-1993	the new concept Balanced Scorecard	UK
1994-1996	about 3,615 articles have been published	
1994 and 1999	The U.K hosted 23 conferences about the performance measurements	
1997	developed performance measurement frameworks that have design and implementation	UK
2001	seen that performance measurement should focus first on measuring stakeholders' needs and contributions and then on the required strategies, processes, and capabilities	
2004	highlighted the main gaps/weaknesses in knowledge and practice indicating that there is a need for a comprehensive or integrated performance measurement framework in construction	UK

2.5.6 Performance Measurement Models

Many performance measurements have emerged in management literature. As cited in (Takim and Akintoye 2002), these include: 1) the financial measures (Kangari et al 1992; Kay 1993; Brown and Lavenric1994; and Kaka et al 1995), 2) client satisfaction measures (Walker, 1984; Bititci,1994; Kometa, 1995; Harvey and Ashworth, 1997; and Chinyio et al 1998), 3) employee measures (Bititci, 1994; Shah and Murphy, 1995; and Abdel-Razek,1997), 4) project performance measures (Belassi and Tukel, 1996) and industry measures (Latham, 1994; Egan, 1998; Construction Productivity Network, 1998); and 5) Construction Industry Board, 1998);

Takim et al (2003) suggested that existing construction performance can be categorized in many ways. These categories include the following: 1) construction project performance; 2) construction productivity, 3) project viability and 4) project quality. These categories form the basis by which models have been developed to measure construction performance at various stages of development. The classification is based on the existing construction performance measurement models.

Takim et al (2003) proposed an "amalgamated-model" which brings together the best practice from the existing techniques and models in measuring construction project performance. The model takes into consideration financial and non financial indicators across project phases: strategy formulation-phase, procurement phase, and implementation-phase and project completion-phase.

Cordero (1990) proposed a model of performance measurements in terms of outputs and resources to be measured at different levels. Outputs are measured to determine whether they help to accomplish objectives (effectiveness) and resources are measured to determine whether a minimum amount of resources is used in the production of outputs (efficiency). However, the model failed to reflect the interests of stakeholders, their needs, and expectations (Takim et al 2003).

For construction companies to remain competitive, they need to understand their economic and moral relations with their clients, suppliers, employees, lenders, (Love et al 2000). The author proposed a model known as stakeholder perspective measurement (SPM) that considers relations with customers, suppliers, employees, financiers and the wider community. All of them are critical to a business's viability, both in the short and long terms.

Pillai et al (2002) proposed a model of performance measurement for R&D projects. Four important areas were identified in this model: 1) the project phases, 2) the performance indicators associated with each phase, 3) the stakeholders and 4) the performance measurements. They proposed to use the Integrated Performance Index (IPI) to reflect the performance of the R&D project at any point during the project life cycle by integrating the key factors from each project phase. The relationship between the needs, expectations and performance of the stakeholders at each phase is thoroughly discussed and formularized.

2.5.7 Summary

The most popularly adopted quality models of measuring and improving performance are the European Foundation for Quality Management (EFQM) Excellence Model in Europe, the key performance indicators (KPIs) report CBPP (2002), the Malcolm Baldrige National Quality Award in the United States, and the Deming Prize in Japan, (Lin and Shen 2007).

"Existence of these frameworks and models prompt two questions: one question is why there is a need for so many frameworks and the second obvious question is which one is better or more correct (Bassioni et al 2004). The answer is that they are all valid and correct, but look at the various facets of performance from different angles (Neely et al 2002)", (Lin and Shen 2007). The common features among these frameworks are the following:

1. Multi-perspective indicators are needed to measure performance;
2. Indicators based on characteristics of organizations or projects in different industries need to be developed;
3. Continuous measurement of performance is encouraged to achieve the best practice; and
4. Real-time feedback is necessary to make on course corrections.

Traditionally, most companies use outcome measures to monitor their performance. Generally there are two types of indicators: Outcome or lagging indicators and Positive or leading indicators. Outcome indicators are relatively easy to collect; easily understood and easily compared for benchmarking or comparative purposes; and they are able to be used to identify trends. However, relying only on them to provide information regarding performance has its limitations. They generally reflect the outcomes of past practices because there is often a time lag before outcomes reflect changes in practices. Leading indicators focus on evaluating how successfully an organization or particular work is performing by monitoring the processes. They provide immediate feedback. As a result, immediate improvements can be made.

Using affirmative indicators on their own also has limitations. Since they may be difficult to evaluate for benchmarking or comparative purposes; they may not be easily measured; they may be time consuming to collect; they are subject to random variation; the measurement system may lead to under reporting or over reporting; and often the relationship between positive performance indicators and outcome measures is not known.

2.6 FINDINGS

2.6.1 Construction and Design Performance Measurement

Based on the previous review conducted on construction and design performance measurement literature, the following shortages are derived:

1. In order to track performance, detect project positive and/or negative factors, and take corrective actions for improvement, a tool is required to measure and assess design performance among different projects in order to have an efficient control system.

2. Studies that have been conducted on KPIs for construction design are lagging measures. They are based on the outcome, i.e., they are used after the project is completed as a result, they do not offer the opportunity to change. Therefore measures which offer opportunity to change during the period for which the measure has been taken are needed.

3. Studies that have been conducted on KPIs for construction design are not aligned with the strategy or objectives of construction companies. They tended to be a complete set of KPIs, which may or may not be aligned to company's business needs.

4. No research has been reported in the literature on the use of key performance indicators in Canadian construction particularly for the design stage of a project.

In summary, a successful key performance measurement system of design should include the following: 1) a well defined mission statement based on the participant company's needs including customers and employees; 2) identifying of critical success factors for all the stakeholders 3) Definition of KPIs ; 4) Definition of data used in the calculation of KPIs; 5) Definition of the method of calculation of each KPI; 6) Proposal measurement frequency; 7) Establishment of a target and plan to achieve the target performance for each KPI; 8) responsibilities assigned at the organizational level.

There are seven criteria across all of the project stages. These are time, cost, quality, client satisfaction, change orders, business performance and health and safety. Design as the heart of the project process needs to take into consideration all those criteria in order to measure and control its impact on the over-all project stages.

2.6.2 Design Models

On the other hand, the design literature gives quite a number of design process models are reported in the literature. However, their impact on the practice of design is still limited.

Adopting one of these models is quite a challenge. All the models have almost the same income and outcome. However, they have different representations. Among them, only the CIRIA model takes into consideration the relationships between internal and external environments in its representation.

Yet, the model consists of two main parts cost and value facilitating the job of developing and measuring the required indicators. In the next section, PWC network and CIRIA model are analyzed and evaluated. Then, a generic conceptual model of the design stage is proposed, in order to identify KPIs and to clarify to where the focus of control would be. However, this will simplify what would and would not be addressed by the study. The design model is essential to approach the development of effective performance indicators.

2.7 ADOPTING AND MODIFYING A DESIGN MODEL

In order to develop a set of design- KPIs for the Canadian construction industry, understanding the main design processes and their outputs is extremely important. However, this understanding can help to first, create a basis for measuring the performance of design processes, and second to provide project managers with the necessary information to control the design stage.

Adopting a design model is an essential step in the application of effective design KPIs. The design model is an effective tool that helps to identify the factors affecting the performance. Chapter Two reviewed what the literature contains regarding the available design models.

The present research has proposed a generic conceptual model for the design stage, in order to identify KPIs and to clarify where the focus of control should be. The proposed design model is mainly based on both the PWC design process network and the CIRIA design model. The PWC and the CIRIA design models have been chosen for the following reasons:

1. The PWC design process network is intended to illustrate both sequence and interrelationships and have certain decision points in the process. The design process includes a detailed description of the related activities.

2. This CIRIA design model has been adopted by the CIRIA in order to develop design performance Indicators.
3. The CIRIA model uses indicators that are related to the costs of the realization of the design and the value of the outcome or product.
4. KPIs based on the CIRIA model have been used by most European countries. They need to be tested in Canada and other countries.

The PWC and CIRIA models are completing each other. For this reason, they are combined in order to satisfy the goal of the present research.

As shown in Figure 2.10, the proposed design phase of a project consists of: concept and development sub-phase (design process) and realization and satisfaction sub-phase (design outcomes).

- The process is composed of conception activities and development activities. These are adopted from the PWC design process network. These activities include the 24 design activities that are described in Chapter Two. Depending on the CIRIA design model, the Indicators that measure the effectiveness of conception activities are value related. Indicators that measure the effectiveness of development activities are cost related. Both conception and development activities are classified as leading indicators (offer opportunity to change and take action during the design stage).
- The outcome is composed of the realization of the design and the satisfaction with the design. These components are adopted from the CIRIA model. The realization of a design usually occurs at the construction stage of a project.

Indicators to measure the effectiveness of the realization of a design will include the variation on estimated construction costs at the planning stage, the number of change orders, and the safety during the construction stage. These indicators are cost related. On the other hand, satisfaction includes client satisfaction during the sub design phases and end-user satisfaction. These indicators are value related. Both the realization of the design and the satisfaction are classified as lagging indicators (do not offer the opportunity to change). Following the CIRIA model, Conception and satisfaction interact with the external environment. Development and realization interact with the internal environment.

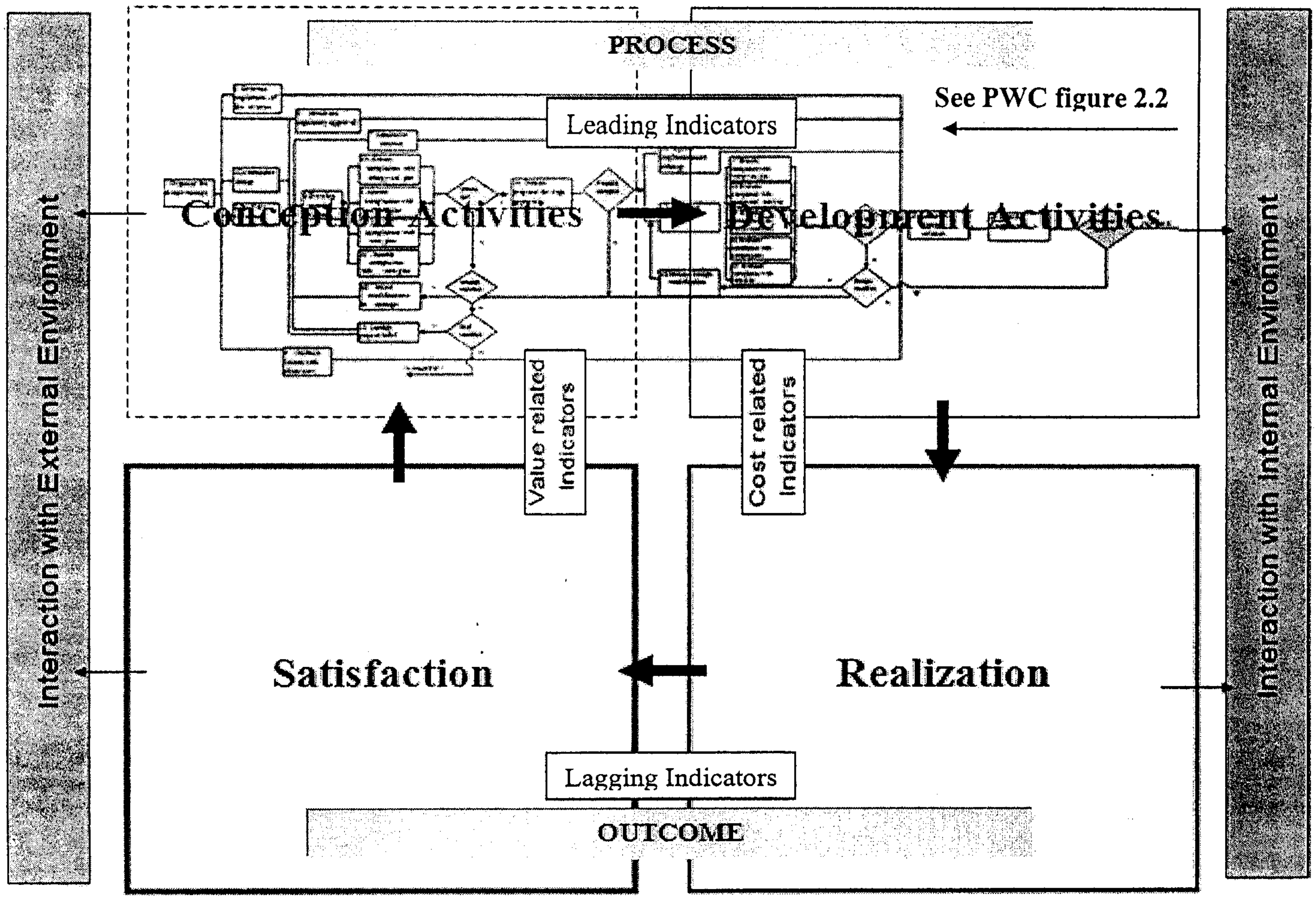


Figure 2. 10 Adopted and Modified Design Model

CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

The proposed work is divided into two major parts as follows:

Part one conducts a questionnaire survey in order to identify indicators affecting the design performance and to clarify how important they are as measures of design performance. In this regard, a web-based survey was developed. It consisted of six multiple-choice questions. The survey targeted Canadian design and construction companies. Five groups were chosen: clients; design companies; construction companies; and sponsors. The Canadian construction industry is divided into four sectors: commercial construction (for example, factories; high rise buildings); civil infrastructure (for example, roads and bridges); heavy engineering (for example, petro-chemical sites); and domestic housing. The four construction sectors were targeted with the intention of determining a general set of design indicators that could be used by all the construction sectors. Indicator identification is the most critical step in the implementation of the Model of Design Performance Measurement (MDPM). The survey, design, analysis, results, and discussion are described in Chapters 4.

Part two introduces a Model for Design Performance Measurement (MDPM). In order to establish a framework for design performance measuring, it is necessary to develop a model. The proposed model is capable of measuring the performance of the design activities at both company and project levels. The standard Analytical Hierarchy Process (AHP) method is used to calculate the weights of the selected design performance indicators. The dataflow and general structure of the model are described in this chapter, Sections 3.2 to 3.4. Its implementation is presented in Chapter 5.

3.2 OVERVIEW OF THE DEVELOPED MODEL

A Model for Design Performance Measurement (MDPM) is developed. The model is capable of measuring the performance of design activities at both company and project levels. Design performance data requires filing; storing and retrieving; therefore a database has been designed for this process. The AHP method is used to calculate the weights to be allocated to an indicator scores. The weight of each score needs to be included to consider the different priorities of each indicator, (Yu et al 2007, Olson and Slater 2002). Excel is used to perform the AHP operations.

In order to develop this model the following steps are taken:

1. Identify the indicators affecting the design performance through a web-based survey
2. Structure the factors hierarchically,
3. Run AHP and calculate global weights for each indicator. These are performed in an Excel environment.
4. Quantify the effects of the indicators on performance. These are performed in an Access environment.

As illustrated in Figure 3.1, the overall structure of the model is divided to serve two main levels, the Company and the Project Levels. Both levels need to address company objectives. Company-level indicators are concerned with the overall design performance of the company. Project-level indicators are used to monitor, measure, and improve the performance of projects. The overall aims of the model are as follows:

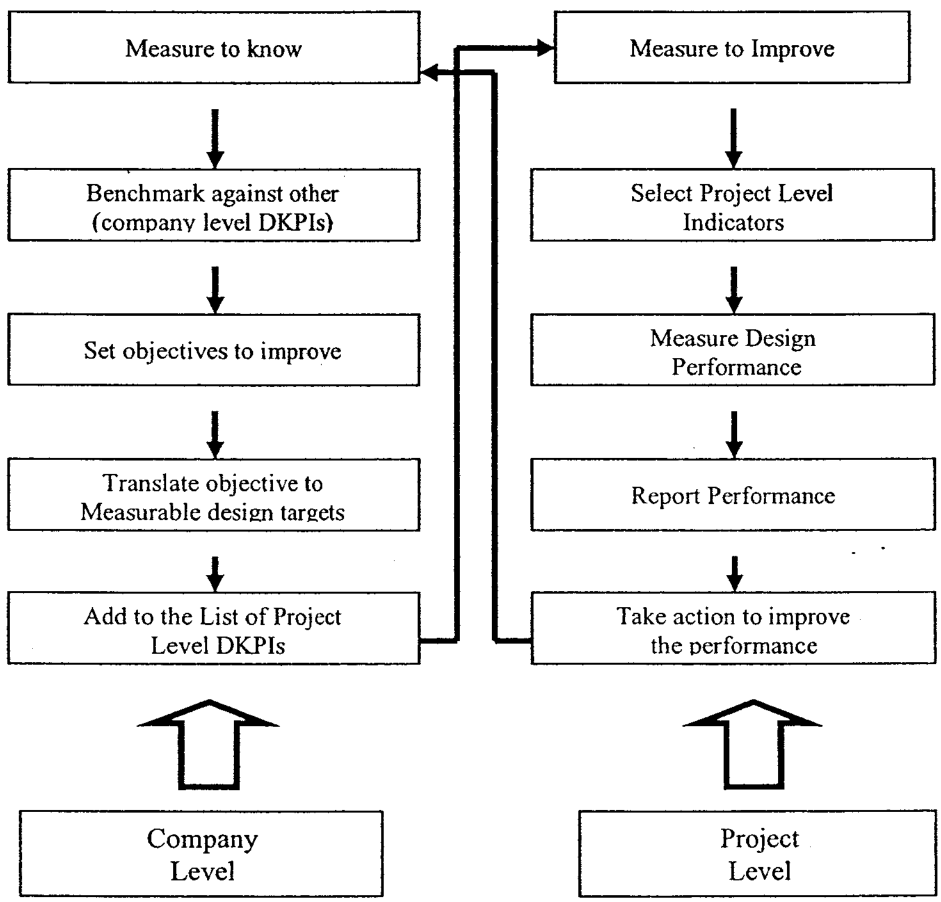


Figure 3.1 The Overall Structure of the Model

1- Benchmarking Against other Companies (Company Level DKPIs)

At the company level, the Overall Design Key Performance Indicators (ODKPIs) could be used to benchmark the design performance of a company against other companies in the same sector. Establishing a benchmarking tool is not the aim of this research. However, the present research highlights the ODKPIs and clarifies how to use them in order to improve the performance of the design activities.

ODPKIs are identified through the survey. After a company benchmarks its design performance against others in the same sector, the company sets a list of its own objectives in order to improve the performance of design activities. These objectives will be translated into design objectives. This would enable the company to establish an internal set of DKPIs. These internal KPIs will vary widely from one company to another. The internal DKPIs need to be added to the set of "the project level" indicators in order to improve the performance of the DKPIs.

2- Tracking the Performance of Design Activities (Project Level KPIs)

At the project level, leading indicators are used to track the performance of a project or a group of projects. As mentioned earlier in the present chapter, leading indicators are used to predict the future performance of the activity being measured, to indicate problems that need corrective action for future activities, and to enable future decisions.

3- Improving the Overall Design Performance

Lagging indicators will be measured following the same procedure. The results must be analyzed to identify problems and to verify whether they satisfy company objectives. Lagging measures will be used to assess completed performance results and to record data to be used for historical review.

3.3 MODEL STRUCTURE AND INFORMATION FLOW

Based on the above-structured hierarchy of design indicators, the Design Performance Measurement (MDPM) model is developed. As presented in Figure 3.2 the model includes a complete set of indicators for design performance prediction and assessment. The MDPM is capable of performing the following main steps:

1. Selecting the proper DKPI to measure;
2. Collecting the necessary data;
3. Getting KPIs scores;
4. Reporting results and identifying problems;
5. Analyzing the results;
6. Taking action; and
7. Measuring again.

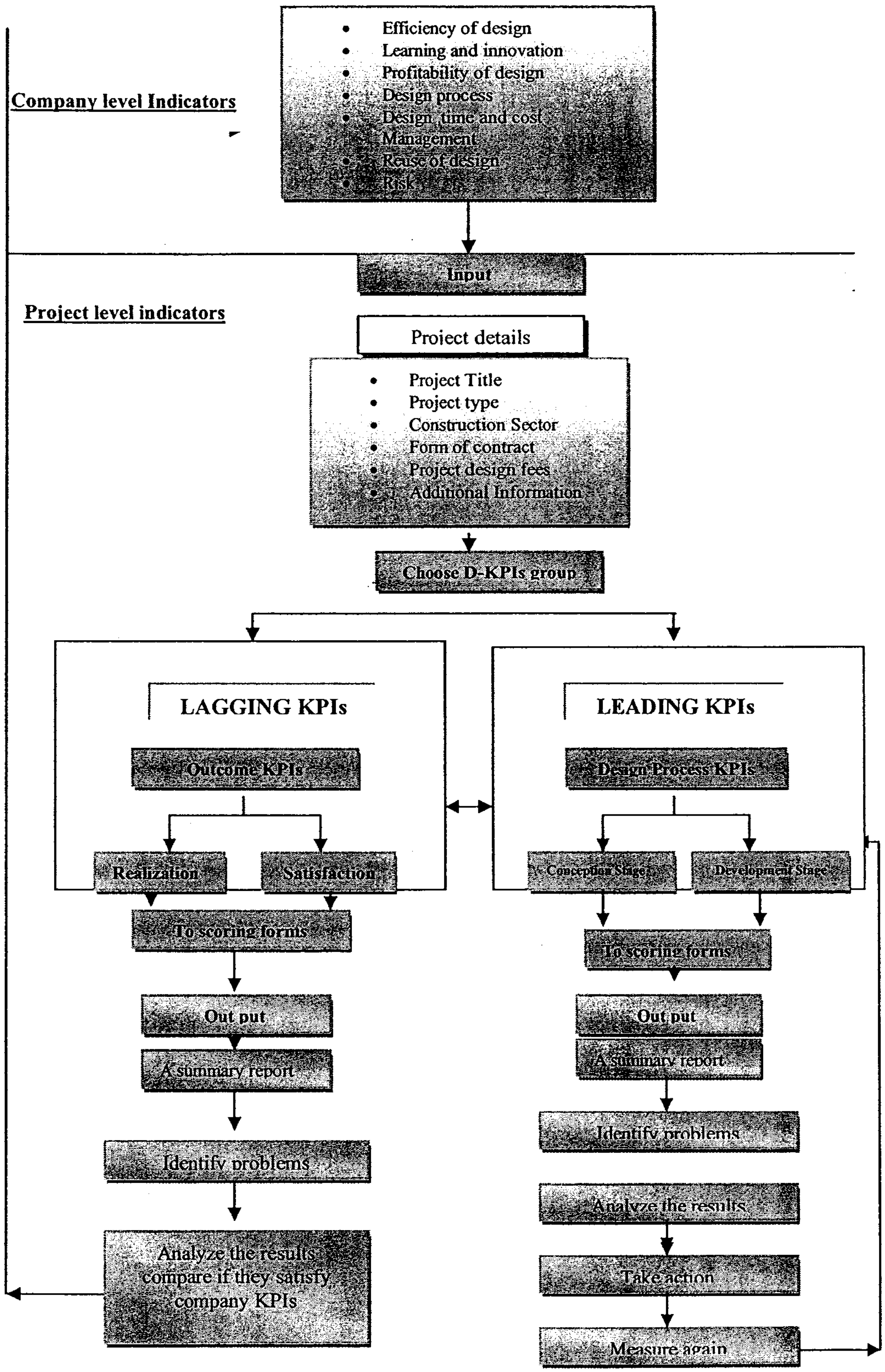


Figure 3.2 Proposed Model Information Flow

3.4 MODEL ARCHITECTURE

The MDPM requires that a large amount of data be stored, manipulated, retrieved, and exchanged. In this regard, Microsoft Access is used to develop the model's database. In order to score the Design Performance Indicators for specific projects, measuring sheets are created in Access on forms that are formatted and stored in the Access database. Based on the survey results, the scores were exported from SPSS statistical package to Microsoft Excel in order to run the Analytical Hierarchy Process (AHP) analysis for the groups of indicators. The final outputs of the AHP analysis are global weight tables for all of the design indicators. These results are exported back to the database in order to create the final reports about the projects. Figure 3.3 represents the data flow and its main inputs and outputs.

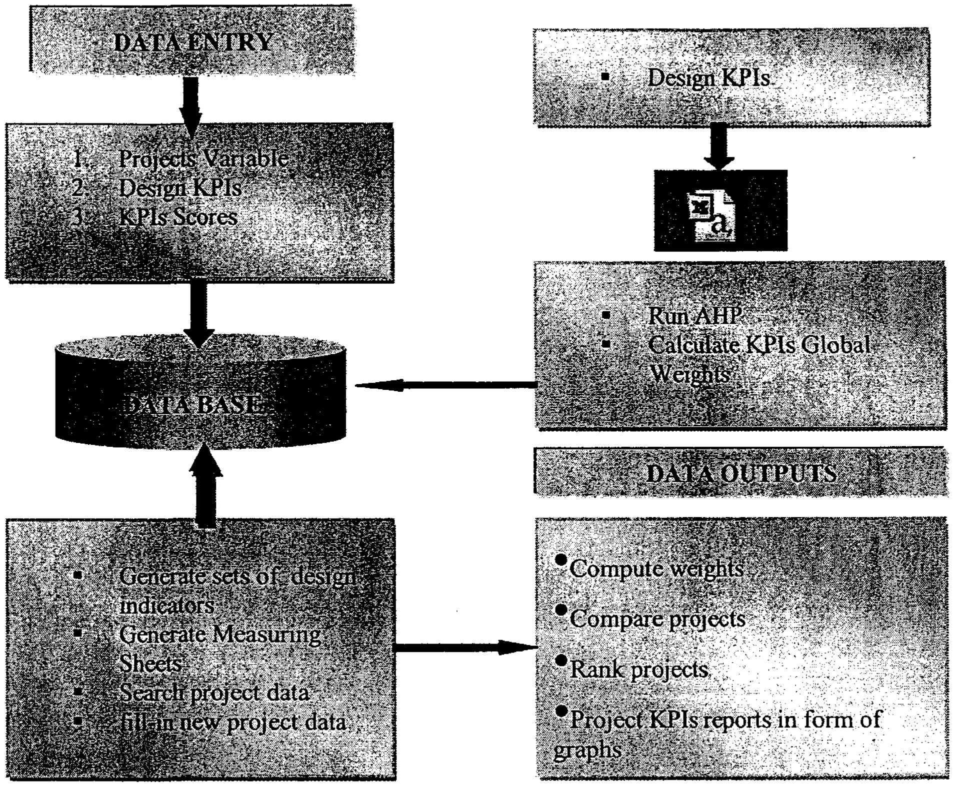


Figure 3.3 Data Flow

3.4.1 Data Base Object

The macros and the database environment of Microsoft Access are used to construct the database in order to store the design performance indicators and its structured data, to perform the basic calculation, and to produce the final reports in the form of a radar chart. The data collection including the main design KPIs groups and sub-groups were stored in separate tables (with their associated measurement sheets and the score results). Important project data were stored in the database for later use, i.e., for reporting comparison and data analysis.

The ranking of DKPIs is based on how important they are as measures of the design activities. These scores are first compared to each other using the absolute difference between their main scores, and, second, they are then exported from SPSS to Microsoft Excel in order to perform the Analytical Hierarchy Process analysis (AHP) for the groups of indicators. The final outputs of the AHP analysis are global weight tables for all of the design indicators. The global weight tables are exported to the database Access in order to evaluate and create the final reports about certain project/s.

As mentioned in Chapter 2, one of the main KPI limitations occurs during the collection of sensitive data such as cost data. Contractors and clients sometimes hesitate to submit these confidential data to the KPIs collectors. Overcome this limitation, the users (client, contractor, cost controller, etc) are allowed to access a specific set of indicators. For example, a senior manager can access all the databases and link the required data to the management systems, where consultant engineers can access the time and cost indicators only and cost controllers can access the risk indicators as well as the time and cost (see Figure 3.4).

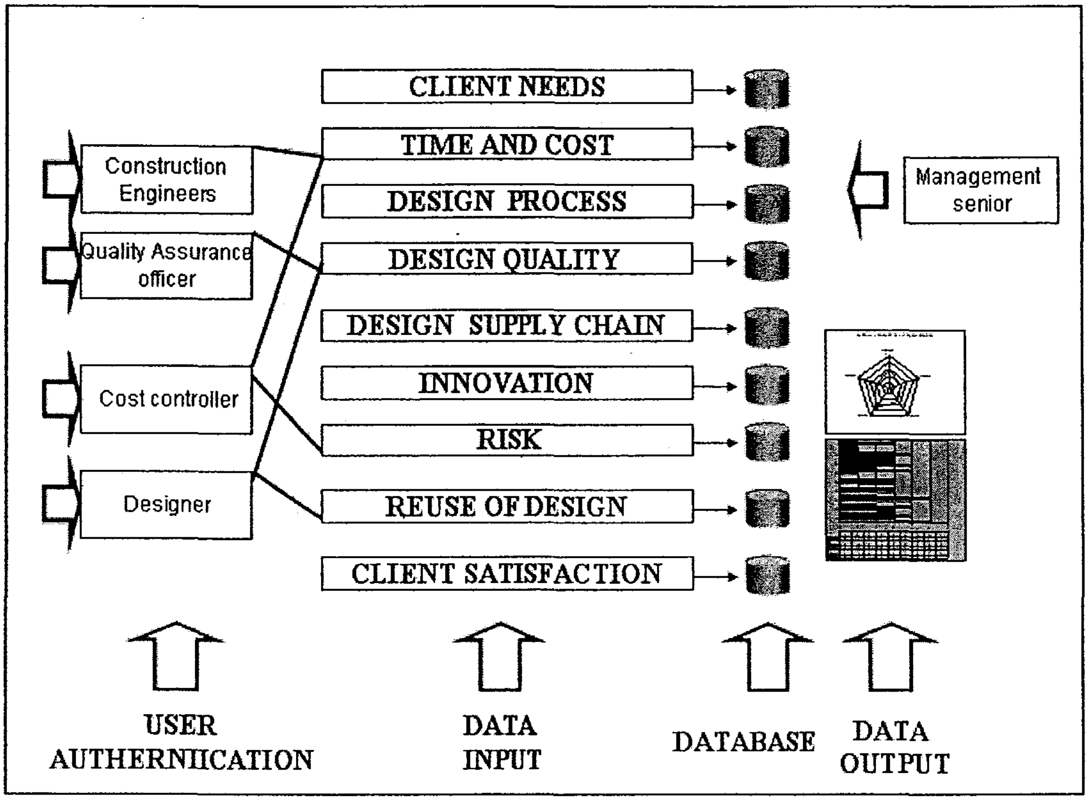


Figure 3.4 Design Performance Measurement Computing Framework

As illustrated in Figure 3.5, the structure of the design KPIs model consists of four major components: the entry of data, data interpretation, reporting, and action. These components are explained as follows:

1. Data Entry:

The user (client, contractor, consultant, etc.) is required to access the database in order to fill in the basic data about each project. The required data for performance indicators were completed manually. However, most projects have a large number of participants, who are located far from their head offices or in different parts of the world. In such cases, the questionnaires can be completed through E-mail on Access. First, data is collected through the E-mail Messages Wizard. A form is created by performing this step. The forms are sent through Microsoft Office Outlook 2007 to recipients with a request to assign scores using a scale from 1 to 5 in the measurement sheet for the questions regarding indicators information. When the recipients reply, Access automatically enters their data into the database. This accelerates the process time. Each project is stored as a record in the database. Users are required to enter the following details about each project:

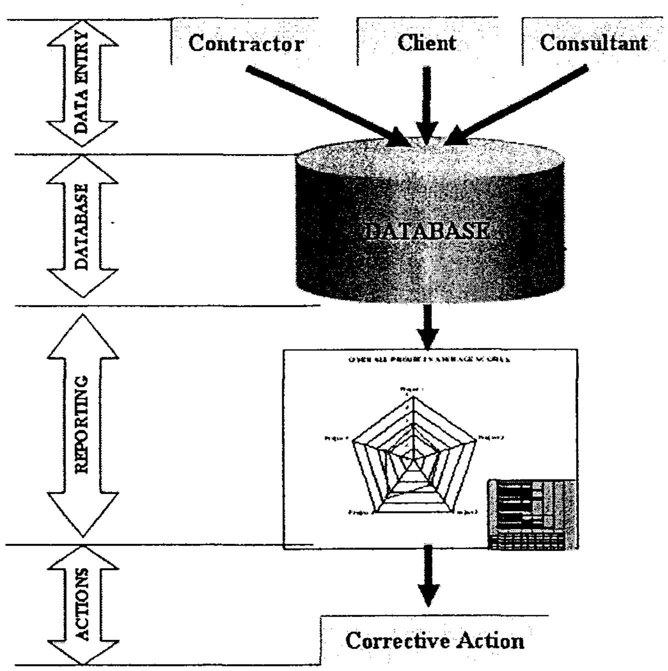


Figure 3.5 Development Structure for Design Performance Measurement.

- Project details: The project manager is required to enter the following project details: project ID, project title, project type, project fees, type of contract, and construction sector.
- Indicators scores: under each indicator, there is a list of sub-indicators. The user is required to put his/her score in the measurement sheet. The measuring questions are clearly stated for each sub-indicator.

2. Data Interpretation:

The main DKPIs groups are addressed in improving the performance of the design. Each group is divided into a set of sub-groups. Each sub-division is explored through a question that has a five point score. The scores used range from 1 to 5. One represents minimum practice and five represents best practice. The DKPIs groups and scores are presented in forms and tables formats and are saved in a database as an evidence of performance. Global weights were calculated with Excel using the standard AHP method and were then exported to the database in a table format.

3. Reporting and Taking Actions (Project Evaluation):

Take one project at a time and measure its performance using the scale from 1 to 5. The weight for each indicator is automatically assigned. Based on project weights and scores, project can be evaluated and its performance is measured.

Each project is a record in the database. The data can be stored or deleted. Once the projects (records) are saved, the projects can easily be compared by using radar charts and reports.

Summary reports about how projects are performing at their design stage or sub-stage can be generated in terms of a radar chart. A radar chart is a simple representation of the indicators with their associated weights. Scores are plotted on the radar chart using a scale from 1 to 5. Figure 3.6 represents an illustrative example of the radar chart. Charts can be stored in the database. As a result, users can compare the design performance of different projects using these charts. Charts indicate where the problem is. The nearer the plotted line is to the outer parameter of the chart, the higher the overall performance is. Users can determine the problem and the reason behind it by referring to the indicators with a lower performance (Indicators that fall nearer to the inner parameter). Corrective actions can then be undertaken to improve the performance of that particular activity.

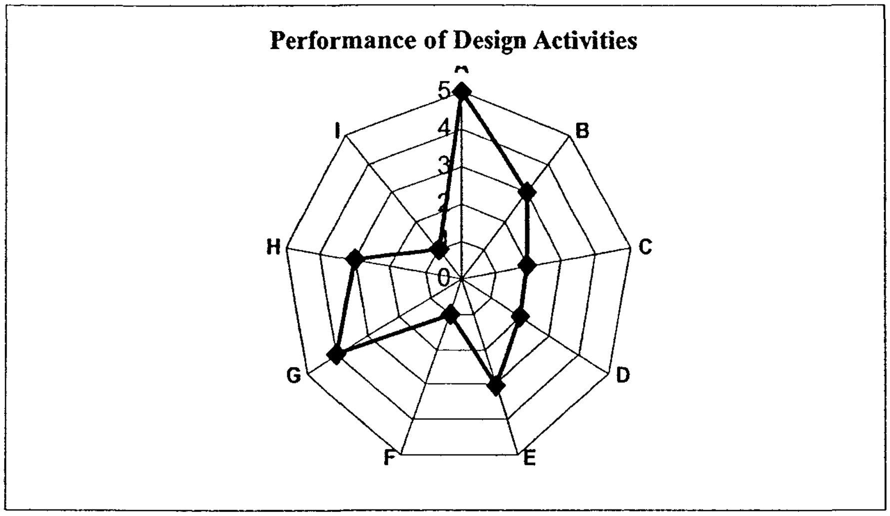


Figure 3.6 Example of Design Process Radar Chart Showing the Overall Performance of One Project

3.4.2 Excel Object

As mentioned in the previous section, Microsoft Excel is employed to run the standard AHP. The Analytical Hierarchy Process (AHP) is used to measure the design performance at both company level and project level. AHP is a mathematical decision technique. It is capable of incorporating objective factors as well as subjective factors into the evaluation process, and it provides a measurement of the projects overall design performance that is fairly accurate. It is a process that leads the decision makers 1) to structure a problem as a hierarchy or as a system with dependency loops, 2) to elicit judgments that reflect ideas, 3) to represent these judgments with meaningful numbers, 4) to synthesize results, and 5) to analyze sensitivity to changes in judgment. The technique was developed in the 1980s by Thomas Saaty. Below are the steps in the measurement process:

1. Model the Design KPIs as a Hierarchy:

The first step on the standard AHP is to model the problem as a hierarchy. The evaluation model consists of the main set of qualitative indicators. Each set is sub-divided into more levels.

2. Determining Design KPIs weights:

Using Excel, pairwise comparison matrices are generated for the main indicators and their subs based on their intensities. The concept of a comparison matrix (reciprocal matrix) is presented as follows (Saaty 1980). :

$$A = \begin{bmatrix} 1 & a & b \\ 1/a & 1 & c \\ 1/b & 1/c & 1 \end{bmatrix} \quad \textbf{(1)}$$

Where a, b, c are the intensities, in other words, how important each indicator is to the other.

3. Computation of a vector of priority:

Vectors of priority are calculated by taking the average of each row. This vector represents the weight of the indicators. This ends up with the so-called eigenvector-normalized priority weights of each attribute. This vector gives the indicators weights. The Consistency Index (CI) is calculated to check the matrices' consistencies using the following equation:

$$CI = \frac{\lambda_{max} - N}{N-1} \quad (2)$$

Where:

λ_{max} = approximation of max eigenvector (sum of elements in each row in the comparison matrix divided by eigenvector)

N = numbers of factors (indicators) compared

The Consistency Ratio (CR) is calculated using Equation 3 to check if the pairewise comparisons are considered to be adequately consistent. CRs less than 0.1 are acceptable. Larger values require the decision maker to reduce the inconsistencies by revising judgments (Saaty 1980).

$$CR = \frac{CI}{RI} \quad (3)$$

RI is a given random consistency index (derived from randomly generated reciprocal matrices).

4. Determining intensities (grades or scores) for the indicators weights:

In order to calculate the global weight, a pair wise comparison matrix was created for the indicators grades (scores), (Rafikul and Shuib 2005). The scale used to evaluate the projects is from 1 to 5. 1= Poor (P), 5= Excellent (E). See Table 3.1. For more illustrations, when the user evaluates a project, s/he gives each indicator a score of from 1 to 5. Five indicates the best performance and one represents a poor performance. A pairwise comparison matrix is then created for these scores, and weights are attached for each score.

Table 3.1 Intensities Pair wise comparison

	E	G	A	S	P	Weight
E	1.00	2.00	3.00	4.00	5.00	0.42
G	0.50	1.00	2.00	3.00	4.00	0.26
A	0.33	0.50	1.00	2.00	3.00	0.26
S	0.25	0.33	0.50	1.00	2.00	0.20
P	0.20	0.25	0.33	0.50	1.00	0.06
	2.28	4.08	6.83	10.50	15.00	1.00
CR=0.017						

Best performance (E) = 5, Good performance, (G) =4, Average performance (A) =3, Satisfactory (S)= 2 Poor performance(P)=1

5. Calculating indicators' global weight:

Each group of indicators consists of a sub set of indicators (sub criteria). Global weight is calculated using the following Equation, (Islam and Rasad 2005):

Global weight of an indicator = $W_i \times W_j \times W_k$ **(4)**

Where:

W_i = the weight of the ith main indicator, (priority of the parent criteria)

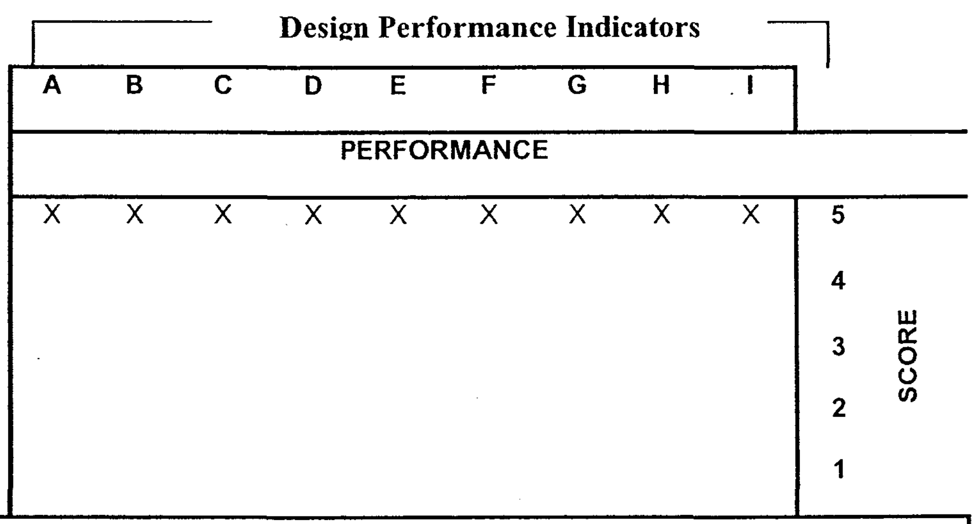
W_j = the weight of the j sub indicator, (priority of the sub criteria)

W_k = the weight of the project indicator grade (score)

A detailed explanation of the implementation of the AHP is presented in Chapter 6. After the global weights for the indicators are calculated, the data are ready to be imported into the database.

6. Measuring the performance of one project:

At the project level, in order to know how each indicator is performing, the objective matrix is used. The objective matrix is a valuable tool that is used to measure how a project is performing at the design stage according to performance measures (CII 1986 and Broaddus, 1991). Figure 3.7 shows the main parts of the objective matrix. The Index is the product of the indicator score multiplied by the weight. The sum of the indicators' index is the overall performance. The best score, which is attained if all indicators for a project were ranked as a five, would result in an index of 500. On the contrary, an index of 100 would be the result if all the indicators were ranked as a one.



Total	5	5	5	5	5	5	5	5	5	score
100	16	14	14	5	16	10	7	7	11	weight
500	80	70	70	25	80	50	35	35	55	Index

Figure 3.7 Objective Matrix

To evaluate the best taken action, the AHP is used and the following steps were taken:

1) Three levels of hierarchy structure are developed as shown in Figure 3.8. The first level is the overall goal. The second level represents the nine indicators and the third level contains the available 3 alternatives.

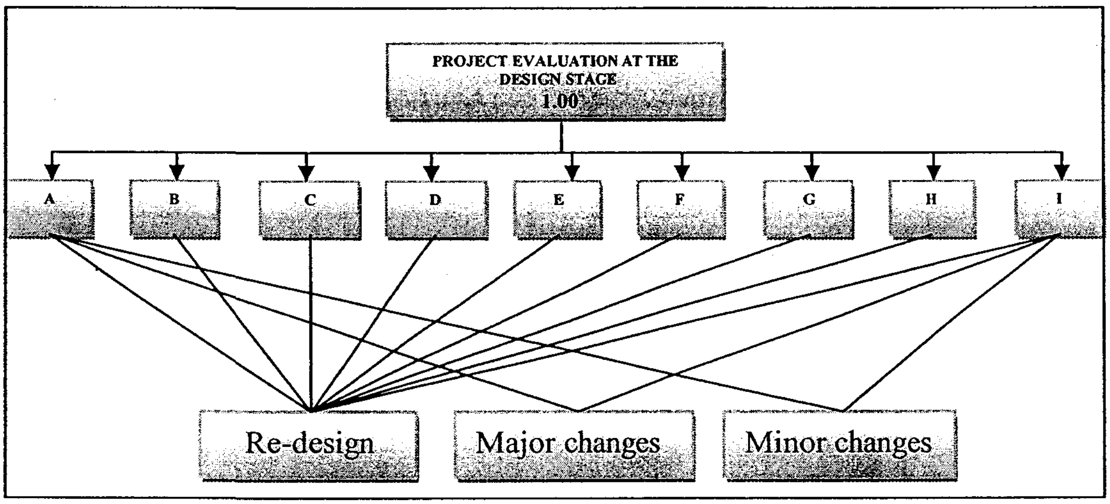


Figure 3.8 Hierarchy Structure for choosing best action

2) Pairwise comparisons are performed between the alternatives with respect to each indicator. The design manager and the project manager of project compare the three alternatives with respect to each indicator.

3) Based on the pair comparison matrices, the weight of each alternative with respect to each indicator is calculated. The total weight of each alternative is calculated using the following equation:

$$\sum_{1}^{9} Aw \times Iw \tag{5}$$

Where:

Aw = Alternative weight

Iw = Indicator parent weight

Parent weight is the average weight of each main indicator.

3.5 THE DESIGN KPIs LEVELS

The main objective of the present research is to identify appropriate performance indicators that can measure performance of design process at company and project levels. Overall design performance indicators reflect company level indicators. Project level indicators assist in predicting, monitoring, and improving the performance of the project. Both company and project level indicators need to address the company`s objectives. This means that design performance indicators should be integrated into the company`s goals and cannot be defined in isolation. Figure 3.9 describes how design KPIs should fit in with the company's main objectives.

According to the guideline of the KPI Working Group in 2000, there are three levels of KPIs: 1) Headline indicators that represent the overall performance of the firm; 2) Operational indicators that provide a measurement of the specific aspect or area of the firm's activities; 3) Diagnostic indicators that provide information about why certain changes have occurred in the headline or operational KPIs. Following this sequence, the present model has presented the three levels. Where the firm's level indicators are the headline indicators, the design-phase indicators are the operational indicators, and the design sub-phases are the diagnostic indicators.

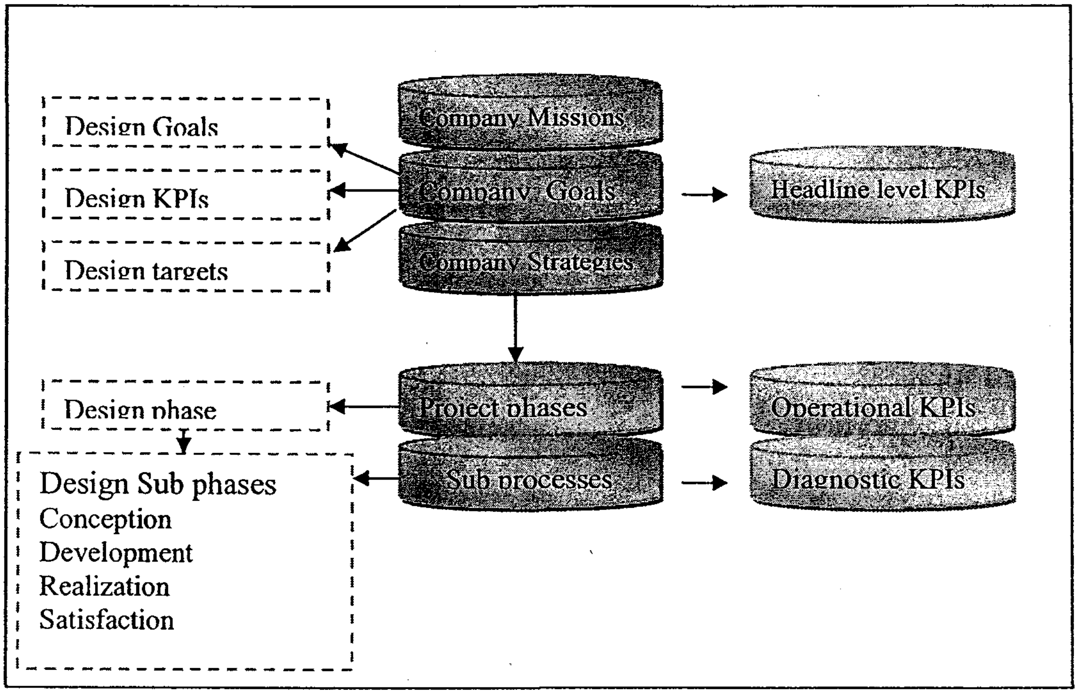


Figure 3.9 Integration of Design Performance Indicators into Company Objectives

3.5.1 Company Level Design Indicators (Headline Level)

One way to derive design indicators at the company level is to identify a particular company's goals and translate these into measurable design targets (Trobett et al, 2001). For example, one of the overall goals of a company may be to become one of the top five industry leaders in new projects. This goal can be translated into design objectives. In other words, what has to be done in the design area in order to help reach that specific business goal? Suppose, for example, one of the design objectives is to increase the share of a radical design (a totally new concept designed from scratch) in the project portfolio from 25% to 50% in 3 years. This would enable the firm to establish appropriate design measurable targets. Examples of measurable targets would be the following: to increase the number of design awards per annum from 1 to 3 and/or increase the ratio of radical to normal designs from 25% to 50 % in 5 years. As a result, company level indicators will widely vary from one company to another. The present research concentrates only on the most commonly used indicators. The determinations of these indicators are based on the survey results. They include the profitability of design, the design process, the efficiency of the design, the learning and innovation needs of the client, etc. Some of them can be achieved through measuring design level indicators, which will be explained in the following section.

3.5.2 Design Level Indicators (Operational Level)

Many Indicators can be used to measure the design performance of construction projects. The Indicators used in the present model were compiled from the literature, including previous research by the CII (1986, 1987) and CIRIA (2001). The indicators considered in the present model were classified according to three groups, based on their functions. The three groups of indicators are Project variables, Design process indicators (leading indicators), and outcome indicators (lagging indicators), see Figure 3.10.

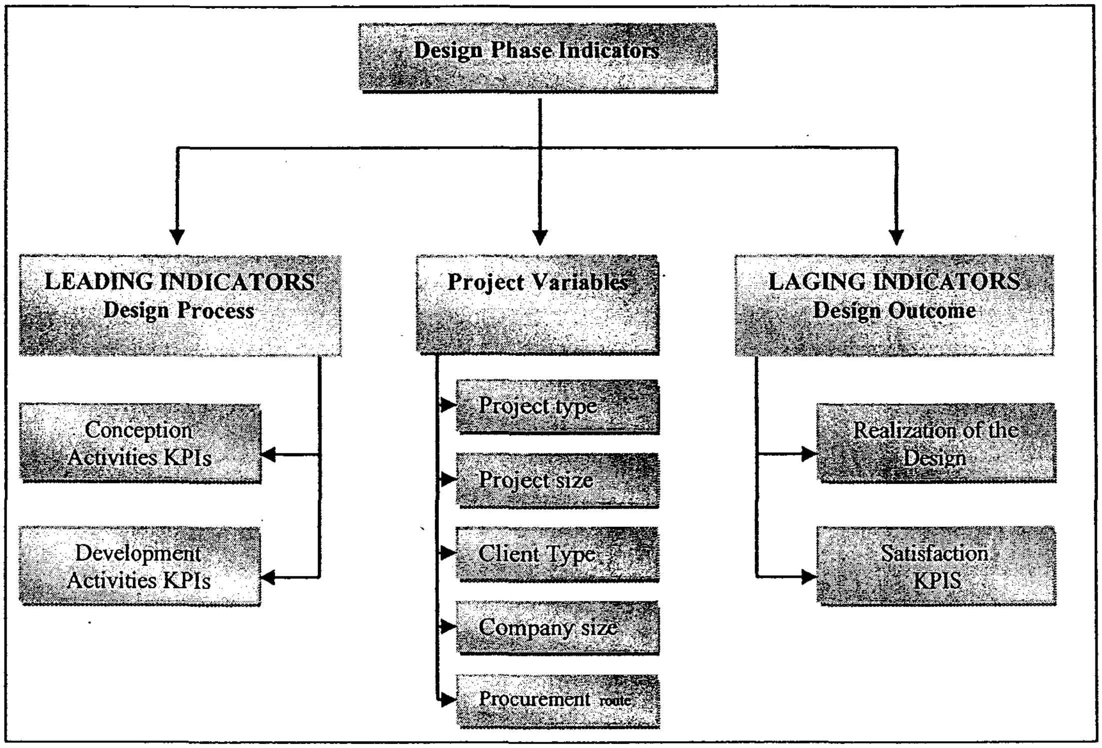


Figure 3.10 the Proposed Design Indicators' Main Groups

1. Project Variables (Diagnostic level)

Project variables, as shown in Figure 3.11, were used to classify design projects into similar groups. These variables are project type, project size, client type, procurement route, and company size. These variables are qualitative in nature.

a) Project types are classified as commercial construction (for example factories and high-rise buildings), civil construction (such as roads and bridges), heavy construction (for example petrochemical), and domestic housing.

b) Project size is categorized according to the general projects value of the firm. A general project value up to $100 million is considered small; up to $300 million is considered average, and more than $300 million is considered large.

c) Client types are divided into governmental and private.

d) Company sizes are ranged from small to large.

e) Procurement route criteria are traditional, design built, construction or project management, partnering, Public Private Partnership (PPP), and others if indicated.

2. Design Process KPIs – Leading Indicators

Leading indicators can perform the following tasks:

- **a)** They can predict future performance of the activity being measured.
- **b)** They can indicate problems that need corrective action for future activities.
- **c)** They can enable future decisions.

It is important to understand where in the design stage indicative measures may occur. Leading indicators can occur any time during the design process. The design process according to the CIRIA design model and PWC consists of conception activities and development activities.

- Conception activities: PWC defined the conception activities and their relationships in more detail (refer to Figure 2.9 and Table 3.2).

- Development activities, according to PWC, start from develop design and end with expedite approvals (refer to Figure 2.9 and Table 3.3).

Measuring the performance of the outcome of these activities helps to determine how effectively the design parameters have been set. Indicators that measure the effectiveness of these activities are related to the value of the design product. Each indicator is variable (they can vary from project to project in a fixed context). All these indicators can be known before the construction begins.

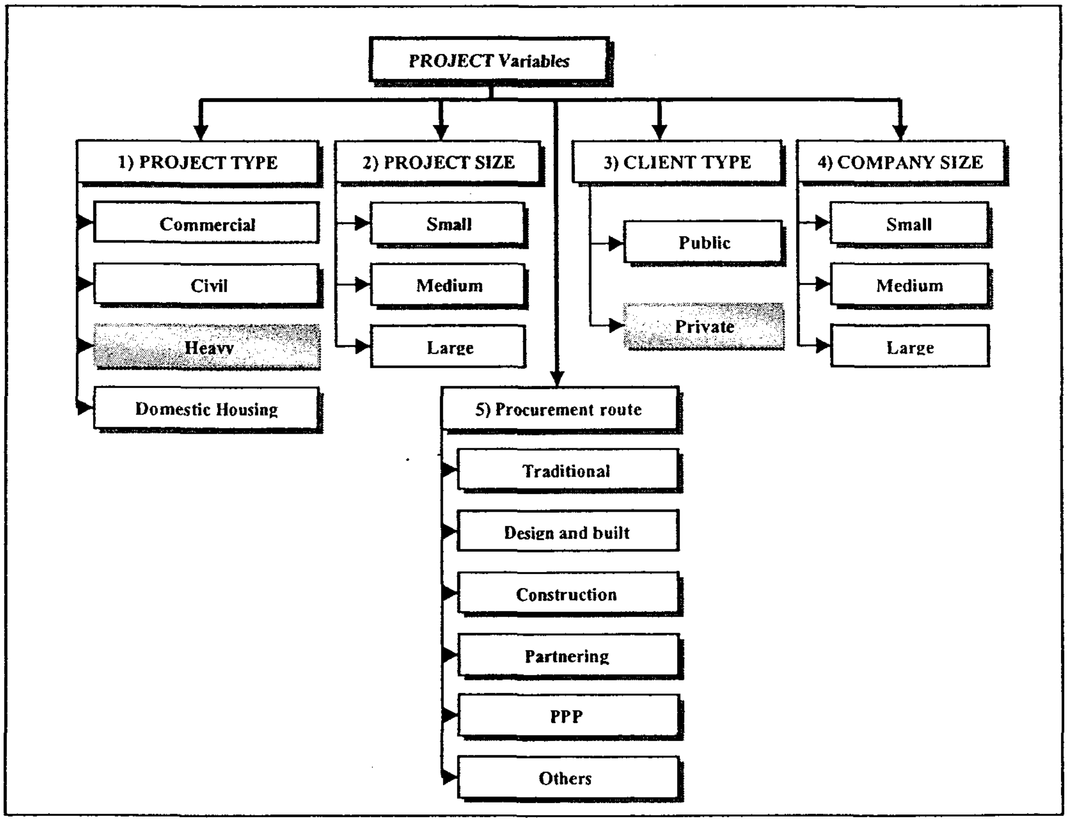


Figure 3.11 Project Variables Impact the Project

Table 3.2 Conception Activities Need to Be Measured

No.	Activity Discription	Activity Objectives	Responsibility
1	Organize for the Design Stage Management	To plan for the management of design	Project Manager
2	Commission Design Indicator	To identify& engage the design team	Project Mnager
3	Brief the design Team Indicator C	To communicate to the design team all pertinent project informantion	Project Manager
4	Manintain Liaison with Client Indicator	To facilitate 2 way communication between the client & the project team	Project Manager
5	Continue Implementation of External Relations program Indicator	To continue communication & interaction with institutions & gorups having an interest in the project & capable of affecting its outcome	Project Manager
6	Obtain External Regolatory Approvals	To ensure that the reqirements of all regularities bodies are identified & approval obtainaed in time to meet project schedule	Project Manager assisted by Design Manager
7	Administer Contracts Indicator	To ensure that design activities under contract are conducted withing time & cost constrains and in accordance with adminstrative procedure	Project Manger
8	Develop Concept proposal Indicator	To analyse projectrequirements, synthesize these into major objectives, and postulate design solution in principle	Design Manager
9	Assess Compliance with Content Plan	To assess if the concept proposal has the potential to lead to a design meeting the criteria in the content plan	Design Manager
10	Assess Compliance with Time Plan Indicator	To assess whether the concept proposal represents a solution which can be impemented within the time plan	Scheduler
11	Assess Compliance with Cost Plan Indicator	To assess whether the concept proposal represents a solution which can be impemented within the cost plan	Cost Planner, Assissted by Property Manager & Energy analyst
12	Intiate Modifications to Concept Proposal Indicator B	To obtain a concept proposal which meets the project brief criteria	Design Manager
13	Modify Project Brief Indicator	To ensue that the project brief remains a current planning and control document by inclusion of any approved changes	Project Manger
14	Present Proposal for Departmental Approval	To provide the departemental; approving authority with relevant details of the concept proposal for review and approval, and to expedit approval	Project Manger

Table 3. 3 Development Activities Need to Be Measured

No.	Activity Discription	Activity Objectives	Responsibility
1	Develop Design Indicator	To develop a concept design in detail sufficient for commencement of detail working doucment	Design Manager
2	Update Implementation Strategy Indicator	To insure that the implementation strategy established in previous stages & articulated in the project brief is suitabley updated to refect any new developments & new knowledge gathered since the issuance of the project brief	Project Manager
3	Evaluate Compliance with Energy Use Plan	To prepare the design energy budget & evaluate its compliance with the planning energy budget in the project brief	Energy Analyst
4	Evaluate Compliance with Operating Cost Plan Indicator	To determine whether the design will result in a facility whose operating & maintenance $ shall be within the operating $ plan of the project brief	Property Manager
5	Evaluate Compliance with Capital Cost Plan Indicator	To determine whether the design can be implemented the capital $ plan of the project brief	Cost Planner
6	Evaluate Compliance with Content Plan	To ensure that the design complies with content plan of the project brief	Design Manager
7	Evaluate Compliance with Time Plan Indicator	To determine whether the design can be implemented with in the time plan	Scheduler
8	Intiate Design Modification Indicator	To obtain a design which meets the project brief criteria	Design Manager
9	Document Design Solution Indicator	To document the design solution in a form required for the necessary approvals & for commencement of the construction stage	Project Manager
10	Expediate Approvals	To obtain all necessary approvals permitting the project to move into the construcution stage	Project Manager

3. Design Outcome KPIs – Lagging Indicators

Lagging indicators are used to measure the accuracy of a design. They can only be known once construction is complete, at which point all design outcome information becomes known. The Lagging measures of design performance that are integrated in the present model are time, cost, quality constructability, and client satisfaction. Lagging measures can perform the following tasks:

a) They can be used to assess completed performance results,

b) They alert the results of associated performance, and

c) They can be used only for historic review.

3. 6SUMMARY

This chapter presented the basic components of the developed model. In an Access environment, the database was created to store and retrieve design indicators information. A Macro was employed to evaluate and generate reports on the design performance indicators. In an Excel environment, the standard AHP procedures were performed in order to assign weight to each indicator. The method of the standard AHP that was used was explained. Two levels of design KPIs were determined, the Company or headline level were varied from one company to another; however the most commonly used ones were determined. The design or operational level was divided into two parts: design process (leading indicators) and outcome (lagging indicators). Project variables were used to classify the design projects. A brief description of the survey is also presented and the identification of key performance indicators was covered through a survey. The survey design and analysis are presented in the next Chapter.

CHAPTER 4: SURVEY DESIGN AND ANALYSIS

4.1 INTRODUCTION

Surveys are one of the most cost-effective ways of dealing with a large number of samples in order to achieve better results (Takim et al, 2004).The purpose of the survey presented in the present research is to identify the key performance indicators for the design stage of a project at both the company and the project levels. The survey was distributed to professionals in the Canadian design and construction companies. Four divisions of the construction industry (Commercial, Civil, Heavy, and domestic housing) were targeted by the present research with the intention of determining whether there are any differences between the divisions so far as the ranking of the key design performance indicators are concerned. Any differences in the ranking of the importance of these indicators are investigated at both the company and the project levels.

A web-based survey consisting of a brief introduction and two main parts was carried out. Lists of design indicators were placed on the survey. The companies were asked to rank the importance of each indicator. Four professional groups (clients, design companies, construction companies, and sponsors) were targeted. The survey was pre-tested with three local design and construction companies. Based on the pre-test feedback, constructing the survey was finalized and was sent to the construction industry professionals. The returned data were analyzed using the SPSS 16.0 statistical package.

The present chapter explains in detail the design of the survey, the data analysis and the results of the survey.

4.2 SURVEY QUESTIONNAIRE DESIGN

A web-based survey was conducted. The survey titled "Design Performance Indicators Survey" can be found in Appendix A. The survey includes the questions that are necessary to elicit opinions on the importance of design performance indicators and to rank these indicators. The survey consists of the following three parts:

1- The instruction part consists of the following two sections:
"Introduction" is used to give a brief summary of the purpose of the survey. A section entitled "General Information" was used to obtain demographic data on the groups being surveyed. Included in this section are the company name and location (optional), the respondent's title, and the respondent's number of years of experience working in the industry. This section is used to group the surveys according to the groups contacted (client, design organization, construction organization, contractor, sponsors, and other group if indicated).

2- The project variables part was used to classify the design projects into similar groups. Part one consists of five questions pertaining to the project variables. The survey asks for items such as the type of project, the value of the project, the company size, and the procurement route.

3- The design performance indicators part consists of four questions. The first question involves a list of eight design performance indicators, which should be ranked according to the company objectives. These indicators represent company level indicators. The function of this question is to determine the significance of each design performance indicator. The participants were asked to use a scale from 1 to10 in order to gather the significance of each item from the respondents. In the ranking, 1 is for not important, and 10 is for extremely important. The second and third questions solicit information about the stage at which companies normally collect performance data and about how these companies benchmark their own work by comparing their design performance to that of other companies in the same sector.

The fourth question is to determine the project level indicators, and to specify the design sub stage at which they are collected. The participants were asked to score the indicator and to pick the design stage at which the indicator is ideally collected. It is a multiple-choice question. It consists of a list of nine groups of design performance indicators. Each group consists of a number of sub-indicators. These Indicators are of two types, leading and lagging indicators. Both were included and mixed with no differentiation between them in order to allow the respondents to determine, without any biases, their level of importance. The scale used to rank the indicators is from 1 to10, where 1 is for not important and 10 is for extreme important.

4.3 DATA COLLECTION

Data used in this work were collected through the survey and were derived based on the literature, this literature including CII 1986, CIRIA 2001, and Torbett 2001. Based on the mentioned literature, the lists of the most significant design indicators were produced so that the respondents could rank their level of importance to the Canadian construction industry. The survey covered both company-level design indicators and project-level design indicators. The data collection exercise was limited to Canada. The link to the survey was sent to the targeted professionals in the construction industry.

4.3.1 Administration of the Survey

The list of targeted respondents was obtained from several sources, i.e., e-source Canada, Design and Construction companies' websites, and organizations that are members of the Association of Consulting Engineers of Canada. About 1,000 individuals were listed from these sources. The response rate of the survey was significantly lower than expected. For this reason, a total of approximately 30 engineers, senior managers, and vice presidents working in the construction industry were met in person and asked to participate in the survey. Others were contacted by phone and email. To increase the response rate, the promise was given that a copy of the respondent inputs would be sent back to each participant after the survey was completed. To encourage the participants to pass the survey on to other possible participants, the promise was given that a copy of the analysis, when finished, would be sent to them. The survey was administered through the web-survey. The responses were tracked and received on Excel in two forms: tables and lists.

4.3.2 Summary of Data

Data was received from all the respondents in a table in an Excel file format. The data was then organized and imported into SPSS 16 software to perform the necessary statistical analysis. A total of 34 responses were received. Thirty three of the respondents were from Montreal and only 1 response was from Toronto. The following groups were contacted: design organizations, construction organizations, contractors, clients, and sponsors. More than 60% of the responses were from design organizations. Figure 4.1 shows the respondents' years of experiences in the construction industry. On an average, the respondents had about 20 years of experience. The maximum was 40 years of experience. 84% of the respondents had at least 10 years of experience in the construction industry. Around 38% of the responses were from managers. Designers and engineers constituted about 62% as shown in Figure 4.2. The summary of the respondents' feedback for the survey is given in Appendix (B).

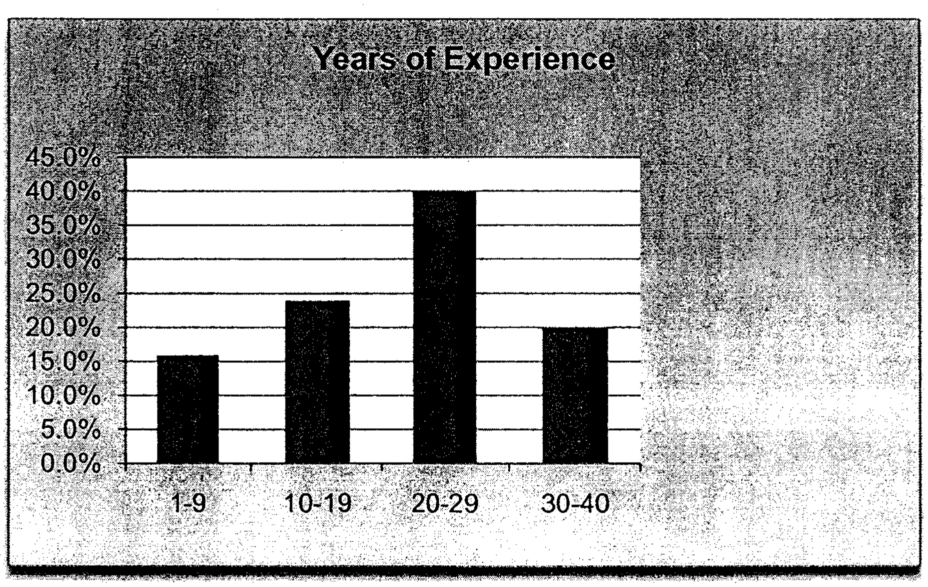


Figure 4. 1 Survey Respondents' Years of Experiences on the Construction Industry

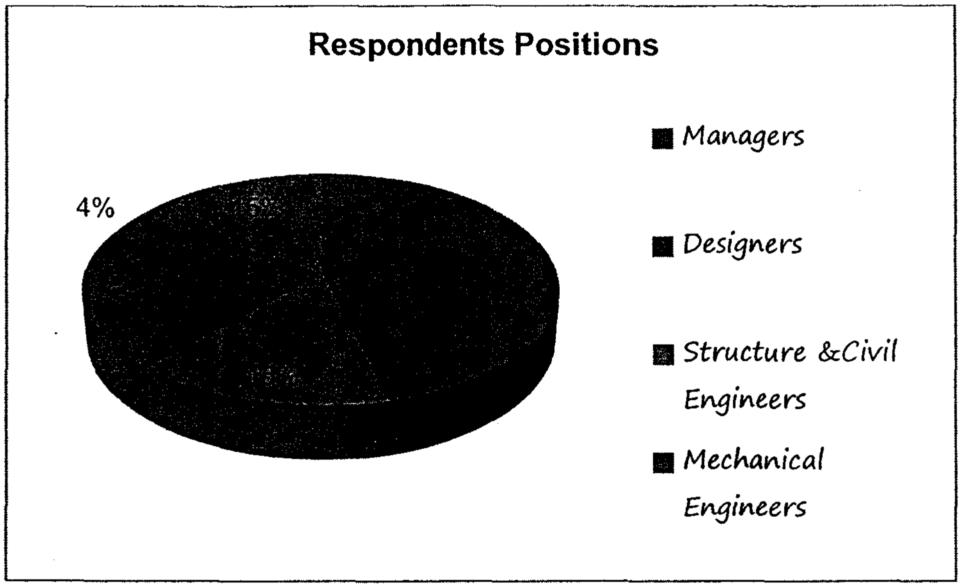


Figure 4.2 Percentage of Respondents by Professions

Of the total respondents, 45% of the companies conduct heavy construction only. About 18% perform commercial, civil, and heavy projects. 15.2% carry out civil and heavy construction projects. The same percentage was involved in commercial constructions, as is given in Figure 4.3.

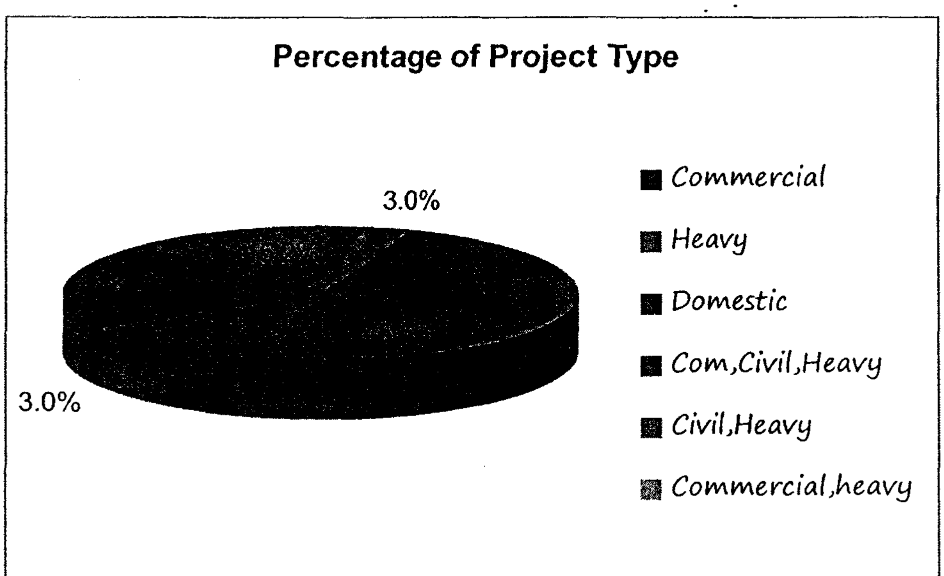


Figure 4.3 Percentage of Project types on the construction Industry

In general, about 55% of the responses use more than one route to procure their construction projects. For companies using one type of procurement route, about 30% use design/built, 3% use a traditional procurement route, and 9% use a partnering procurement route. Figure 4.4 presents, as percentages, the different procurement routes that the respondents use.

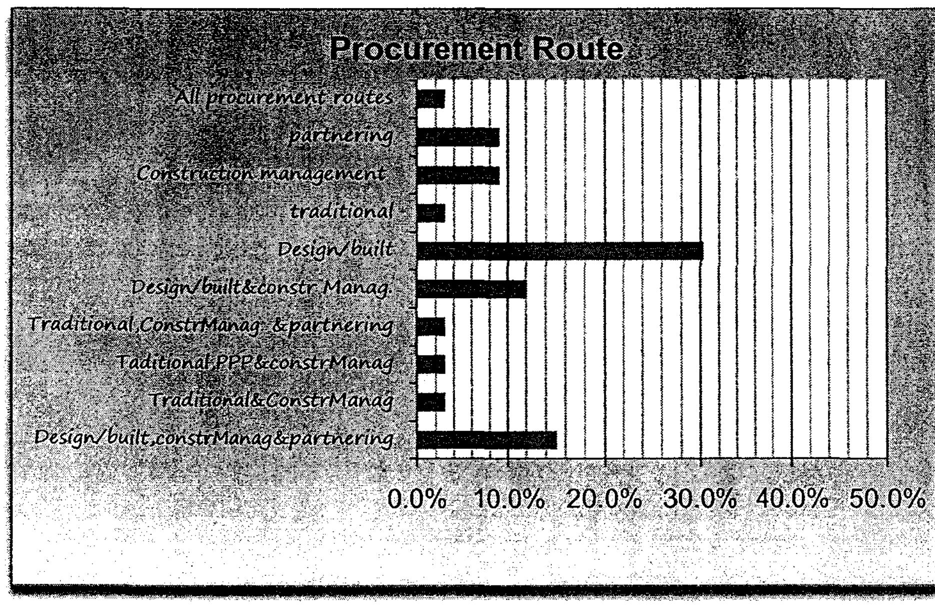


Figure 4.4 Respondents' procurement route on the construction industry

Respondents were asked to indicate the general values of their projects. Of the 34 responses, 94% of them were carrying out projects worth more than $300 million. 88% of those were big companies, and about 9% were small companies, and the value of their projects was around $100 million.

Opinions about which design indicators should be aligned to the strategy or objectives of a company were collected and ranked according to their importance. The overall frequencies of the responses were ranked using applied by sorting the indicators according to their frequencies. The indicator that was most frequently raised was ranked as the top, followed by the second most frequently raised indicator, and so forth. The results are given in Table 4.1 and Figure 4.5.

Table 4. 1 Ranking of Design Indicators

	Design Indicators	Frequency %			**Rank**
		Very Important	**Important**	**Not Important**	
A	Learning & Innovations	36.4	63.6	0	7
B	Efficiency of Design	69.7	21.2	9.1	2
C	Client need & Satisfaction	87.9	12.1	0	1
D	Internal Design Process	43.8	56.2	0	6
E	External Design Process	48.5	48.5	3	4
F	Design Time & Cost Management	51.5	48.5	0	3
G	Re-use of Design Experience	30.3	69.7	0	8
H	Risk	45.5	51.5	3	5

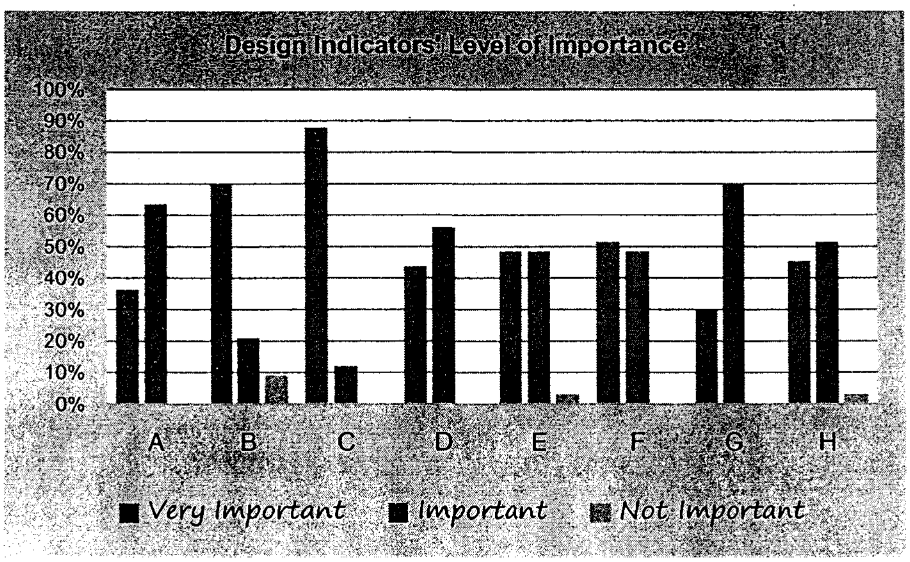


Figure 4. 5 Design Performance Indicators' Level of Importance

The eight indicators for design are ranked and listed in Table 4.1. Respondents indicated that the client's needs and satisfaction was the most important indicator, as it constitutes about 88% of the total responses. The efficiency of the design represented 69.7% of the total responses. As a result, it represents the second most important indicator for the design stage of construction projects. Design Time & Cost Management are ranked the third most important as an indicator for design. Re-use of design experiences is the least important factor.

Respondents were asked at which stage of a project design performance data is collected. Respondents revealed a wide variety of mechanisms. As presented in Figure 4.6, more than 60% of the respondents tended to collect information about the design performance at the first stage of their projects (project brief, preliminary sketch, final sketch, and detailed design), 45% of the respondents collect design performance data during the detailed design stage, as shown in Figure 4.7. The remaining 39.4% of the respondents collect the data during the sub-design stages and during most of all the other project stages (construction, commissioning, and hand over). See Figure 4.8.

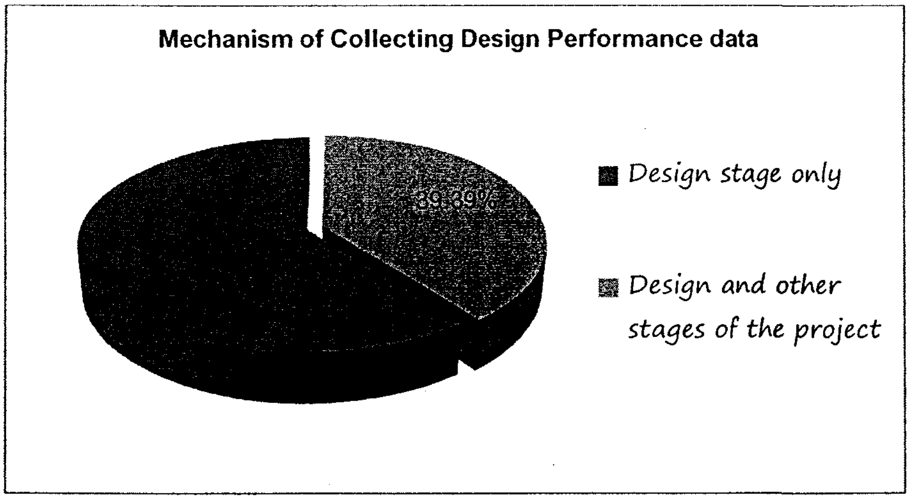


Figure 4. 6 Overall Respondents' Rate about Project Stages where Design Data is collected

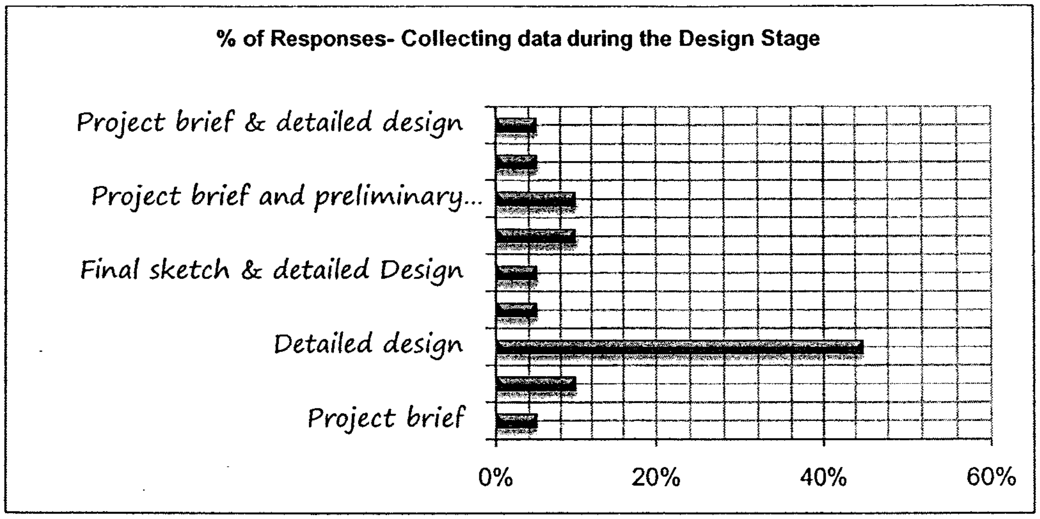


Figure 4. 7 Respondents Rate -which design sub stage data is better collected

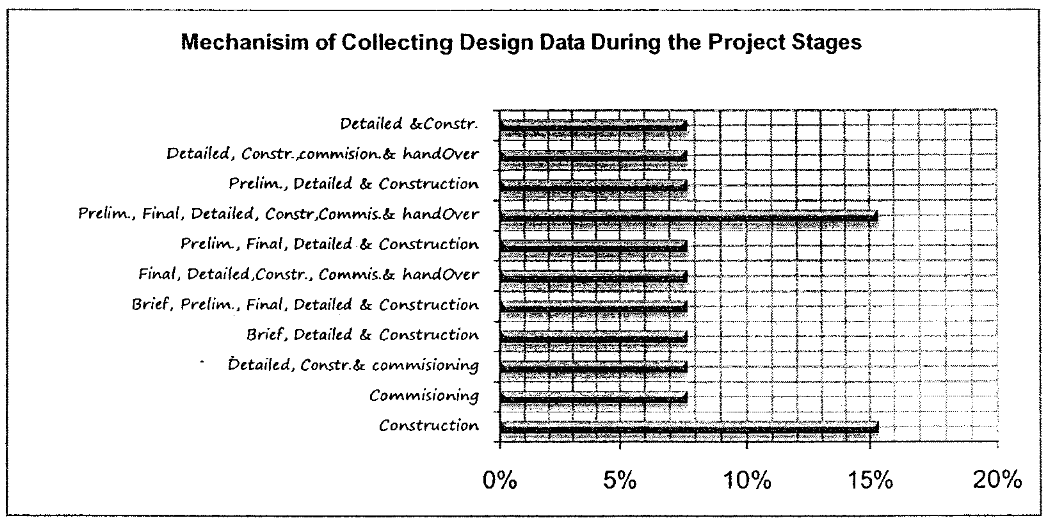


Figure 4. 8 Respondents Rate -which project stage data is better collected

4.4 DATA ANALYSIS

The collected data was analyzed using the SPSS 16.0 statistical package to determine the main set of indicators for measuring the performance of the design activities. On this survey, the respondents' observations in the second part of the questionnaire were measured using a ten point scale where 1 to 10 represented not important to extreme important respectively. The following measurements of the statistics were undertaken:

1- Reliability analysis to estimate the reliability of test scores
2- T-test analysis to check whether the population would consider the design indicators and their associated groups to be significant
3- ANOVA analysis to compare samples in terms of respondents' years of experience, project types, organization type, and procurement routes.

1- Reliability analysis

Cronbach's alpha is the most widely used measure of reliability (Sun, Wei et al 2007). Cronbach's alpha (α) is an index used to estimate the reliability of a scale containing several items.The closer alpha (α) is to 1.00, the greater the internal consistency of the items in the instrument being assessed; (α) will generally increase when the correlations between the items increase. The lower acceptable limits of (α) .50-.60 were suggested by Kaplan and Saccuzzo (1993).

The reliability of the ten-point scale used in this study was determined by using Cronbach's coefficient alpha. The main purpose is to test whether the measurement scales that have been constructed are reliable (i.e. do they actually measure what they are trying to measure?). Factors (sub-indicators) under each indicator group should be highly correlated to attest to the higher internal consistency of the test. Cronbach's alpha will generally increase when the correlations between the items under each variable increase. The results of the reliability analysis are shown in Table 4.2. The table describes the reliability of the variables with their contents of items. Variable "D" (Design quality) has the lowest reliability rate (0.5). Variables "E" and "H" (Design time and cost management, and risk respectively) record the highest reliability rate (0.91). The results ranged between 0.53 - 0.91. Since they are above 0.5, the scale can be considered reliable with the sample.

Table 4. 2 Reliability of the Measurement Scale

Variable	Reliability (α)	Inter-Item Correlation Matrix							
		Indicator A	A1	A2	A3	A4	A5	A6	A7
		A1	1.000	.102	.391	.162	.123	-.029	.382
A		A2	.102	1.000	.389	.385	.314	.068	.212
Understanding Client Needs	0.68	A3	.391	.389	1.000	.383	.132	.314	.430
		A4	.162	.385	.383	1.000	.174	.078	.218
		A5	.123	.314	.132	.174	1.000	.087	.377
		A6	-.029	.068	.314	.078	.087	1.000	.278
		A7	.382	.212	.430	.218	.377	.278	1.000
		Indicator B	B1	B2	B3	B4	B5	B6	
		B1	1.000	.091	.496	.249	.250	.443	
B		B2	.091	1.000	.057	.555	.114	.377	
Design Process	0.79	B3	.496	.057	1.000	.338	.472	.609	
		B4	.249	.555	.338	1.000	.463	.567	
		B5	.250	.114	.472	.463	1.000	.788	
		B6	.443	.377	.609	.567	.788	1.000	
		Indicator C	C1	C2	C3	C4	C5		
		C1	1.000	.355	-.003	.094	.660		
C		C2	.355	1.000	.384	.478	.481		
Integration of design with	0.7	C3	-.003	.384	1.000	.227	-.005		
supply chain		C4	.094	.478	.227	1.000	.462		
		C5	.660	.481	-.005	.462	1.000		
		Indicator D	D1	D2	D3	D4			
		D1	1.000	-.147	.097	.230			
D		D2	-.147	1.000	.390	.283			
Design quality	0.53	D3	.097	.390	1.000	.447			
		D4	.230	.283	.447	1.000			
		Indicator E	E1	E2	E3	E4	E5	E6	
		E1	1.000	.721	.432	.406	.361	.360	
E		E2	.721	1.000	.523	.581	.595	.499	
Cost & Time Management	0.91	E3	.432	.523	1.000	.794	.756	.891	
		E4	.406	.581	.794	1.000	.733	.903	
		E5	.361	.595	.756	.733	1.000	.748	
		E6	.360	.499	.891	.903	.748	1.000	

Table 4.1 Reliability of the Measurement Scale (continued)

Variable	Reliability (α)		Inter-Item Correlation Matrix					
		Indicator F	F1	F2	F3	F4	F5	F6
		F1	1.000	.698	.701	.661	.640	.717
F		F2	.698	1.000	.611	.755	.567	.624
Risk	0.91	F3	.701	.611	1.000	.578	.581	.350
		F4	.661	.755	.578	1.000	.418	.525
		F5	.640	.567	.581	.418	1.000	.661
		F6	.717	.624	.350	.525	.661	1.000
		Indicator G	G1	G2	G3	G4	G5	G6
		G1	1.000	.602	.464	.403	.455	.160
G		G2	.602	1.000	.674	.215	.141	-.137
Re –use of Design	0.79	G3	.464	.674	1.000	.440	.374	.102
Experiences		G4	.403	.215	.440	1.000	.707	.449
		G5	.455	.141	.374	.707	1.000	.656
		G6	.160	-.137	.102	.449	.656	1.000
		Indicator H	H1	H2	H3	H4	H5	H6
		H1	1.000	.690	.624	.502	.549	.453
H Innovations		H2	.690	1.000	.775	.662	.273	.339
	0.86	H3	.624	.775	1.000	.616	.159	.411
		H4	.502	.662	.616	1.000	.574	.452
		H5	.549	.273	.159	.574	1.000	.388
		H6	.453	.339	.411	.452	.388	1.000
		Indicator I	I1	I2	I3	I4	I5	I6
		I1	1.000	.561	.465	.286	.120	0.306
I Client Satisfaction		I2	.561	1.000	.758	.752	.444	.513
	0.85	I3	.465	.758	1.000	.385	.231	.182
		I4	.286	.752	.385	1.000	.705	.800
		I5	.120	.444	.231	.705	1.000	.832
		I6	.306	.513	.182	.800	.832	1.000

2. t- test

The t- test is used to estimate and test a population mean when the population variance is not known. In this study, the t-test is employed in order to check whether the population would consider design indicators and their associated groups to be significant. The decision rule was to reject the null hypothesis when the calculation of the observed t value(t_o), Equation 1, was greater than the critical t value(t_c), Equation 2, as shown in Equation 3.

$$t_o = \frac{\bar{x}-\mu}{S/\sqrt{n}} \tag{1}$$

$$t_c = t_{(n-1,\propto)} \tag{2}$$

$$t_0 > t_c \tag{3}$$

Where:

$t_o = t - \text{statistic (observed t value)}$

$\bar{x} = \textit{the sample mean}$

$\mu = \textit{the critical rating specified by the null hypothesis}$

$S = \textit{the sample standard deviation}$

$n = \textit{sample size}$

$n - 1 = \textit{degree of freedom}$

$\propto = \textit{the significant level}$

$(\textit{set at } .05 \textit{ following the conventional risk level})$

In this research the value of μ is fixed at '4' because, by definition, ratings above 4 represent "important" the attributes according to the scale. If the observed t value(t_o) of the mean ratings by the respondents' is greater than the critical value(t_c), $t_{(34-1,.05)}$=1.697 at 95% confidence level, then the null hypothesis(H_o) which states attributes below (4) only were rejected and the alternative hypothesis accepted. The conclusion is then drawn that the attributes were significant. The nine groups of variables were considered to be important indicators and have a great impact on measuring the design stage performance.

3- Comparison of Samples

Analysis of variance (ANOVA) is generally used for comparing sample means to infer that the means of the sample distributions differ significantly from each other if there are three or more samples (George and Mallery 2007). The ANOVA analysis is used in this research to compare independent samples in terms of respondents' project types, years of experiences, company sizes, and procurement routes. The LSD (Least Significant Difference) method in hoc multiple comparisons is used for this analysis.

It is simply a series of t tests. Once differences exist among the means, post hoc range tests and pair wise multiple comparisons can determine which means differ. The significance indicates the probability of the observed value happening by chance, so the means differ significantly at the $p<.05$ level if this index is less than .05.

4.5 THE RESULTS AND FINDINGS

4.5.1 The significance of the variables and attributes of design KPIs

4.5.1.1 Indicators Confidence Levels

Respondents were asked to rank the design KPIs. They were also asked to add new indicator/s if necessary. The T test was performed using the SPSS 16 package to check the confidence level, (i.e. to check whether $t_0 > t_c$, where t_c is 1.697). The results are shown in Table 4.2. The df column displays the degrees of freedom. In this case, the value in the df column equals the number of cases under each sub-indicator minus 1. The Mean Difference is obtained by subtracting the test value (the critical rating = 4) from each sample mean. The 95% confidence interval of the difference provides an estimate of the boundaries between which the true mean difference in 95% of all possible 34 responses. Since the confidence intervals for all of the variables and attributes lie entirely above 0,0, and the t_0 of all of the variables and attributes is greater than 1.697 as shown in Figure 4.9, we can safely say that all of the indicators and sub-indicators are significantly agreed with the values given by respondents. We can also conclude that the nine groups of the design KPIs with their attributes are considered to have an impact on the design stage performance of the construction projects.

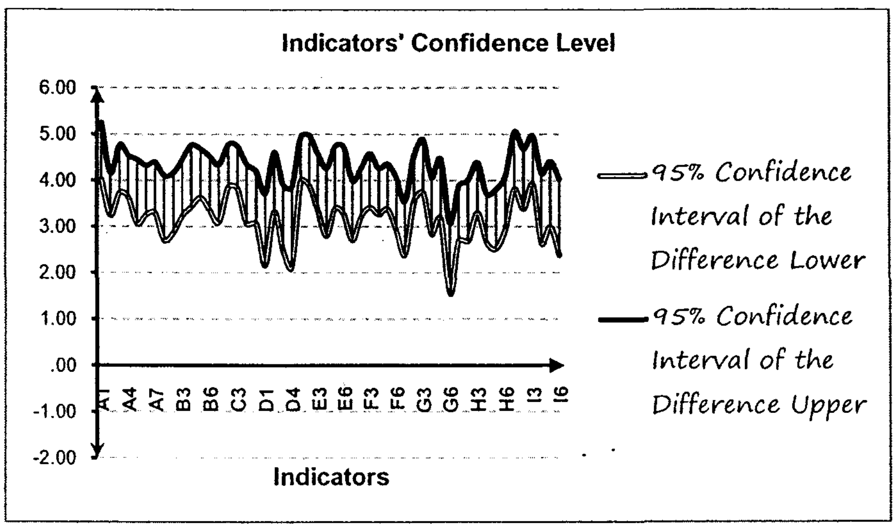


Figure 4. 9 Indicators Confidence Level

Table 4. 2 the Significance of the Variables and Attributes of Design KPIs

Indicators	N	Mean	Std. Deviation	Std. Error Mean	t-value	df	Mean Difference	95% Confidence Interval of the Difference	
								Lower	**Upper**
A1	33	8.64	1.729	.301	15.406	32	4.636	4.02	5.25
A2	33	7.70	1.287	.224	16.507	32	3.697	3.24	4.15
A3	32	8.25	1.437	.254	16.732	31	4.250	3.73	4.77
A4	33	8.09	1.284	.223	18.308	32	4.091	3.64	4.55
A5	33	7.76	1.953	.340	11.052	32	3.758	3.07	4.45
A6	33	7.79	1.495	.260	14.556	32	3.788	3.26	4.32
A7	32	7.84	1.526	.270	14.246	31	3.844	3.29	4.39
B1	32	7.41	1.932	.342	9.973	31	3.406	2.71	4.10
B2	31	7.52	1.768	.317	11.075	30	3.516	2.87	4.16
B3	32	7.84	1.706	.302	12.746	31	3.844	3.23	4.46
B4	32	8.09	1.855	.328	12.481	31	4.094	3.42	4.76
B5	32	8.16	1.462	.258	16.087	31	4.156	3.63	4.68
B6	32	7.94	1.625	.287	13.706	31	3.938	3.35	4.52
C1	32	7.72	1.727	.305	12.180	31	3.719	3.10	4.34
C2	32	8.31	1.281	.226	19.043	31	4.313	3.85	4.77
C3	32	8.28	1.276	.226	18.981	31	4.281	3.82	4.74
C4	31	7.71	1.755	.315	11.770	30	3.710	3.07	4.35
C5	32	7.63	1.561	.276	13.140	31	3.625	3.06	4.19
D1	32	6.94	2.169	.383	7.660	31	2.938	2.16	3.72
D2	32	7.97	1.787	.316	12.565	31	3.969	3.32	4.61
D3	31	7.19	1.939	.348	9.168	30	3.194	2.48	3.90
D4	32	7.00	2.396	.424	7.082	31	3.000	2.14	3.86
E1	30	8.47	1.279	.234	19.123	29	4.467	3.99	4.94
E2	30	8.43	1.455	.266	16.693	29	4.433	3.89	4.98
E3	30	7.97	1.650	.301	13.166	29	3.967	3.35	4.58
E4	30	7.53	1.961	.358	9.871	29	3.533	2.80	4.27
E5	30	8.07	1.799	.328	12.381	29	4.067	3.39	4.74
E6	30	8.00	1.948	.356	11.249	29	4.000	3.27	4.73
F1	31	7.35	1.762	.316	10.603	30	3.355	2.71	4.00
F2	31	7.74	1.437	.258	14.500	30	3.742	3.21	4.27
F3	31	8.00	1.592	.286	13.992	30	4.000	3.42	4.58
F4	30	7.77	1.331	.243	15.502	29	3.767	3.27	4.26
F5	30	7.87	1.306	.238	16.216	29	3.867	3.38	4.35
F6	31	7.48	1.568	.282	12.372	30	3.484	2.91	4.06
G1	31	6.97	1.581	.284	10.453	30	2.968	2.39	3.55
G2	32	8.03	1.379	.244	16.534	31	4.031	3.53	4.53
G3	32	8.31	1.575	.278	15.491	31	4.313	3.74	4.88
G4	31	7.45	1.670	.300	11.507	30	3.452	2.84	4.06
G5	32	7.81	1.786	.316	12.076	31	3.813	3.17	4.46
G6	32	6.31	2.132	.377	6.136	31	2.313	1.54	3.08
H1	32	7.28	1.631	.288	11.380	31	3.281	2.69	3.87
H2	32	7.34	1.825	.323	10.366	31	3.344	2.69	4.00
H3	32	7.84	1.505	.266	14.447	31	3.844	3.30	4.39
H4	32	7.19	1.447	.256	12.464	31	3.188	2.67	3.71
H5	31	7.16	1.753	.315	10.041	30	3.161	2.52	3.80
H6	32	7.53	1.606	.284	12.437	31	3.531	2.95	4.11
I1	30	8.43	1.654	.302	14.678	29	4.433	3.82	5.05
I2	30	8.03	1.732	.316	12.757	29	4.033	3.39	4.68
I3	30	8.43	1.406	.257	17.265	29	4.433	3.91	4.96
I4	30	7.40	2.027	.370	9.185	29	3.400	2.64	4.16
I5	30	7.70	1.896	.346	10.686	29	3.700	2.99	4.41
I6	30	7.20	2.203	.402	7.954	29	3.200	2.38	4.02

4.5.1.2 Ranking Design Performance Indicators and mechanism of collecting its data

Based on the results shown in table 4.2, each individual design KPI was ranked under its main group. The rankings of the attributes for all of their representative variables are listed on Table 4.3. However, Heavy and commercial construction participants ranked the indicators differently. The ranking of the indicators for heavy and commercial construction can be found in Appendix (C).

When ranking each design indicator respondents were asked to indicate when that indicator should be collected. Table 4.5 presents a list of indicators and the design sub phases, during which the data should be collected.

Table 4. 3 Ranking the Attributes of Design KPIs

Indicators	*Design Indicator Name*	*Rank*
A	**UNDERSTANDING CLIENT NEEDS**	
A1	Seeking client needs	**1**
A3	Alignment of project goals (Agreement on the priority and uncertainties of the project e.g. goals/risks, mission statement, budget constraints)	**2**
A4	Client project brief and client collaboration during the design process	**3**
A7	Whole life cost model integration (Design process contribution to the development of a whole life cost model for the project)	**4**
A6	Management of client expectation (the use of visualization methods to present the client with intelligible design options e.g. 3D virtual reality tools, project visits)	**5**
A5	End user collaboration	**6**
A2	Value management	**7**
B	**DESIGN PROCESS**	
B5	Formal documented and audited design process	**1**
B4	Routinely formal resource plan	**2**
B6	Establishment of Formal design program with all design team at the start of projects	**3**
B3	Establishment and use of Change control Management by all project stakeholders	**4**
B2	Designers active involvement in the implementation of health and safety procedures	**5**
B1	Designer involvement in the implementation of environmental management procedures appropriate to each project	**6**
C	**INTEGRATION OF DESIGN WITH SUPPLY CHAIN**	
C2	Integration of Design data exchange process (being used by all project stakeholders)	**1**
C3	The involvement of specialist design and construction expertise during the pre construction design process	**2**
C1	Grouping the design team in one location to promote the integration of project knowledge	**3**
C4	Benefit derived through design supply chain integration Shared between all parties including client	**4**
C5	Project benefits from firm's management and development of its relationships with key design suppliers to mutual business benefit	**5**
D	**DESIGN QUALITY**	
D2	Clarity and ease of plans & specifications	**1**
D3	No. of questions comes from contractor requesting clarification of plans & specifications	**2**
D4	Frequency of Architects and Engineers site visit to resolve problems	**3**
D1	Frequency of changes to the original plans & specifications regardless of the reason	**4**

Table 4.3 Ranking the Attributes of Design KPIs Continued

Indicators	Design Indicator Name	Rank
E	**COST and TIME MANAGEMENT**	
E1	Cost estimate of design	1
E2	Cost impact of design change	2
E5	Time impact of design change	3
E6	Time impact of design errors	4
E3	Cost impact of design errors	5
E4	Estimated time for design	6
F	**RISK**	
F3	Establishment of Formal design program with all design team at the start of projects	1
F5	Continues Monitoring and reviewing of Risk assessment undertaken	2
F4	Risk Mitigation plan	3
F2	The use of formal risk identification techniques	4
F6	Accuracy of risk	5
F1	Defining risk assessment process by the design team at the commencement of the project	6
G	**RE-USE OF DESIGN EXPERIENCES**	
G3	Design review and feedback (design reviews being held and recorded at key project milestone, and integrated with ongoing project activities)	1
G2	Availability and accessibility of standards details/ specifications and/or innovative solutions from previous projects to relevant design personnel	2
G5	Feed back of the result of the project completion reviews	3
G4	Project reviews at completion to identify factors might have affected successes or failure	4
G1	Benefit from the use of recycled design	5
G6	project publicity (publications, presentations, awards, citations etc)	6
H	**INNOVATION**	
H3	Construction method innovation	1
H6	New client inquiries based on the use of innovative solutions	2
H2	Process innovation	3
H1	Technological innovation	4
H4	Over all use of innovation on project	5
H5	Feedback of the innovative ideas used on the project to relevant design team personnel	6
I	**CLIENT SATISFACTION**	
I1	Client satisfaction with the finished construction product or service quality	1
I3	Client satisfaction with cost of the finished construction product or service delivered	1
I2	Client satisfaction with time of the finished construction product or service delivered	2
I5	Obtaining and documented project feedback from all clients on the design product (aim to improve the company performance)	3
I4	Obtaining and documenting project feedback from all clients on the design service (aim to improve the company performance)	4
I6	Obtaining and documenting project feedback from all end users on the design product (aim to improve the company performance)	5

Table 4.4 Design KPIs and Design Sub Stage Where Data Is Better Collected

	Indicator	N	Percentage	
			Conception %	Development %
A1	Seeking client needs	33	78.8	21.2
A2	Value management	33	45.5	54.5
A3	Alignment of project goals (Agreement on the priority and uncertainties of the project e.g. goals/risks, mission statement, budget constraints)	32	59.4	40.6
A4	Client project brief and client collaboration during the design process	32	54.5	45.5
A5	End user collaboration	33	57.6	42.4
A6	Management of client expectation (the use of visualization methods to present the client with intelligible design options e.g. 3D virtual reality tools, project visits)	33	36.4	63.6
A7	Whole life cost model integration (Design process contribution to the development of a whole life cost model for the project)	31	32.3	67.7
B1	Designer involvement in the implementation of environmental management procedures appropriate to each project	32	53.1	46.9
B2	Designers active involvement in the implementation of health and safety procedures	31	45.2	54.8
B3	Establishment and use of Change control Management by all project stakeholders	32	68.8	31.2
B4	Routinely formal resource plan	32	37.5	62.5
B5	Formal documented and audited design process	32	46.9	53.1
B6	Establishment of Formal design program with all design team at the start of projects	31	54.8	45.2
C1	Grouping the design team in one location to promote the integration of project knowledge	32	40.6	59.4
C2	Integration of Design data exchange process (being used by all project stakeholders)	32	37.5	62.5
C3	The involvement of specialist design and construction expertise during the pre construction design process	31	58.1	41.9
C4	Benefit derived through design supply chain integration Shared between all parties including client	31	38.7	61.3
C5	Project benefits from firm's management and development of its relationships with key design suppliers to mutual business benefit	32	40.6	59.4
D1	Frequency of changes to the original plans & specifications regardless of the reason	32	28.1	71.9
D2	Clarity and ease of plans & specifications	32	40.6	59.4
D3	No. of questions comes from contractor requesting clarification of plans & specifications	31	41.9	58.1
D4	Frequency of Architects and Engineers site visit to resolve problems	32	28.1	71.9
E1	Cost estimate of design	31	64.5	35.5
E2	Cost impact of design change	31	25.8	74.2
E3	Cost impact of design errors	31	29	71
E4	Estimated time for design	30	66.7	33.3
E5	Time impact of design change	31	45.2	54.8
E6	Time impact of design errors	31	41.9	58.1

Table 4. 4 Design KPIs and Design Sub Stage Where Data Is Better Collected (continued)

	Indicator	*N*	*Percentage*	
			Conception%	Development%
F1	Defining risk assessment process by the design team at the commencement of the project	31	80.6	19.4
F2	The use of formal risk identification techniques	31	54.8	45.2
F3	Establishment of Formal design program with all design team at the start of projects	31	64.5	35.5
F4	Risk Mitigation plan	30	46.7	53.3
F5	Continues Monitoring and reviewing of Risk assessment undertaken	30	26.7	73.3
F6	Accuracy of risk	31	29	71
G1	Benefit from the use of recycled design	30	53.3	46.7
G2	Availability and accessibility of standards details/ specifications and/or innovative solutions from previous projects to relevant design personnel	32	59.4	40.6
G3	Design review and feedback (design reviews being held and recorded at key project milestone, and integrated with ongoing project activities)	32	50	50
G4	Project reviews at completion to identify factors might have affected successes or failure	31	38.7	61.3
G5	Feed back of the result of the project completion reviews	32	28.1	71.9
G6	project publicity (publications, presentations, awards, citations etc)	31	35.5	64.5
H1	Technological innovation	32	62.5	37.5
H2	Process innovation	32	65.6	34.4
H3	Construction method innovation	32	59.4	40.6
H4	Over all use of innovation on project	32	62.5	37.5
H5	Feedback of the innovative ideas used on the project to relevant design team personnel	31	45.2	54.8
H6	New client inquiries based on the use of innovative solutions	29	55.2	44.8
I1	Client satisfaction with the finished construction product or service quality	29	34.5	65.5
I2	Client satisfaction with time of the finished construction product or service delivered	29	27.6	72.4
I3	Client satisfaction with cost of the finished construction product or service delivered	29	27.6	72.4
I4	Obtaining and documenting project feedback from all clients on the design service (aim to improve the company performance)	29	31	69
I5	Obtaining and documented project feedback from all clients on the design product (aim to improve the company performance)	29	31	69
I6	Obtaining and documenting project feedback from all end users on the design product (aim to improve the company performance)	29	34.5	65.5

4.5.2 Comparison of Samples

This section examines the differences between independent samples using an analysis of variance (ANOVA) to compare more than two samples. Four different comparisons in terms of the respondents' project types, years of experiences, organization type, and procurement routes are presented in the following sections.

4.5.2.1 Types of Projects

For the purpose of this research projects are classified into five different groups: Commercial, Civil, Heavy, Domestic Housing, and Mix. The fifth group includes respondent companies conducting more than one type of the mentioned types of projects. Domestic Housing is excluded from the comparison because there was only one response.

As shown in Table 4.6, there is a difference in the responses according to the project type. There is a difference between the statistical means of commercial and heavy projects type, and also there is a difference between the means of the Heavy and Mixed project types in "the Management of Client Expectation - Indicator A6". However, respondents conducting heavy projects found "Management of Client Expectations" more important than did respondents conducting commercial projects. On the other hand, respondents dealing with heavy construction believe that the Management of Client Expectations as an indicator is more important than do respondents dealing with more than one type of project. One can conclude that the respondents of heavy construction projects consider the Management of Client Expectation more important than do the respondents of all other types of construction projects.

There is a significant difference between the means of commercial and mixed project types in Indicator A3 "Alignment of Project Goals". Respondents of commercial construction projects think that Indicator A3 is more important than do the respondents conducting more than one construction type.

A significant difference also exists between the means of commercial and mixed projects, and those of Heavy and mixed types in Indicator B1 "Implementation of Environmental Management". Respondents of both commercial and heavy construction projects ranked Indicator B1as much more important than did the respondents conducting more than one project type.

From the point of view of heavy projects respondents, Integration of project knowledge, "Indicator C1", is more important than it is for other project types'. However it has almost the same importance for the Commercial project group and the Heavy project group. Project benefits from firm's management "Indicator C5", according to heavy projects responses, is more important than it is for the mix project type. For the respondents in the mixed project type group, Indicator E4 (the Estimated Time for Design) is less important than it is for the heavy project group. Heavy project type respondents' shows that Indicator E6 (Time Impact of Design Errors) is very important compared to mix and commercial projects types. Indicator F2 (Risk Identification Techniques) and Indicator F4 (Risk Mitigation Plan) are more important indicators for commercial project type respondents than it is for the mixed and heavy projects type.

Commercial projects respondents indicated that the following indicators are more important than they are for mix and heavy project type:

- Feed back of the Result of the Project Completion Reviews "G5",

- Availability and Accessibility of Standards details from previous projects " G2",
- Technological Innovation "H1", and
- Process Innovation "H2".

Heavy projects respondents found that the following indicators are more important compared to respondents conducting different types of projects:

- Client satisfaction with the finished construction product (I1),
- Client satisfaction with time of the finished construction product (I2),
- Client satisfaction with cost of the finished construction (I3),
- Obtaining and documenting project feedback from all clients on the design service (I5), and
- Obtaining and documenting project feedback from all end users on the design product (I6).

Table 4. 5 Summary of Comparison on Project Types

Dependent Variable		Mean				Significance		
		Commercial	Heavy	Mix	Total	Commercial -Heavy	Commercial -Mix	Heavy - Mix
A1	Seeking client needs	9.40	9.07	8.54	8.91	.549	.126	.194
A2	Value management	8.20	8.00	7.31	7.75	.762	.187	.162
A3	**Alignment of project goals**	9.60	8.57	7.50	8.32	.117	**.003**	**.034**
A4	Client project brief	8.60	8.07	7.92	8.09	.451	.340	.774
A5	End user collaboration	7.20	7.93	8.08	7.88	.468	.388	.841
A6	**Management of client expectation**	6.80	8.57	7.46	7.84	**.018**	.362	**.042**
A7	Whole life cost model integration	7.80	8.07	7.83	7.94	.732	.967	.691
B1	**Implementation of environmental management**	8.20	8.43	6.00	7.45	.787	.016	.001
B2	implementation of health and safety procedures	8.00	7.29	7.91	7.63	.426	.922	.370
B3	*Change control Management*	8.20	8.14	7.33	7.84	.950	.359	.248
B4	resource plan	9.20	7.64	8.17	8.10	.121	.308	.482
B5	documented and audited design process	8.40	8.50	7.83	8.23	.895	.467	.250
B6	Formal design program	8.40	8.29	7.58	8.03	.890	.337	.265
C1	**Integration of project knowledge**	8.40	8.50	6.83	7.84	.895	.051	**.007**
C2	Integration of Design data exchange	9.20	8.29	8.17	8.39	.160	.121	.805
C3	The involvement of specialist design and construction expertise during the pre construction design process	8.60	8.36	8.08	8.29	.728	.471	.604
C4	Benefit derived through design supply chain integration	7.60	7.71	8.09	7.83	.898	.594	.584
C5	**Project benefits from firm's management**	7.80	8.29	7.00	7.71	.521	.304	**.031**
D1	Frequency of changes to the original plans & specifications	6.80	7.29	6.67	6.97	.682	.912	.491
D2	Clarity and ease of plans & specifications	8.20	8.64	6.92	7.90	.607	.152	.012
D3	No. of questions comes from contractor requesting clarification of plans & specifications	6.60	7.57	6.91	7.17	.358	.776	.417
D4	Frequency of Architects and Engineers site visit to resolve problems	6.20	7.36	7.00	7.03	.378	.549	.717
E1	Cost estimate of design	8.40	8.43	8.60	8.48	.968	.788	.761
E2	Cost impact of design change	8.80	8.71	8.10	8.52	.909	.377	.306
E3	Cost impact of design errors	8.80	8.43	7.10	8.03	.646	.053	.046
E4	Estimated time for design	7.80	8.36	6.60	7.66	.548	.224	.023
E5	Time impact of design change	8.60	8.36	7.40	8.07	.801	.241	.217
E6	**Time impact of design errors**	8.40	8.71	7.10	8.10	.741	.201	.040

Table 4.5 Summary of Comparison on Project Types (Continued)

	Dependent Variable	Mean				Significance		
		Commercial	Heavy	Mix	Total	Commercial -Heavy	Commercial -Mix	Heavy - Mix
F1	Defining risk assessment process	8.00	7.93	6.45	7.40	.935	.098	.038
F2	**Risk identification techniques**	9.20	7.93	7.09	7.83	.051	.003	.094
F3	Formal design program with all design team at the start of projects	8.40	8.43	7.36	8.03	.973	.234	.105
F4	**Risk Mitigation plan**	9.20	7.71	7.10	7.76	.024	.003	.222
F5	reviewing of Risk assessment undertaken	8.60	8.07	7.40	7.93	.424	.091	.205
F6	Accuracy of risk	8.20	7.79	7.09	7.60	.586	.165	.242
G1	use of recycled design	7.20	7.50	6.18	6.97	.711	.231	.043
G2	**Availability and accessibility of standards details from previous projects**	7.80	8.64	7.33	8.00	.221	.503	**.015**
G3	Design review and feedback	8.00	8.64	8.17	8.35	.451	.848	.459
G4	Project reviews at completion	8.20	7.86	6.82	7.53	.682	.118	.116
G5	**Feed back of the result of the project completion reviews**	9.00	8.50	6.83	7.94	.515	**.009**	**.007**
G6	project publicity	6.80	6.93	5.67	6.42	.905	.309	.130
H1	**Technological innovation**	8.20	7.71	6.33	7.26	.543	.028	.028
H2	**Process innovation**	8.800	7.857	6.417	7.452	.253	.007	.026
H3	Design sub phase for IndicatorH3	8.40	8.07	7.42	7.87	.682	.236	.284
H4	Over all use of innovation on project	7.20	7.79	6.75	7.29	.395	.521	.053
H5	Feedback of the innovative ideas	7.40	7.57	6.64	7.20	.854	.432	.202
H6	New client inquiries based on the use of innovative solutions	7.20	8.29	6.67	7.48	.167	.500	.009
I1	**Client satisfaction with the finished construction product**	8.60	9.08	7.45	8.38	.559	.177	**.016**
I2	**Client satisfaction with time of the finished construction product**	8.60	8.62	7.09	8.03	.986	.103	**.033**
I3	**Client satisfaction with cost of the finished construction**	8.80	9.00	7.73	8.48	.775	.143	**.026**
I4	**Obtaining and documenting project feedback from all clients on the design service**	8.20	8.08	6.36	7.45	.904	.089	**.039**
I5	Obtaining and documented project feedback from all clients on the design product	8.20	8.38	7.09	7.86	.833	.224	.067
I6	**Obtaining and documenting project feedback from all end users on the design product**	7.80	8.15	6.09	7.31	.739	.124	**.018**

4.5.2.2 Years of Experiences

The present research divided the respondents into three different groups so far as their years of experience were concerned: respondents with up to 15 years of experience, respondents with 16 and 30 years of experience, and respondents with over 30 years of experience. These three groups can be defined as "less experienced group", "more experienced group", and "very experienced group" respectively. The summarized results of the responses are shown in Table 4.7. An interesting finding here was that all the means of the responses under "indicator B and I" from less experienced group were higher than the means of the responses from more and higher experienced groups in variables with a significant difference. This indicates that respondents in the less experienced group consider the design process and client satisfaction as very important key performance indicators compared to the more experienced group and to the very experienced group. Indicators A3 and A6", Alignment of project goals (Agreement on the priority and uncertainties of the project, e.g. goals/risks, mission statement, budget constraints) and the management of client expectations, are more important for the less and very experienced groups compared to the more experienced group. In general, the very experienced group believes that the following indicators are more important than they are for the other two groups :

- Seeking client needs,
- Integration of project knowledge,
- Number of questions comes from contractor requesting clarification of plans and specifications,
- Frequency of architects and engineers site visit to resolve problems,

- Estimated time for design reviewing of Risk assessment undertaken,
- Project publicity, and
- Client satisfaction with the finished construction product.

As for the rest of the indicators there are no significant differences between the groups.

Table 4. 6 Summary of Comparison on Years of Experience

	Dependent Variable	Mean				Significance		
		1	2	3	Total	1 &2	1&3	2&3
A1	Seeking client needs	8.83	8.87	9.00	8.90	.926	.672	.672
A2	Value management	7.83	7.60	7.67	7.67	.591	.724	.860
A3	**Alignment of project goals**	8.91	7.67	8.50	8.15	**.012**	.432	**.043**
A4	Client project brief	8.75	7.73	7.67	7.92	.027	.031	.865
A5	End user collaboration	7.75	7.67	8.00	7.78	.896	.719	.550
A6	**Management of client expectation**	8.33	7.20	8.17	7.72	**.025**	.757	**.028**
A7	Whole life cost model integration	8.27	7.47	8.00	7.78	.162	.660	.272
B1	**Implementation of environmental management**	8.82	6.40	7.33	7.14	**.000**	**.025**	.068
B2	implementation of health and safety procedures	8.09	7.27	7.00	7.36	.180	.116	.626
B3	**Change control Management**	8.64	7.27	7.83	7.69	**.029**	.232	.278
B4	resource plan	8.82	7.93	7.17	7.86	.185	**.025**	.175
B5	documented and audited design process	8.45	7.87	8.33	8.12	.289	.840	.320
B6	Formal design program	8.55	7.53	7.83	7.81	.083	.258	.539
C1	**Integration of project knowledge**	8.00	7.27	8.33	7.73	.218	.604	**.036**
C2	Integration of Design data exchange	8.64	8.27	7.83	8.20	.375	.079	.220
C3	The involvement of specialist design and construction expertise during the pre construction design process	8.00	8.33	8.67	8.37	.465	.181	.388
C4	Benefit derived through design supply chain integration	8.45	7.40	7.00	7.50	.103	.047	.486
C5	Project benefits from firm's management	8.27	7.07	7.83	7.53	.029	.455	.098
D1	Frequency of changes to the original plans & specifications	7.55	6.53	6.83	6.81	.214	.419	.662
D2	Clarity and ease of plans & specifications	8.09	7.80	8.17	7.97	.661	.916	.514
D3	**No. of questions comes from contractor requesting clarification of plans & specifications**	7.73	6.53	8.00	7.16	.078	.716	**.017**
D4	Frequency of Architects and Engineers site visit to resolve problems	7.64	6.13	8.00	6.98	.063	.675	.007
E1	Cost estimate of design	8.36	8.64	8.20	8.46	.560	.759	.306
E2	Cost impact of design change	8.73	8.29	8.20	8.35	.407	.375	.857
E3	Cost impact of design errors	8.36	7.64	8.00	7.89	.248	.599	.522
E4	**Estimated time for design**	8.09	6.86	8.20	7.48	.084	.889	**.037**
E5	Time impact of design change	8.36	7.71	8.40	8.04	.344	.962	.267
E6	Time impact of design errors	8.64	7.43	8.20	7.89	.096	.585	.233

1= 1 to15 years of experience, 2=16 to30 years of experience, 3=31 to 46 years of experience

Table 4.6 Summary of Comparison on Years of Experience (Continued)

	Dependent Variable	Mean				Significance		
		1	2	3	Total	1 &2	1&3	2&3
F1	Defining risk assessment process	7.82	7.36	6.50	7.18	.504	.080	.147
F2	**Risk identification techniques**	8.36	7.50	7.17	7.56	.086	.028	.430
F3	Formal design program with all design team at the start of projects	8.55	7.64	7.83	7.88	.148	.287	.717
F4	**Risk Mitigation plan**	8.27	7.50	7.40	7.63	.091	.087	.805
F5	reviewing of Risk assessment undertaken	8.00	8.00	7.20	7.78	1.000	.106	**.046**
F6	Accuracy of risk	8.00	7.36	6.83	7.32	.244	.052	.263
G1	use of recycled design	7.20	6.87	6.83	6.91	.560	.553	.943
G2	Availability and accessibility of standards details from previous projects	7.73	8.07	8.50	8.14	.452	.118	.258
G3	Design review and feedback	8.00	8.60	8.17	8.36	.282	.782	.358
G4	Project reviews at completion	8.09	7.27	6.60	7.25	.171	.030	.216
G5	**Feed back of the result of the project completion reviews**	8.64	7.27	7.67	7.64	.029	.150	.442
G6	project publicity	7.09	5.47	7.00	6.24	.026	.906	**.013**
H1	**Technological innovation**	8.09	6.73	7.17	7.12	.020	.139	.371
H2	Process innovation	8.091	6.933	7.000	7.169	.074	.120	.902
H3	Design sub phase for IndicatorH3	8.45	7.33	8.00	7.75	.041	.438	.147
H4	Over all use of innovation on project	8.00	6.60	7.17	7.03	.005	.115	.168
H5	Feedback of the innovative ideas	8.09	6.67	6.60	6.93	.023	.034	.903
H6	New client inquiries based on the use of innovative solutions	7.55	7.27	8.17	7.59	.625	.318	.066
I1	**Client satisfaction with the finished construction product**	9.00	7.79	9.00	8.39	**.044**	1.000	**.015**
I2	Client satisfaction with time of the finished construction product	8.60	7.79	7.67	7.89	.213	.183	.823
I3	Client satisfaction with cost of the finished construction	8.60	8.36	8.33	8.39	.624	.615	.953
I4	Obtaining and documenting project feedback from all clients on the design service	7.90	7.36	6.67	7.23	.516	.171	.315
I5	Obtaining and documented project feedback from all clients on the design product	8.30	7.14	8.00	7.63	.117	.701	.156
I6	Obtaining and documenting project feedback from all end users on the design product	7.90	6.71	7.17	7.07	.161	.415	.511

1= 1 to15 years of experience, 2=16 to30 years of experience, 3=31 to 46 years of experience

4.5.2.3 Organization Type

The present research classified the organization types into four groups: Design Organization, Construction Organization, Contractor, and Mixed. The last group includes respondents' companies that represent more than one type. The summarized results of the ANOVA analysis are shown in Table 4.8. In general, there are significant differences among the groups so far as indicators A, D, and F are concerned. A significant difference exists between the means of design organization respondents and Construction organization respondents in Alignment of project goals, "Indicator A3", risk identification techniques, "Indicator F2", and risk Mitigation plan, "Indicator F4". Construction companies thought that these indicators are more important than they are for design companies.

From the contractors' point of view, the management of client expectation, "Indicator A6", frequency of changes to the original plans & specifications, "Indicator D1", and frequency of Architects and Engineers site visit to resolve problems, "Indicator D4" are more important than they are for construction companies and mix type organization groups.

Table 4. 7 Summary of Comparison on Organization Type

Dependent Variable		Mean					Significance					
		1	2	3	4	Total	1 &2	1&3	1&4	2&3	2&4	3&4
A1	Seeking client needs	9.00	9.50	8.00	9.14	8.97	.528	.139	.764	.129	.674	.126
A2	Value management	7.53	9.00	7.67	7.71	7.69	.169	.876	.770	.304	.260	.961
A3	**Alignment of project goals**	7.76	10.00	9.50	8.57	8.25	**.040**	.104	.203	.719	.207	.407
A4	Client project brief	7.82	9.00	8.00	8.43	8.07	.258	.837	.331	.428	.605	.652
A5	End user collaboration	7.76	6.00	7.00	8.57	7.76	.251	.549	.379	.590	.123	.267
A6	**Management of client expectation**	7.71	6.00	9.00	8.29	7.86	.129	.168	.383	**.033**	.061	.484
A7	Whole life cost model integration	7.59	9.50	8.00	7.71	7.79	.119	.731	.861	.352	.172	.824
B1	Implementation of environmental management	7.06	9.00	9.50	7.29	7.43	.208	.117	.804	.806	.298	.182
B2	implementation of health and safety procedures	7.59	6.50	8.00	8.00	7.63	.445	.771	.648	.431	.337	1.000
B3	Change control Management	7.82	9.00	9.00	7.00	7.79	.387	.387	.315	1.000	.175	.175
B4	resource plan	8.12	9.00	9.00	8.71	8.39	.506	.506	.454	1.000	.840	.840
B5	documented and audited design process	8.12	9.00	8.50	7.43	8.04	.430	.731	.308	.737	.195	.373
B6	Formal design program	7.94	9.00	8.50	7.29	7.89	.424	.672	.411	.777	.232	.393
C1	Integration of project knowledge	7.29	8.50	8.50	8.00	7.64	.387	.387	.399	1.000	.736	.736
C2	Integration of Design data exchange	8.18	10.00	9.00	8.29	8.39	.064	.389	.848	.434	.102	.485
C3	The involvement of specialist design and construction expertise during the pre construction design process	8.24	8.00	8.50	8.43	8.29	.828	.807	.766	.730	.712	.951
C4	Benefit derived through design supply chain integration	7.88	9.00	8.50	7.17	7.85	.410	.647	.407	.782	.220	.369
C5	Project benefits from firm's management	7.35	8.50	8.50	7.71	7.61	.358	.358	.628	1.000	.555	.555
D1	**Frequency of changes to the original plans & specifications**	7.00	3.50	8.50	8.00	7.11	**.016**	.280	.232	**.011**	**.005**	.734
D2	Clarity and ease of plans & specifications	8.00	8.50	9.00	7.43	7.96	.718	.471	.493	.787	.472	.294
D3	No. of questions comes from contractor requesting clarification of plans & specifications	7.06	6.50	8.50	6.67	7.04	.722	.363	.695	.346	.923	.291
D4	**Frequency of Architects and Engineers site visit to resolve problems**	7.41	4.00	9.50	6.43	7.07	**.032**	.176	.285	**.011**	.144	.068
E1	Cost estimate of design	8.29	8.50	10.00	8.40	8.46	.838	.102	.878	.273	.929	.166
E2	Cost impact of design change	8.00	10.00	10.00	8.40	8.38	.075	.075	.589	1.000	.196	.196
E3	Cost impact of design errors	7.35	9.00	10.00	8.60	7.92	.178	.036	.136	.534	.765	.302
E4	Estimated time for design	7.18	8.50	10.00	7.40	7.54	.396	.078	.832	.471	.527	.143
E5	Time impact of design change	7.53	9.00	10.00	8.20	7.96	.292	.083	.477	.589	.605	.250
E6	Time impact of design errors	7.47	8.50	10.00	8.20	7.88	.507	.111	.489	.470	.862	.303

Table 4.7 Summary of Comparison on Organization Type (Continued)

Dependent Variable		Mean					Significance					
		1	2	3	4	Total	1 &2	1&3	1&4	2&3	2&4	3&4
F1	Defining risk assessment process	7.29	8.50	9.00	6.50	7.33	.395	.232	.378	.790	.201	.113
F2	**Risk identification techniques**	7.24	10.00	9.00	7.67	7.67	**.012**	.095	.510	.469	.046	.241
F3	Formal design program with all design team at the start of projects	7.82	9.00	9.00	7.33	7.89	.323	.323	.514	1.000	.203	.203
F4	**Risk Mitigation plan**	7.41	10.00	8.50	8.20	7.85	**.007**	.221	.194	.208	.076	.759
F5	reviewing of Risk assessment undertaken	7.53	8.50	9.00	8.40	7.88	.346	.158	.217	.714	.930	.600
F6	Accuracy of risk	7.12	8.50	9.00	8.00	7.56	.232	.108	.230	.743	.688	.425
G1	use of recycled design	6.94	5.50	7.50	7.29	6.96	.267	.661	.653	.248	.199	.875
G2	Availability and accessibility of standards details from previous projects	7.94	8.00	9.50	7.43	7.93	.957	.158	.433	.305	.623	.084
G3	Design review and feedback	8.41	8.00	9.50	7.71	8.29	.746	.396	.366	.382	.834	.198
G4	**Project reviews at completion**	7.12	9.00	9.50	7.83	7.59	.092	**.036**	.303	.730	.328	.167
G5	Feed back of the result of the project completion reviews	7.29	8.50	9.00	8.29	7.75	.406	.244	.259	.796	.890	.645
G6	project publicity	5.71	7.50	7.00	7.00	6.25	.278	.431	.195	.819	.775	1.000
H1	**Technological innovation**	6.94	9.00	8.00	7.14	7.21	.099	.386	.782	.539	.162	.512
H2	**Process innovation**	7.000	9.000	8.500	7.000	7.250	.172	.301	1.000	.795	.201	.334
H3	Design sub phase for IndicatorH3	7.71	9.00	9.00	7.29	7.79	.280	.280	.556	1.000	.185	.185
H4	Over all use of innovation on project	7.12	6.50	8.50	7.00	7.14	.602	.249	.868	.213	.694	.244
H5	Feedback of the innovative ideas	7.06	7.50	8.00	7.33	7.22	.753	.503	.758	.789	.913	.663
H6	New client inquiries based on the use of innovative solutions	7.29	7.00	8.50	7.71	7.46	.808	.323	.564	.358	.583	.546
I1	Client satisfaction with the finished construction product	8.00	10.00	9.50	8.60	8.38	.136	.258	.502	.775	.343	.540
I2	Client satisfaction with time of the finished construction product	7.76	10.00	10.00	7.60	8.08	.080	.080	.844	1.000	.092	.092
I3	Client satisfaction with cost of the finished construction	8.18	9.00	10.00	8.60	8.46	.471	.119	.585	.513	.753	.277
I4	Obtaining and documenting project feedback from all clients on the design service	7.06	8.50	10.00	7.00	7.38	.296	.040	.949	.414	.331	.059
I5	Obtaining and documented project feedback from all clients on the design product	7.24	8.50	10.00	7.40	7.58	.392	.070	.869	.448	.505	.123
I6	Obtaining and documenting project feedback from all end users on the design product	6.76	7.50	9.50	7.40	7.15	.674	.127	.594	.396	.959	.289

1=Design Organization, 2=Construction Organization, 3=Contractor, 4= Mix (more than one type)

4.5.2.4 Procurement Route

The present research classified the organization types into four groups: Design Organization, Construction Organization, Contractor, and Mixed. The last group includes respondents' companies that represent more than one type. The summarized results of the ANOVA analysis are shown in Table 4.9. In general, there are significant differences among the groups so far as indicators A, D, and F are concerned. A significant difference exists between the means of design organization respondents and Construction organization respondents in Alignment of project goals, "Indicator A3", risk identification techniques, "Indicator F2", and risk Mitigation plan, "Indicator F4". Construction companies thought that these indicators are more important than they are for design companies.

From the contractors' point of view, the management of client expectation, "Indicator A6", frequency of changes to the original plans & specifications, "Indicator D1", and frequency of Architects and Engineers site visit to resolve problems, "Indicator D4" are more important than they are for construction companies and mix type organization groups.

Table 4. 8 Summary of Comparison on Procurement Route

	Dependent Variable	Mean						Significance									
		Design/Built (1)	PPP (2)	Construction Management (3)	Partnering (4)	Mix (5)	Total	1&2	1&3	1&4	1&5	2&3	2&4	2&5	3&4	3&5	4&5
A1	Seeking client needs	8.78	9.00	9.50	8.00	9.17	9.00	.759	.203	.289	.346	.535	.287	.814	.071	.535	.109
A2	**Value management**	6.89	8.00	8.25	9.00	8.17	7.83	.211	.051	**.022**	**.015**	.796	.374	.845	.441	.897	.333
A3	**Alignment of project goals**	7.67	8.00	8.75	7.50	9.00	8.38	.759	.202	.878	**.038**	.534	.719	.350	.304	.755	.166
A4	Client project brief	7.89	8.50	8.75	8.50	8.00	8.14	.554	.282	.554	.848	.826	1.000	.619	.826	.328	.619
A5	**End user collaboration**	6.22	8.00	9.25	7.00	8.67	7.83	.198	**.007**	.568	**.004**	.410	.566	.616	.144	.562	.217
A6	Management of client expectation	7.11	9.00	8.50	7.00	7.92	7.76	.136	.153	.928	.255	.715	.214	.374	.279	.525	.451
A7	**Whole life cost model integration**	7.11	9.00	9.75	7.50	7.67	7.86	.076	**.003**	.706	.344	.513	.261	.193	.058	**.011**	.868
B1	Implementation of environmental management	7.67	8.50	8.00	6.00	7.67	7.66	.585	.776	.280	1.000	.767	.207	.577	.243	.767	.269
B2	implementation of health and safety procedures	6.33	8.00	7.25	7.50	8.45	7.50	.192	.347	.357	.007	.591	.756	.713	.857	.207	.442
B3	Change control Management	7.56	8.50	8.75	10.00	7.75	8.03	.451	.220	.059	.782	.856	.351	.539	.369	.283	.074
B4	resource plan	6.78	8.00	8.75	6.50	9.08	8.07	.315	.042	.818	.002	.575	.335	.361	.101	.708	.036
B5	documented and audited design process	7.56	8.00	9.75	7.00	8.42	8.21	.646	.006	.567	.123	.111	.422	.660	.016	.071	.142
B6	Implementation of environmental management	7.24	7.90	10.00	7.70	8.91	8.39	.511	-.275	.726	-.144	.182	.416	.514	-.046	.140	-.005
C1	Integration of project knowledge	6.67	7.50	9.50	8.50	8.17	7.86	.498	.006	.143	.038	.149	.525	.579	.464	.149	.781
C2	Integration of Design data exchange	7.22	8.00	9.25	8.50	8.67	8.24	.394	.007	.166	.009	.220	.666	.453	.457	.386	.850
C3	The involvement of specialist design and construction expertise during the pre construction design process	7.67	7.50	9.25	5.50	9.00	8.28	.795	.003	.002	.001	.020	.021	.023	.000	.598	.000
C4	Benefit derived through design supply chain integration	6.56	8.50	7.50	8.00	8.55	7.71	.145	.350	.274	.013	.490	.764	.972	.729	.288	.671
C5	Project benefits from firm's management	6.78	8.50	8.00	8.00	8.17	7.72	.175	.210	.332	.057	.718	.754	.784	1.000	.856	.891

1= Design\built, 2=PPP, 3=Construction Management, 4=Partnering, 5=Mix

Table 4. 8 Summary of Comparison on Procurement Route

	Dependent Variable	Mean						Significance									
		Design/Built (1)	PPP (2)	Construction Management (3)	Partnering (4)	Mix (5)	Total	1&2	1&3	1&4	1&5	2&3	2&4	2&5	3&4	3&5	4&5
A1	Seeking client needs	8.78	9.00	9.50	8.00	9.17	9.00	.759	.203	.289	.346	.535	.287	.814	.071	.535	.109
A2	**Value management**	6.89	8.00	8.25	9.00	8.17	7.83	.211	.051	**.022**	**.015**	.796	.374	.845	.441	.897	.333
A3	**Alignment of project goals**	7.67	8.00	8.75	7.50	9.00	8.38	.759	.202	.878	**.038**	.534	.719	.350	.304	.755	.166
A4	Client project brief	7.89	8.50	8.75	8.50	8.00	8.14	.554	.282	.554	.848	.826	1.000	.619	.826	.328	.619
A5	**End user collaboration**	6.22	8.00	9.25	7.00	8.67	7.83	.198	**.007**	.568	**.004**	.410	.566	.616	.144	.562	.217
A6	Management of client expectation	7.11	9.00	8.50	7.00	7.92	7.76	.136	.153	.928	.255	.715	.214	.374	.279	.525	.451
A7	**Whole life cost model integration**	7.11	9.00	9.75	7.50	7.67	7.86	.076	**.003**	.706	.344	.513	.261	.193	.058	**.011**	.868
B1	Implementation of environmental management	7.67	8.50	8.00	6.00	7.67	7.66	.585	.776	.280	1.000	.767	.207	.577	.243	.767	.269
B2	implementation of health and safety procedures	6.33	8.00	7.25	7.50	8.45	7.50	.192	.347	.357	.007	.591	.756	.713	.857	.207	.442
B3	Change control Management	7.56	8.50	8.75	10.00	7.75	8.03	.451	.220	.059	.782	.856	.351	.539	.369	.283	.074
B4	resource plan	6.78	8.00	8.75	6.50	9.08	8.07	.315	.042	.818	.002	.575	.335	.361	.101	.708	.036
B5	documented and audited design process	7.56	8.00	9.75	7.00	8.42	8.21	.646	.006	.567	.123	.111	.422	.660	.016	.071	.142
B6	Implementation of environmental management	7.24	7.90	10.00	7.70	8.91	8.39	.511	-.275	.726	-.144	.182	.416	.514	-.046	.140	-.005
C1	Integration of project knowledge	6.67	7.50	9.50	8.50	8.17	7.86	.498	.006	.143	.038	.149	.525	.579	.464	.149	.781
C2	Integration of Design data exchange	7.22	8.00	9.25	8.50	8.67	8.24	.394	.007	.166	.009	.220	.666	.453	.457	.386	.850
C3	The involvement of specialist design and construction expertise during the pre construction design process	7.67	7.50	9.25	5.50	9.00	8.28	.795	.003	.002	.001	.020	.021	.023	.000	.598	.000
C4	Benefit derived through design supply chain integration	6.56	8.50	7.50	8.00	8.55	7.71	.145	.350	.274	.013	.490	.764	.972	.729	.288	.671
C5	Project benefits from firm's management	6.78	8.50	8.00	8.00	8.17	7.72	.175	.210	.332	.057	.718	.754	.784	1.000	.856	.891

1= Design\built, 2=PPP, 3=Construction Management, 4=Partnering, 5=Mix

Table 4.8 Summary of Comparison on Procurement Route (Continued)

	Dependent Variable	Mean						Significance									
		Design/Built (1)	PPP (2)	Construction Management (3)	Partnering (4)	Mix (5)	Total	1&2	1&3	1&4	1&5	2&3	2&4	2&5	3&4	3&5	4&5
D1	Frequency of changes to the original plans & specifications	6.11	5.50	6.50	9.00	7.58	6.93	.729	.774	.110	.147	.609	.130	.233	.208	.408	.414
D2	**Clarity and ease of plans & specifications**	7.33	9.00	9.50	7.50	8.50	8.24	.139	**.016**	.880	.069	.682	.292	.642	.110	.225	.356
D3	No. of questions comes from contractor requesting clarification of plans & specifications	7.22	8.00	6.75	6.00	7.73	7.32	.613	.689	.428	.568	.464	.313	.856	.659	.397	.258
D4	**Frequency of Architects and Engineers site visit to resolve problems**	7.22	3.50	9.00	7.00	7.08	7.14	**.037**	.182	.896	.885	**.007**	.117	**.039**	.294	.136	.960
E1	Cost estimate of design	7.44	8.50	9.50	9.00	8.64	8.39	.251	**.007**	.096	**.030**	.325	.667	.878	.620	.210	.684
E2	Cost impact of design change	7.67	9.00	9.25	8.00	8.55	8.36	.257	.086	.774	.196	.846	.502	.691	.335	.419	.633
E3	*Cost impact of design errors*	7.22	8.50	9.75	5.50	8.36	8.00	.259	**.007**	.132	.085	.317	.045	.901	**.002**	.106	**.015**
E4	Estimated time for design	6.78	8.00	8.75	4.50	8.27	7.57	.395	.082	.120	.078	.636	.065	.846	.012	.655	**.012**
E5	Time impact of design change	7.78	8.50	9.25	4.00	8.45	8.04	.543	.115	.004	.325	.569	.006	.969	**.000**	.372	**.001**
E6	Time impact of design errors	7.33	8.50	9.75	5.00	8.55	8.07	.401	**.030**	.100	.136	.416	.057	.973	**.005**	.249	**.014**
F1	Defining risk assessment process	6.44	7.50	8.50	7.50	7.58	7.34	.464	.072	.464	.168	.531	1.000	.953	.531	.391	.953
F2	**Risk Identification techniques**	7.22	7.50	8.50	8.00	7.92	7.76	.818	.177	.521	.313	.457	.746	.724	.709	.515	.944
F3	Formal design program with all design team at the start of projects	7.44	8.00	9.25	8.00	8.17	8.07	.669	.080	.669	.328	.388	1.000	.895	.388	.264	.895
F4	**Risk Mitigation plan**	7.00	7.50	8.50	7.50	8.27	7.79	.633	.072	.633	.043	.391	1.000	.455	.391	.771	.455
F5	reviewing of Risk assessment undertaken	6.89	8.50	8.25	7.00	8.55	7.86	.098	.071	.906	**.005**	.811	.222	.961	.240	.676	.106
F6	Accuracy of risk	6.11	8.50	7.25	7.50	8.42	7.48	.033	.172	.200	**.001**	.295	.465	.936	.832	.147	.382

1= Design\built, 2=PPP, 3=Construction Management, 4=Partnering, 5=Mix

4.6 MAIN FINDINGS

The survey results indicated that all of the nine groups of design indicators and their attributes are considered to have an impact on the performance of the design stage of a project. In general, the main nine groups of design KPIs were ranked as shown in Table 4.3 in the previous chapter. As presented in Figure 4.10, the main groups' levels of importance were as follows:

1) Cost and Time management,

2) Understanding client needs,

3) Integration of design with supply chain,

4) Client satisfaction,

5) Design process,

6) Risk,

7) Re-use of design experience,

8) Innovation, and

9) Design quality..

This list agrees with the CIRIA nine groups of indicators, since the Canadian construction professionals strongly indicated how important these indicators are for measuring the performance of the design activities for construction projects.

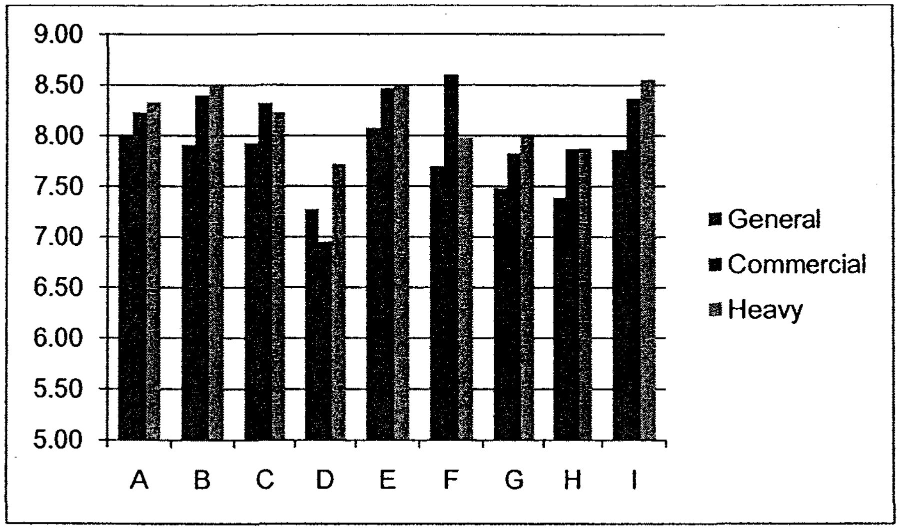


Figure 4.10 Design KPIs Level of Importance Comparison

Design performance indicators, when examined according to project types, years of experience, company type, and procurement routes have yielded different findings. In terms of years of experience and organization types there are no significant differences between the groups. Based on project types, the results reveal that there are significant differences in the ranking of the indicators, particularly between the respondents in the commercial construction sector and those in the heavy construction sector. However, heavy projects responses constitute the biggest portion, representing 45% of the total responses. Regarding procurement routes, more than 50% of the construction companies use more than one procurement route. Meanwhile, about 30% of the respondents use a design/build procurement route. In terms of project size, 94% of the responses were considered as big companies. Their projects were worth more than $300 million. The survey shows that heavy construction participants comprising the large categories. Therefore, this study is focused on the design KPIs for the heavy construction types.

4.7 SUMMARY

This chapter describes a survey questionnaire for design performance indicators. The survey design is described. The data collection and administration of the survey are explained. The summaries of the data received from respondents are presented. Accordingly, a detailed data analysis was run using the SPSS 14 package. Three statistical analyses were used: a reliability analysis, a t-test, and a comparison of samples. The main results of the survey consisted of nine group of indicators ranked according to their level of importance as indicators to measure design performance. According to the respondents' feedback, the projects were limited to heavy and commercial construction projects. Heavy construction respondents strongly agreed that all of the nine groups of indicators are important measures for the design stage of a project.

CHAPTER 5: IMPLICATION OF DESIGN KPIs TO THE PROPOSED FRAMEWORK

5.1 INTRODUCTION

The present research considers the identified set of key performance indicators as the final measures of the design activities performance. Results from the survey described in chapter (4) revealed that the Construction industry professionals in Canada, particularly in Montreal, believe that the nine groups of indicators are very important in measuring the performance of design activities for construction projects. The MDPM model can be used to measure the performance of design activities at any level. Companies can use this model to: predict, measure, track, and/or improve the performance of design activities for certain projects, or to check how they performed in previous projects. The MDPM model is designed to facilitate entering, retrieving, measuring, ranking, and comparing data from different projects. The user of the model can choose any indicators among the nine groups of indicators to measure design performance. By using leading measures, users can determine problematic areas, prevent future problems, and document the performance of the design stage of a project. By using lagging measures, the users can determine the areas of improvement for future projects. The following sections present the model which is designed using Access and Excel environments and is presented in the present chapter.

5.2 EXCEL ENVIRONMENT

The Analytical Hierarchy Process (AHP) is used to measure the importance of the selected design performance indicators for heavy construction projects. The Nine groups of design performance indicators are evaluated based on judgment of 13 experts. As mentioned in Chapter 3, the indicators are first presented in a hierarchical structure. Second, pair-wise comparisons are performed to measure the impact of the indicators in the design stage. Third, indicators weights and global weights are obtained. The main steps for the AHP implementation are explained in the following sections. The major challenge was the volume of data, since the use of 52 variables, each with 2 weighting variable, created 156 data point per project. Excel software was used to calculate the weights and the global weights.

5.2.1 Hierarchical Structure for the Design Performance Indicators

Figures 5.1a and b represent the hierarchy that has been developed for the heavy construction. The hierarchy consists of four levels. **Level one - goal:** The overall goal is to measure the performance of the design activities using nine sets of indicators. **Level 2 - Criteria**: The Goal is divided into nine main criteria: A: Understanding Client Needs; B: Design Process; C: Integration of Design with Supply Chain; D: Design Quality; E: Cost and Time Management; F: Risk; G: Re-use of Design; H: Innovation; and I: Client Satisfaction. **Level 3 – Sub-Criteria:** Each of the nine indicators is divided into sub-criteria or sub-indicators. **Level 4 – Alternatives:** Projects need to be evaluated.

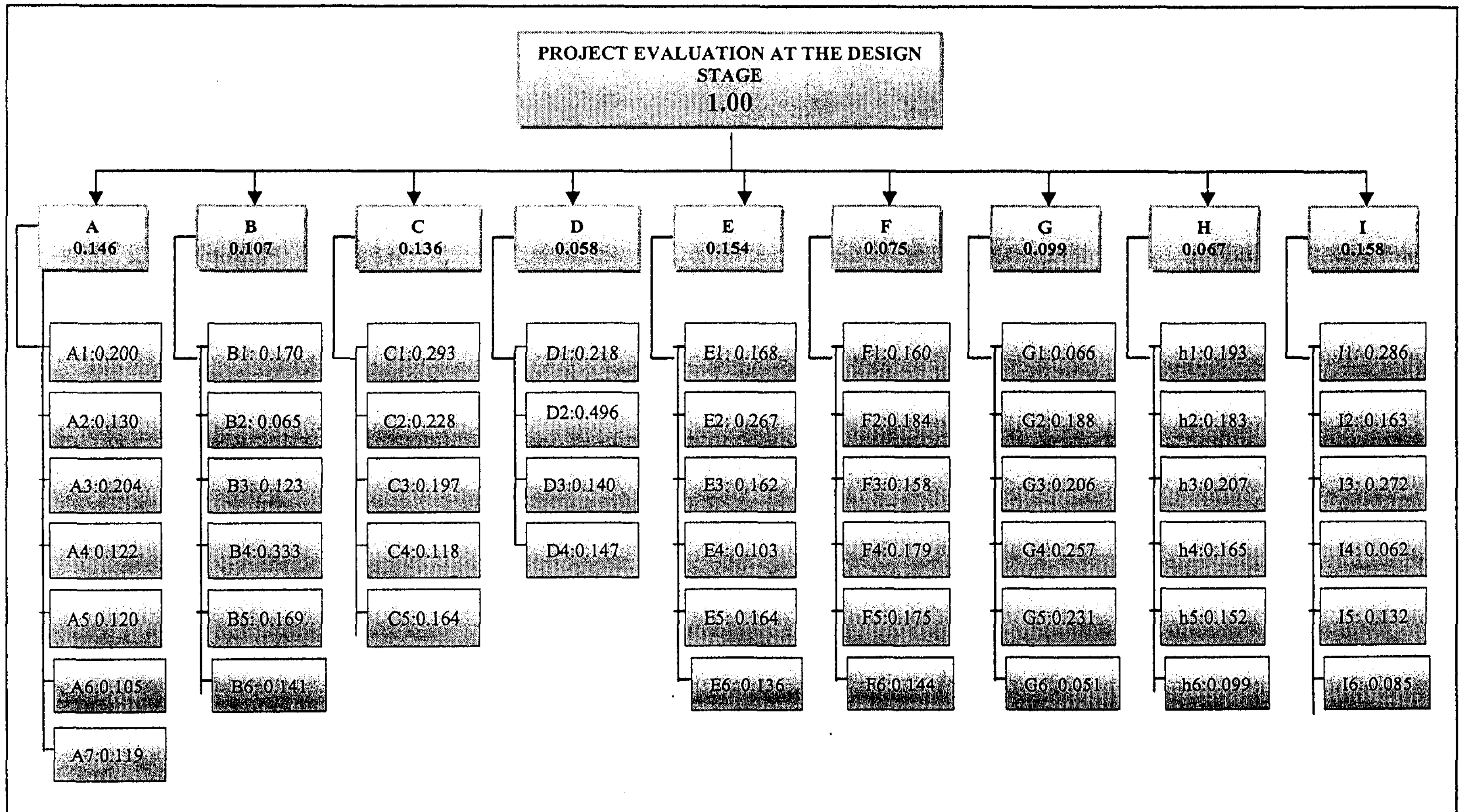


Figure 5.1 a Hierarchy Structure for Heavy Constructions set of Design Performance Indicators

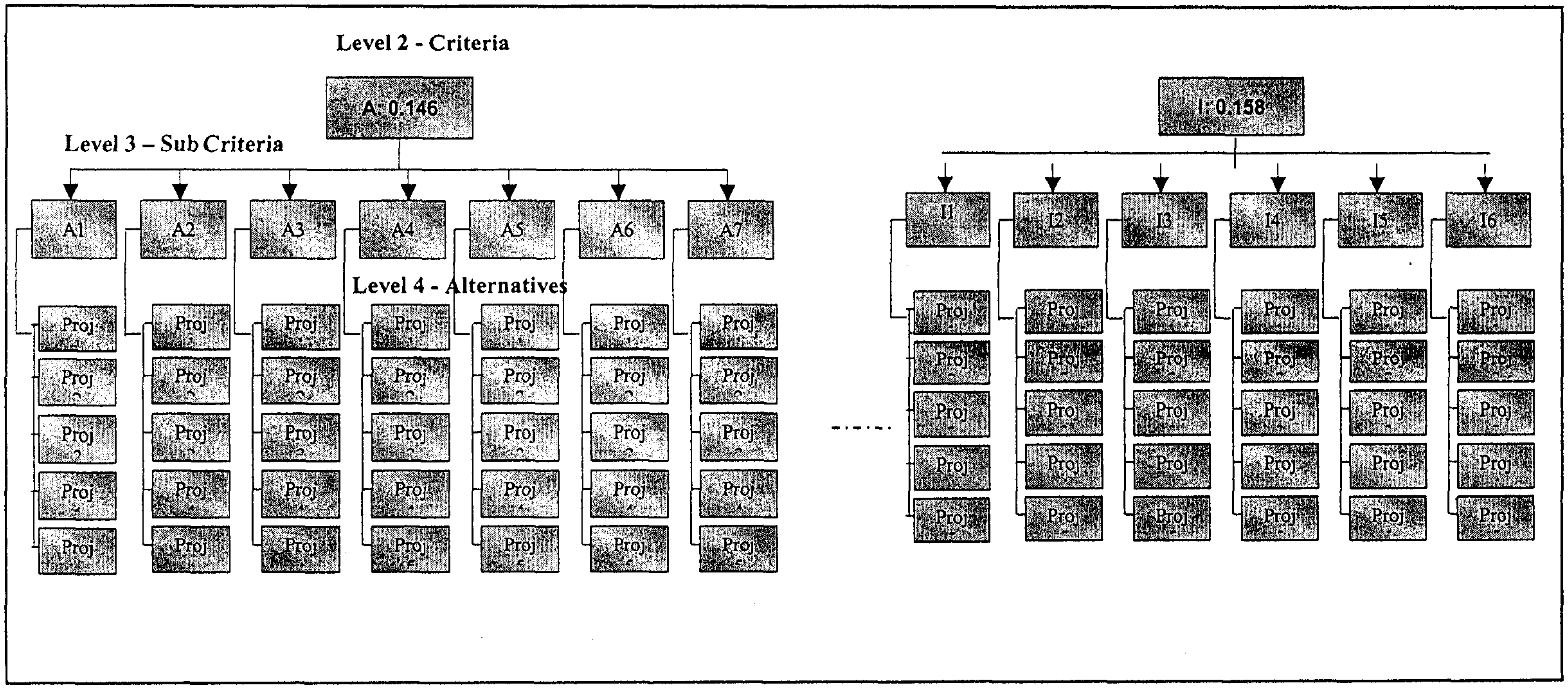


Figure 5.1 b Partial Hierarchy Structure for Heavy Constructions set of Design Performance Indicators

5.2.2 Assigning Design Indicator Intensities

In order to assign weights to the design performance indicators, the indicators were first presented in a hierarchal structure. Then, experts from heavy construction projects were asked to compare indicators in pairs with respect to their importance to the design stage of a project and to indicate their intensities using the fundamental scale. Table 5.1 represents the fundamental scale of the pair-wise comparisons, (Saaty 1980).

Table 5. 1Fundamental Scale of the Absolute Values

INTENSITY	DEFINITION	EXPLANATION
1	Equal importance	The two indicators have the same level of importance to the design stage
3	Week importance	One indicator is slightly favoured over the other
5	Strong importance	One indicator is strongly favoured over the other
7	Very strong Importance	One indicator is very strongly favoured over the other
9	Extreme importance	One indicator is extremely favoured over the other
2,4,6,8	Intermediate values can be applied in between	Whenever is needed

16 project and design experts from the construction sector dealing with the heavy construction participated in the comparison of the design indicators in pairs. Three replies were found to be not consistence. These replies were sent back to participants to revise their judgments, but no response was received. As a result, 13 responses were included and analyzed in this study.

The generated pairwise comparison matrices consisted of ten matrices to compare the indicators against each other. These matrices are as following:

1) Main indicators matrix: 9X9 matrix,

2) Indicator A (Understanding Client Needs) matrix: 7X7 matrix,

3) Indicator B (Design Processes) Matrix: 6X6 matrix,

4) Indicator C (Integration of the Design with Supply Chain) Matrix: 5X5 matrix

5) Indicator D (Design Quality) matrix: 4X4 matrix,

6) Indicator E (Cost and Time management) matrix: 6X6 matrix

7) Indicator F (Risk) matrix: 6X6 matrix,

8) Indicator G (Reuse of Design) matrix: 6X6 matrix,

9) Indicator H (Innovations) matrix: 6X6 matrix, and

10) Indicator I (Client Satisfactions) matrix: 6X6 matrix

The CI, RI, and CR results for each of the ten matrices can be found in appendix (D1). Figure 5.2 shows that all matrices are acceptable because CR<0.1. However, some of them have a CR of 0.085 and above.

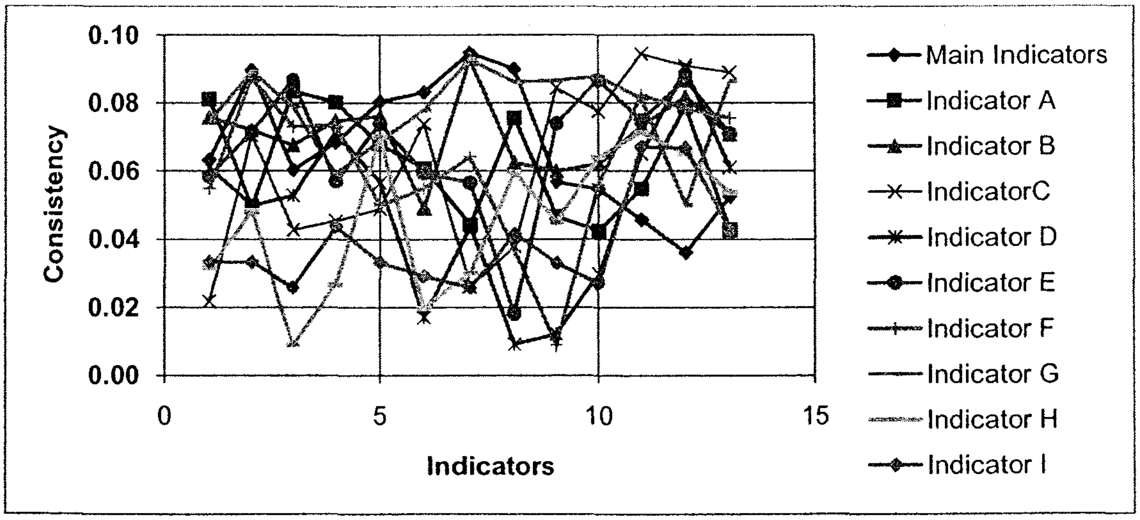


Figure 5. 2 Consistency Ratios for the Pairwise Comparison Matrices

5.2.3 Determining Design Indicators Weights

Pair-wise comparison matrices for the main group of indicators (Level 2) are generated using the concept of a reciprocal matrix described in Chapters 3 and 5. In a similar manner, pairwise comparison tables are then created for the sub-indicators (Level 3). The Eigen values are estimated, these values represent the weight of all of the indicators. The weight vectors are the final result of the Eigen value method calculations. There are 13 weight vectors for each main and sub-indicator. The weight tables for the thirteen participants can be found in Appendix (D2). Table 5.2 shows the average weights for the indicators.

Table 5.2 Average Weights for the indicators resulted from Eigen value calculation.

I	Weight	I	Weight	I	Weight	I	Weight	I	Weight
A	0.1458	A1	0.2000	B1	0.1699	C1	0.2935	D1	0.2177
B	0.1066	A2	0.1297	B2	0.0653	C2	0.2276	D2	0.4959
C	0.1360	A3	0.2042	B3	0.1226	C3	0.1968	D3	0.1399
D	0.0582	A4	0.1222	B4	0.3328	C4	0.1183	D4	0.1465
E	0.1545	A5	0.1198	B5	0.1688	C5	0.1638		
F	0.0748	A6	0.1054	B6	0.1405				
G	0.0991	A7	0.1187						
H	0.0668								
I	0.1582								
Total	1.0000		1.0000		1.0000		1.0000		1.0000

I	Weight	I	Weight	I	Weight	I	Weight	I	Weight
E1	0.1678	F1	**0.1599**	G1	0.0664	H1	0.1928	I1	0.2863
E2	0.2674	F2	**0.1836**	G2	0.1884	H2	0.1834	I2	0.1628
E3	0.1616	F3	**0.1577**	G3	0.2062	H3	0.2068	I3	0.2720
E4	0.1025	F4	**0.1795**	G4	0.2567	H4	0.1655	I4	0.0619
E5	0.1642	F5	**0.1752**	G5	0.2311	H5	0.1523	I5	0.1318
E6	0.1364	F6	**0.1443**	G6	0.0512	H6	0.0992	I6	0.0854
Total	1.0000		1.0000		1.0000		1.0000		1.0000

5.2.4 Determining the Global Weights

The global weight is estimated in order to compare different projects. The global weights for heavy construction projects are calculated using Equation 4. Each Indicator is multiplied by its parent criteria and by its grade. As mentioned in Chapter 3, the grades used to evaluate projects are from 1 to 5 where the grade of 5 represents the best performance and the grade of 1 represents the poorest performance. Tables 5.3 present the estimated global weight. For example, if Indicator A3 for project x had a performance score of 3, then its global weight is 0.005 and so on. The totals of the sub-indicators for each main indicator are then compared between projects.

Table 5. 3 Heavy Projects Global weights

score/weight	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**Total**
score5	0.0121	0.0079	0.0124	0.0074	0.0073	0.0064	0.0072	
score4	0.0076	0.0049	0.0078	0.0047	0.0046	0.0040	0.0045	
score3	0.0047	0.0030	0.0048	0.0029	0.0028	0.0025	0.0028	
score2	0.0029	0.0019	0.0029	0.0018	0.0017	0.0015	0.0017	
score1	0.0018	0.0012	0.0019	0.0011	0.0011	0.0010	0.0011	
Total	0.029	0.019	0.030	0.018	0.017	0.015	0.017	**0.146**
B	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**		
score5	0.008	0.003	0.005	0.015	0.007	0.006		
score4	0.005	0.002	0.003	0.009	0.005	0.004		
score3	0.003	0.001	0.002	0.006	0.003	0.002		
score2	0.002	0.001	0.001	0.003	0.002	0.001		
score1	0.001	0.000	0.001	0.002	0.001	0.001		
Total	0.018	0.007	0.013	0.035	0.018	0.015		**0.107**
C	**C1**	**C2**	**C3**	**C4**	**C5**			
score5	0.0166	0.0129	0.0111	0.0067	0.0093			
score4	0.0105	0.0081	0.0070	0.0042	0.0058			
score3	0.0064	0.0050	0.0043	0.0026	0.0036			
score2	0.0039	0.0031	0.0026	0.0016	0.0022			
score1	0.0025	0.0019	0.0017	0.0010	0.0014			
Total	0.040	0.031	0.027	0.016	0.022			**0.136**
D	**D1**	**D2**	**D3**	**D4**				
score5	0.0053	0.0120	0.0034	0.0036				
score4	0.0033	0.0076	0.0021	0.0022				
score3	0.0020	0.0046	0.0013	0.0014				
score2	0.0012	0.0028	0.0008	0.0008				
score1	0.0008	0.0018	0.0005	0.0005				
Total	0.013	0.029	0.008	0.009				**0.058**
E	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**		
score5	0.0108	0.0172	0.0104	0.0066	0.0106	0.0088		
score4	0.0068	0.0108	0.0065	0.0041	0.0066	0.0055		

score3	0.0042	0.0067	0.0040	0.0026	0.0041	0.0034		
score2	0.0026	0.0041	0.0025	0.0016	0.0025	0.0021		
score1	0.0016	0.0026	0.0016	0.0010	0.0016	0.0013		
Total	0.026	0.041	0.025	0.016	0.025	0.021		**0.154**
F	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**		
score5	0.0050	0.0057	0.0049	0.0056	0.0055	0.0045		
score4	0.0031	0.0036	0.0031	0.0035	0.0034	0.0028		
score3	0.0019	0.0022	0.0019	0.0022	0.0021	0.0017		
score2	0.0012	0.0014	0.0012	0.0013	0.0013	0.0011		
score1	0.0007	0.0009	0.0007	0.0008	0.0008	0.0007		
Total	0.012	0.014	0.012	0.013	0.013	0.011		**0.075**
G	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**		
score5	0.0027	0.0078	0.0085	0.0106	0.0095	0.0021		
score4	0.0017	0.0049	0.0054	0.0067	0.0060	0.0013		
score3	0.0011	0.0030	0.0033	0.0041	0.0037	0.0008		
score2	0.0006	0.0018	0.0020	0.0025	0.0023	0.0005		
score1	0.0004	0.0012	0.0013	0.0016	0.0014	0.0003		
Total	0.007	0.019	0.020	0.025	0.023	0.005		**0.099**

score/weight	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**		**Total**
score5	0.0054	0.0051	0.0057	0.0046	0.0042	0.0028		
score4	0.0034	0.0032	0.0036	0.0029	0.0027	0.0017		
score3	0.0021	0.0020	0.0022	0.0018	0.0016	0.0011		
score2	0.0013	0.0012	0.0014	0.0011	0.0010	0.0007		
score1	0.0008	0.0008	0.0009	0.0007	0.0006	0.0004		
Total	0.013	0.012	0.014	0.011	0.010	0.007		**0.067**
I	**I1**	**I2**	**I3**	**I4**	**I5**	**I6**		
score5	0.0189	0.0107	0.0179	0.0041	0.0087	0.0056		
score4	0.0119	0.0067	0.0113	0.0026	0.0055	0.0035		
score3	0.0073	0.0041	0.0069	0.0016	0.0034	0.0022		
score2	0.0045	0.0025	0.0042	0.0010	0.0021	0.0013		
score1	0.0028	0.0016	0.0027	0.0006	0.0013	0.0008		
Total	0.0189	0.0107	0.0179	0.0041	0.0087	0.0056		**0.158**
	0.045	0.026	0.043	0.010	0.021	0.014		1.00

5.2.5 Measuring the performance of one project

In order to know how well each indicator is performing, the objective matrix techniques described in Chapter 3 are used. The weighting of the indicators and sub-indicators for the subjective matrix are obtained by using the mentioned AHP. For a project under evaluation, Project and design managers assign scores on a scale from one to five in reply to the question assigned to each score. Indices are then calculated for each indicator. After the scores were collected for a project, the objective matrix evaluation technique was used. Scores for each main indicator variables were multiplied by their respective weights and the sum of these variables yielded an index. The maximum index value is 500 and the minimum index value is 100. The critical index value is 250. In other words, if the indicator's index value is approaching to 500 then the performance is on its highest level and if the indicator's index value is 100 then performance is on its lowest level. The example presented in Figure 5.3, we can see that the project has a high performance in term of design quality (Indicator D), and Risk (Indicator F). However, the project suffers of poor performance in term of Understanding clients needs (Indicator A), Innovation (Indicator H), and reuse of design (Indicator G). Cost and time management (Indicator C), located on the critical line, means that the project tend to run over cost and of slack behind schedule. Action need to be taken. The weights of all the indicators are stored in the database, and the calculation of indices and the evaluation of a project are performed in an Access environment.

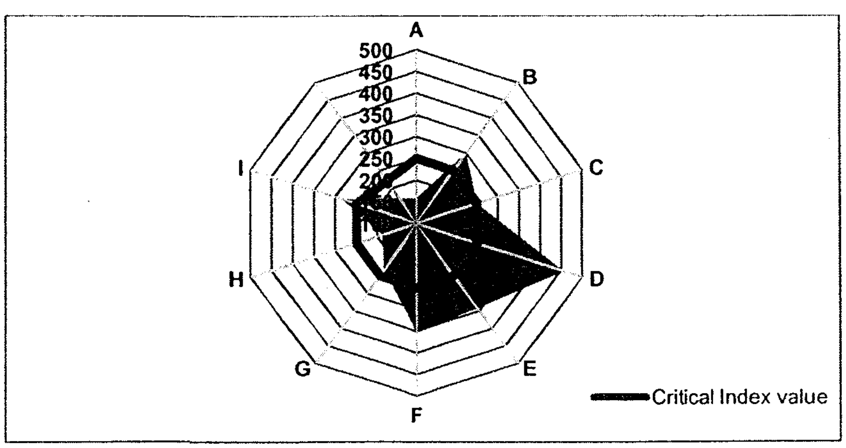


Figure 5. 3 Project Evaluation Example

An action is required to improve the design performance. The available actions are as following: 1) Redesign, 2) Major design changes, or 3) Minor design changes.

To evaluate the best taken action, the AHP described in chapter 3 is used and the following steps were taken:

1) Three levels of hierarchy structure were developed as shown in Figure 5.4. The first level is the overall goal. The second level represents the nine indicators and the third level contains the available 3 alternatives.

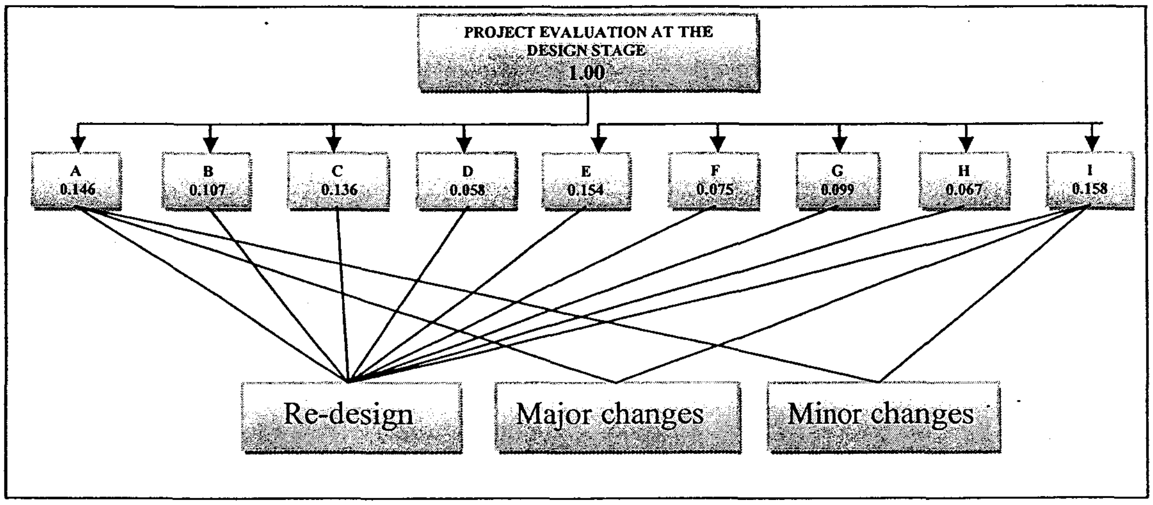


Figure 5.4 Hierarchy Structure for choosing best action

2) Pairwise comparisons were performed between the alternatives with respect to each indicator. The design manager and the project manager of project compare the three alternatives with respect to each indicator.

3) Based on the pair comparison matrices, the weight of each alternative with respect to each indicator was calculated. The total weight of each alternative is calculated using equation (5), chapter 3:

Parent weight is the average weight of each main indicator, estimated previously based on the 13 experts judgment and presented in Table 5.2.

5.3 DATABASE

Access is used as data base platform to perform the functions and the management tasks in order to measure the performance of certain projects at the design stage. As described in Chapter 3, the developed model uses a database to store and/or retrieve project data and to measure and to compare projects by using the set of nine indicators. The indicator weights and the global weight are exported from Excel work sheets. The MDPM is implemented using macros and a database environment in Access. In Access, design performance indicator forms are constructed along with their measurement sheets and saved in the data base. The basic equations for the calculations of scores are also assembled. The score for each main indicator is calculated by taking the average score for its attributes (sub-indicators). The main outputs, as mentioned in Chapter 3, are Indicator average scores, Indicator global weights, Indicator index, reports, and actions evaluation.

The developed model consists of project data entry forms and project evaluation forms. These forms contain all the necessary data to evaluate or rank projects.

The project data entry consists of project detail forms and project score forms. Project evaluation consists of project evaluation screens, compared project screens, and report pages.

5.3.1 Project Data Entry

Project details and indicator scores are the main entries in the Access database. The model consists of three project detail forms and nine indicator forms. Project detail forms are these three: 1) authentication, 2) project details, and 3) project stage. Indicator forms contain the nine groups of indicators (A to I). Each indicator is used to measure the performance of the design stage of a project using a scale from 1 to 5. Components of these forms are explained as follows:

Project Details Form

The Project Details screen enables the user to specify project information. Figure 5.5 is a snapshot of the Project Details screen. In this screen, the user can fill in the necessary information about each project. These data are the following: the project name, the project type, the industry sector, the procurement method, the design fees, and the client type. Once the user fills in the project detail the project is assigned an identification number (ID). The project commencement date and the completion date are also indicated on this screen.

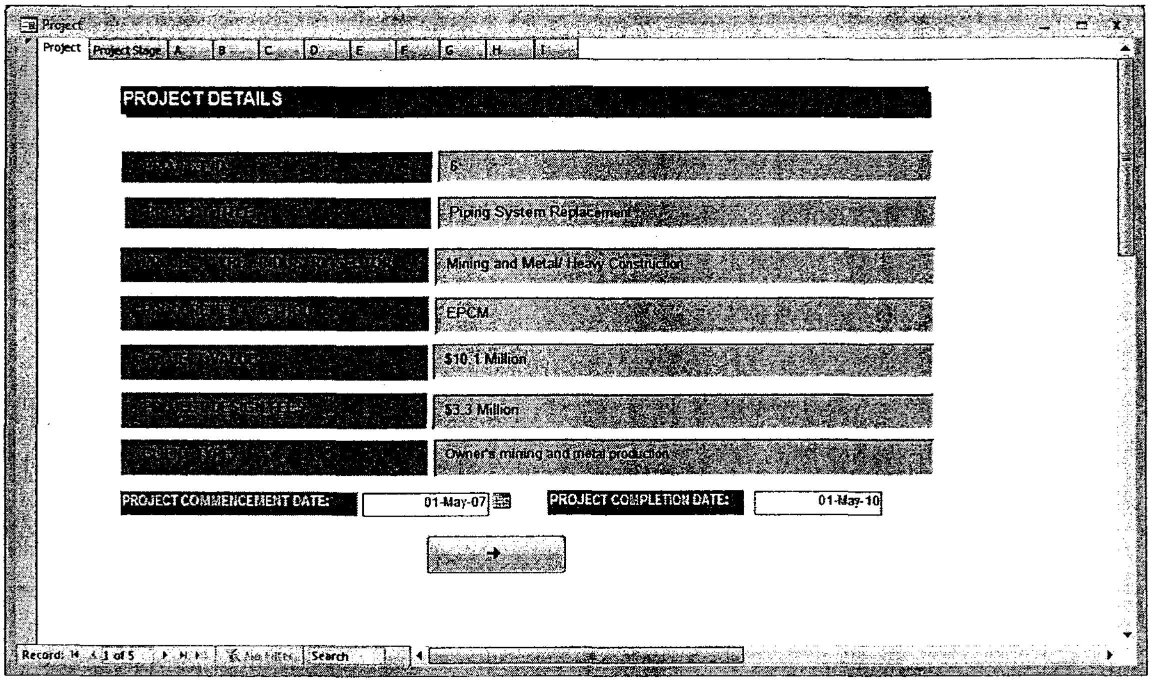


Figure 5.5 Project Details Form

Project Stage Form

As presented in Figure 5.6, through this screen the users choose for which stage of the project they are measuring the performance and the percentage completed of the required work on that stage. This screen is mainly useful when measuring performance during the design stage or before the project is completed, where leading indicators are used to measure the performance of the design stage of the project. However, to get an accurate measurement, it is important to indicate the percentage of that stage of the project that has been completed.

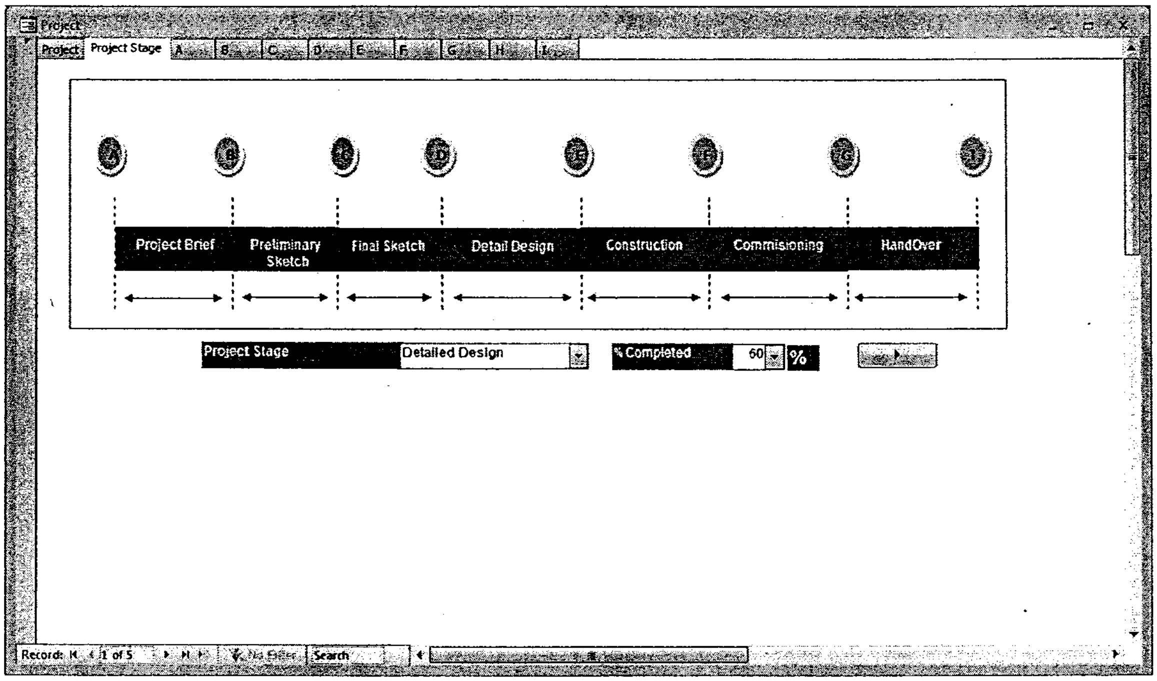


Figure 5. 6 Project Stage Selection Screen

Indicator Score Screens

After giving the project details, the user is required to enter the indicator scores. This task can be performed during or after the completion of the design stage or project. Figure 5.7 shows the main screen for the Understanding Client Needs performance indicator. This screen is divided into two parts: the left-hand part, representing the indicator detail information. The right-hand part is the measuring sheet arranged on a scale from 1 to 5 where 5 represents the best score and 1 is the worst. Nine screens with the same design were constructed for the nine groups of indicators (A, B, C, D, and I).

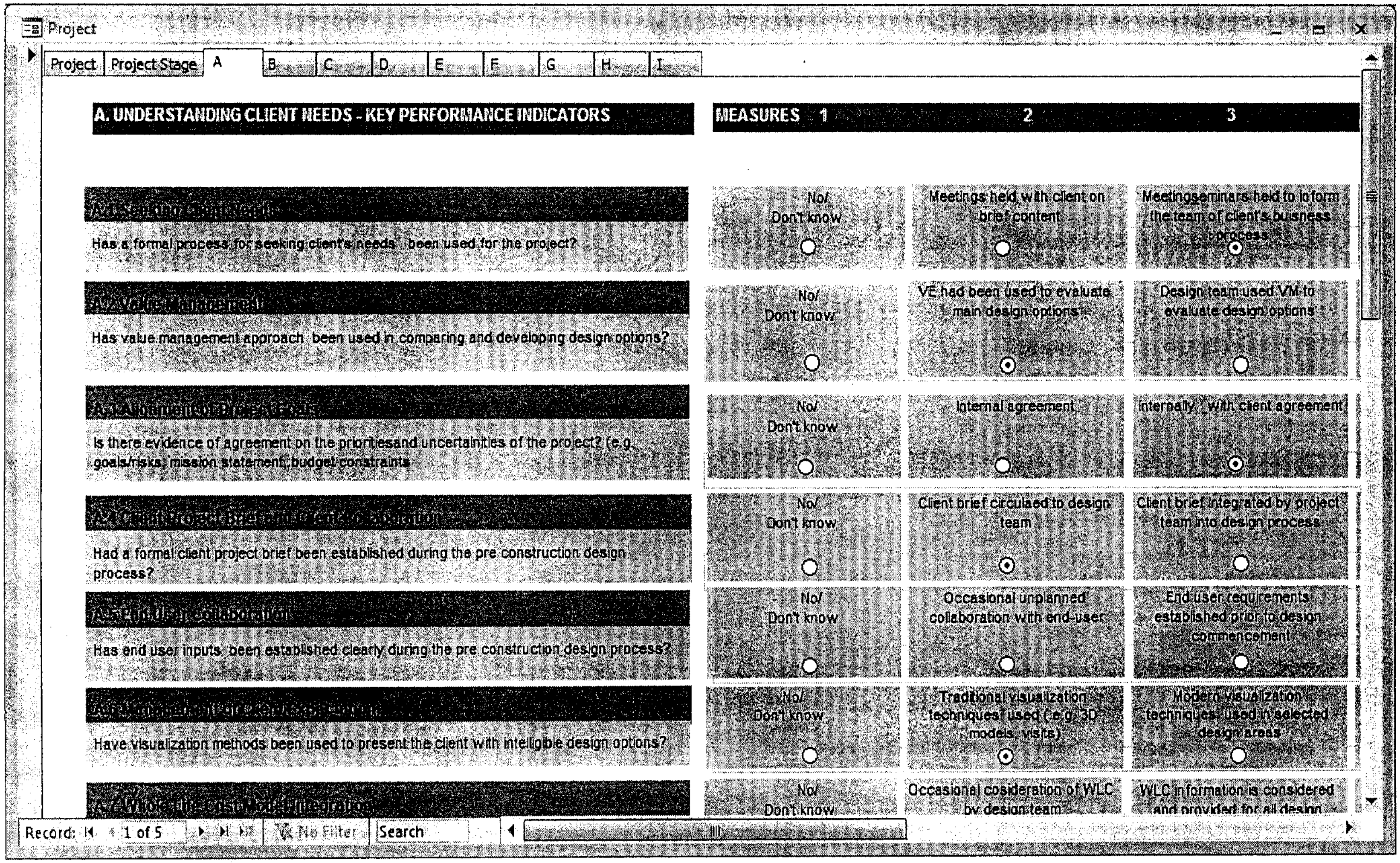


Figure 5. 7 Understanding client needs design key performance indicator main screen.

5.3.2 Data Evaluation and Outputs

The model provides a good tool for the evaluation and comparison of projects. For the project evaluation, the model can display how each project is performing using the nine set of indicators.

Measuring a project performance

Figure 5.8 displays the project evaluation screen. Using this screen, users can measure the performance of one project at a time. Forms for the indicators contain the name and scores of the indicator and the value of the indicator index. Once scores for the indicators are assigned, the program automatically imports the assigned weights. Each project is stored as a record. Under the icon "SHOW CHART" there are two options: SCORES and INDEX. The "SCORES" icon displays indicator scores on charts without assigning weights. The "INDEX" icon presents indicator index values. The index value as mentioned in Chapter 3 represents the subjective matrix method. In order to measure the project performance, each indicator criterion is compared to the total index value of 500. The closer to 500 the better the performance is.

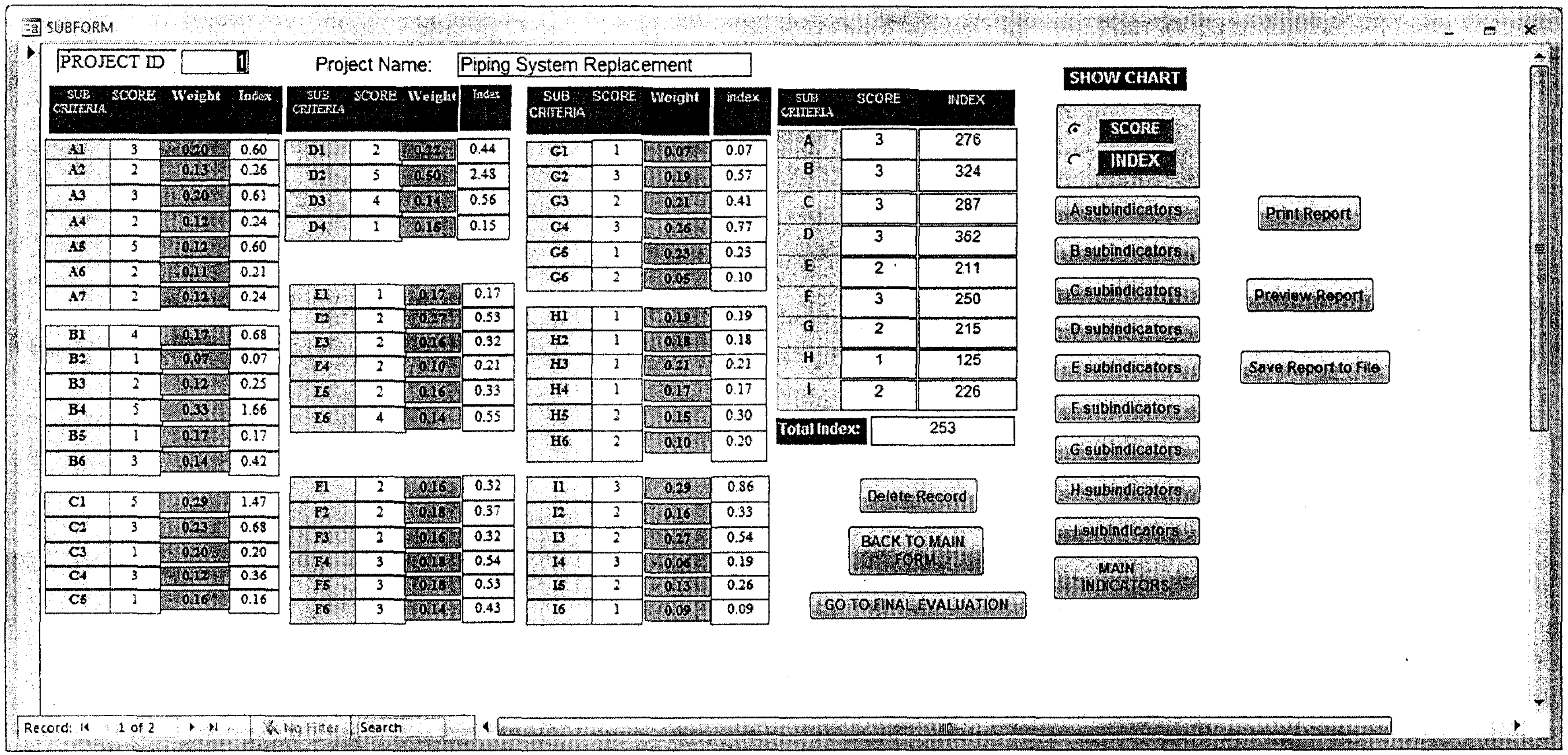
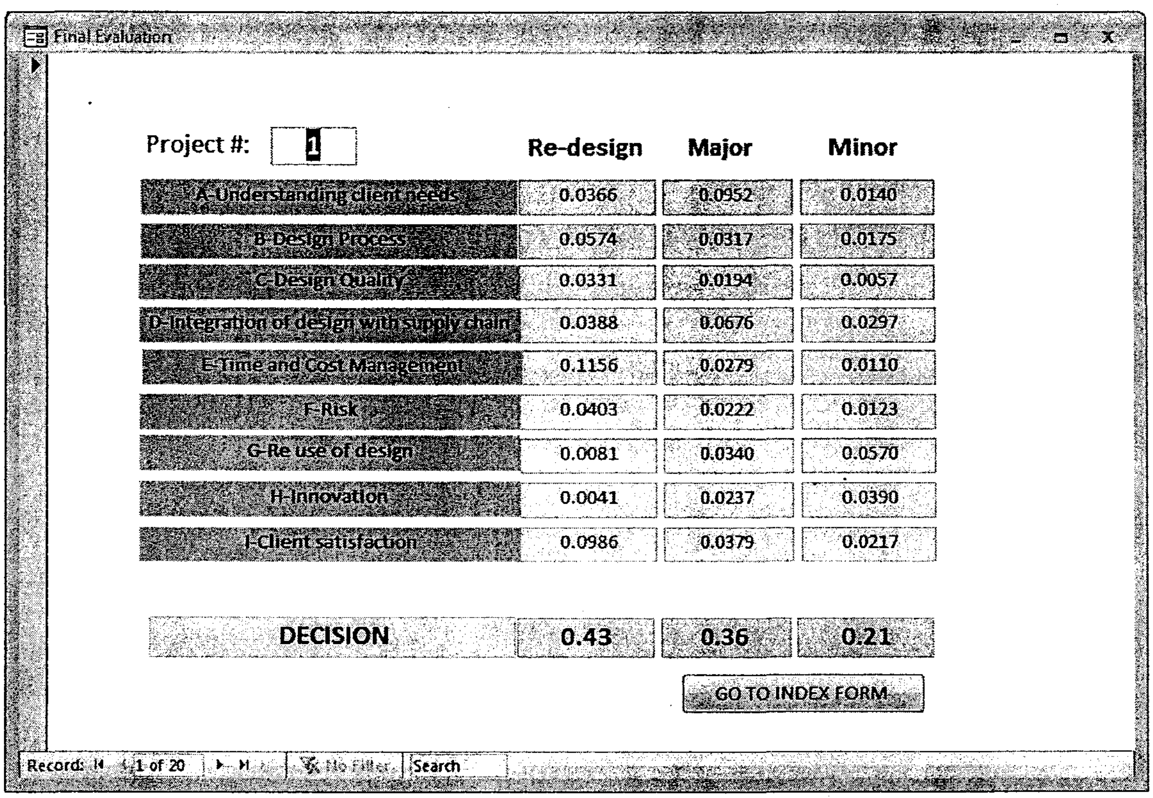


Figure 5. 8 Project Evaluation Screen

Evaluating the best taken action

Through this screen, project or design manager evaluate the best taken actions. Figure 5.9, presents the results of comparing the three design actions, Re-design, Major design changes, and Minor design changes were compared with respect to each indicator, using the AHP described in section 5.2.5. The result of this analysis is a weight of each analyzed action. The highest weight presents the best action to take.



Project #: 1	Re-design	Major	Minor
A-Understanding client needs	0.0366	0.0952	0.0140
B-Design Process	0.0574	0.0317	0.0175
C-Design Quality	0.0331	0.0194	0.0057
D-Integration of design with supply chain	0.0388	0.0676	0.0297
E-Time and Cost Management	0.1156	0.0279	0.0110
F-Risk	0.0403	0.0222	0.0123
G-Re use of design	0.0081	0.0340	0.0570
H-Innovation	0.0041	0.0237	0.0390
I-Client satisfaction	0.0986	0.0379	0.0217
DECISION	0.43	0.36	0.21

Figure 5. 9 Final Evaluation Screen

Comparing projects performance

Based on saved records (projects), the model can use the submitted project scores to compare different projects. Figure 6.10 presents a compared projects screen. This screen contains project IDs, overall weight, and rank. Wanting to get details about a specific indicator, the user can choose a project and check its sub-indicator. Figure 5.11 displays a project global weight screen. This screen contains the name and scores of the indicator, the indicator global weight, and the total score %.

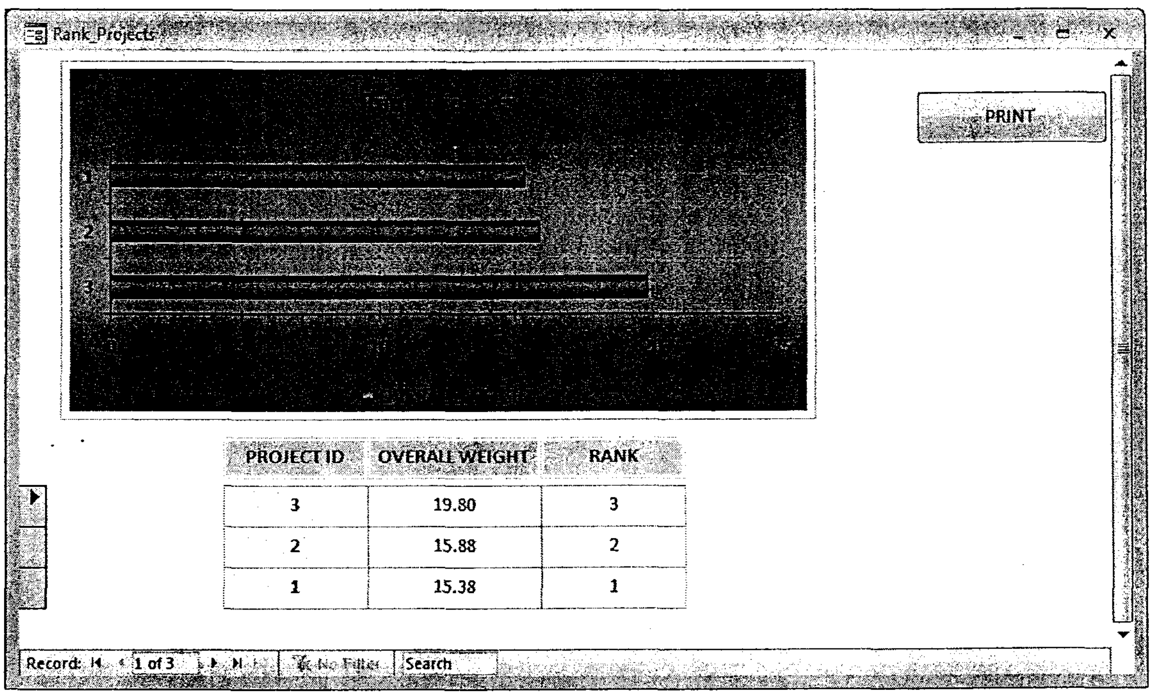


Figure 5.10 Rank Projects Screen

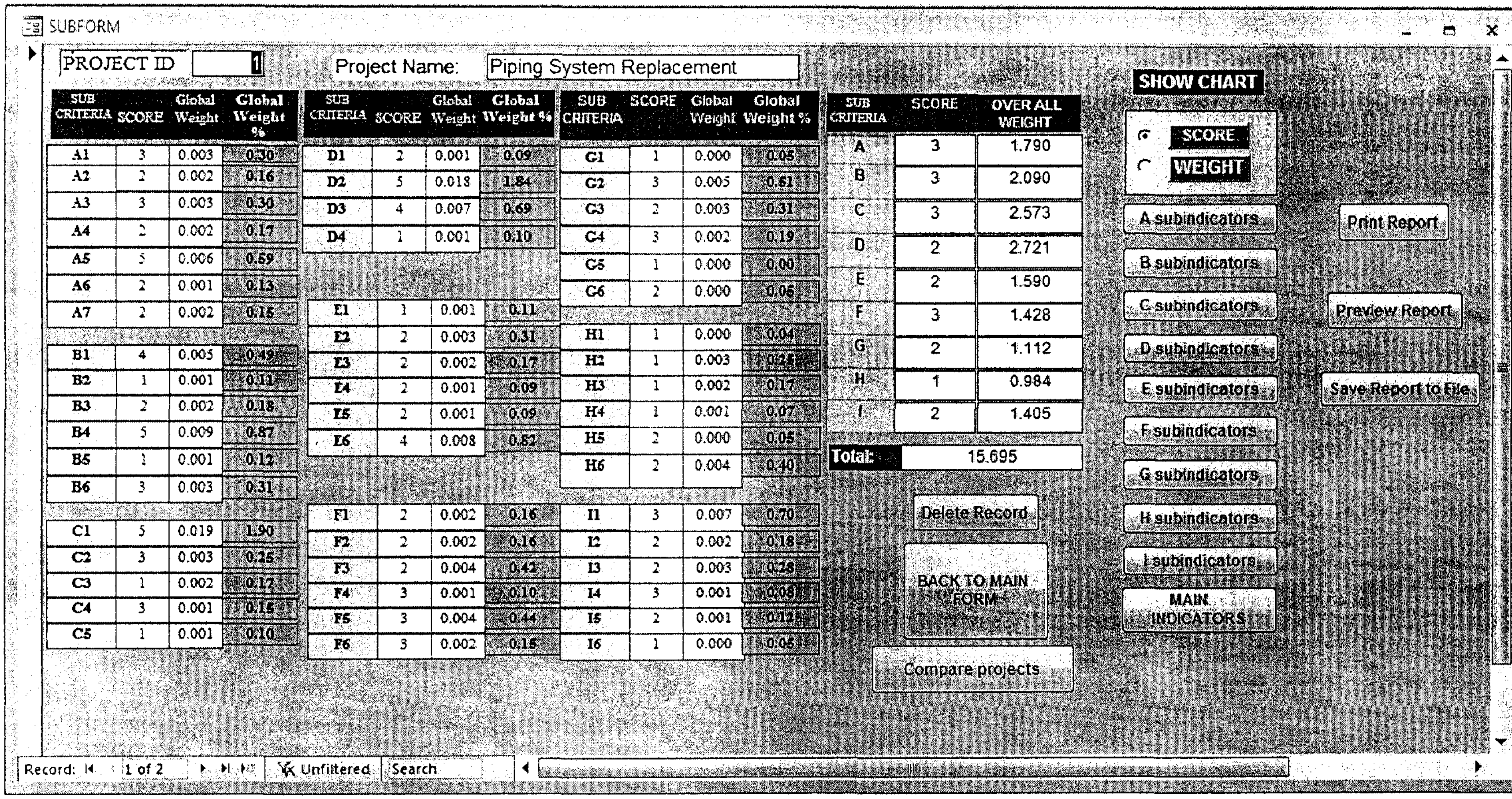


Figure 5. 11 Projects Global Weight Screens

Report Screen

The "Preview Report" icon displays a summary report about a project. The model provides the flexibility to produce reports based on indicator scores, index values and global weights. As presented in Figure 6.12, the report contains project details, indicator scores in the form of radar charts, percentage of work completed, and the date of the evaluation. Reports can be saved to file or deleted.

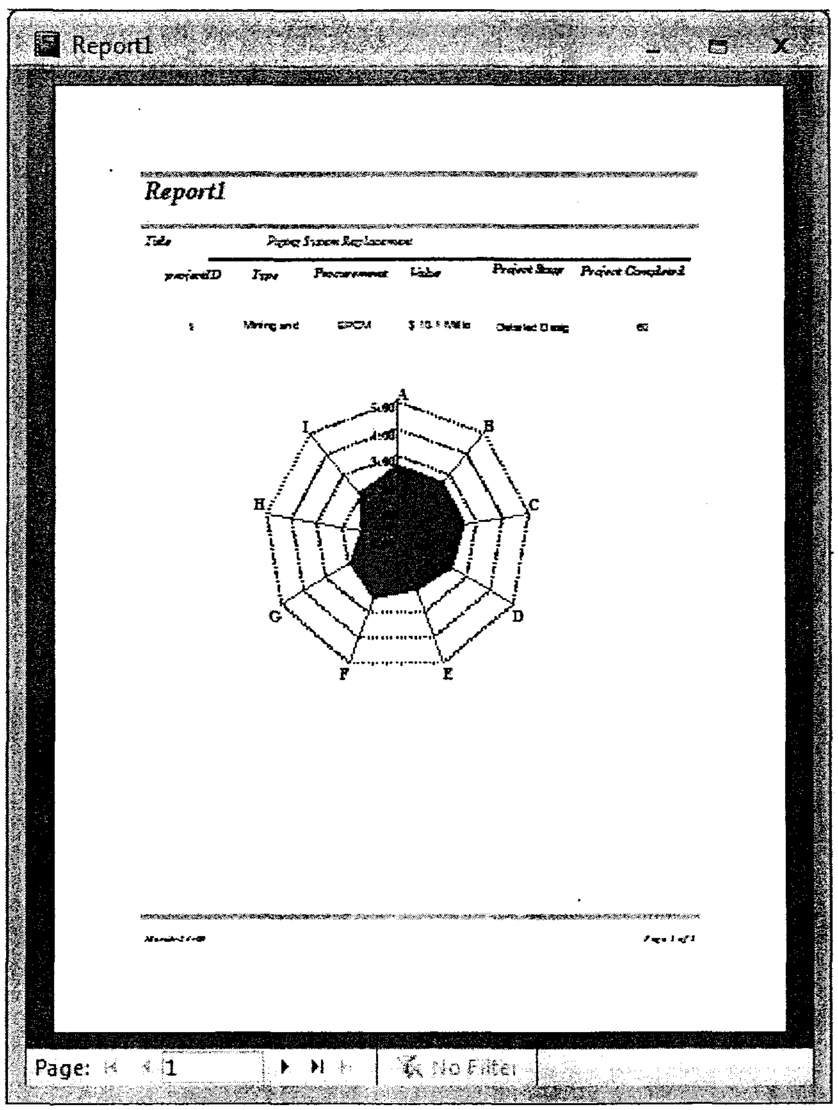


Figure 5.12 Report Screen

5.4. SUMMARY

The present chapter presented MDPM, an implementation of the developed design performance measurement model. MDPM is implemented using macros and a database environment in Access. It employed Excel to run the AHP. Access and Excel are flexible and easy to use software. They can carry the necessary procedures of the implementation. An Access model and an Excel environment were briefly presented. An AHP that was essential to get the weights and the global weights of indicators was described.

The functionality of the MDPM was described. User data entry, data evaluation, and outputs in Access were given special attention. However, this yields a friendly usable tool to measure the performance of the design stage of a construction project.

CHAPTER 6: CASE STUDIES AND PERFORMANCE EVALUATION

6.1 INTRODUCTION

Design performance indicators are used to measure the performance of projects at its design stage. Weights were formulated and assigned to each design performance indicator and a model is developed to perform the necessary functions as outlined in the previous chapter.

To better demonstrate the application of design performance indicators and to test the developed model, case studies on 2 ongoing projects were examined. Interviews were conducted with design and project managers to verify the practicality and usefulness of the developed model. Data for these projects is extracted by requesting experts from the two projects to provide their assessments. Objective information such as cost and time were drawn from the chosen companies' databases. Qualitative information such as client satisfaction is difficult to obtain, since it is available only from the stakeholders of the projects and not readily to attain from records or data bases. Members of the client teams for the chosen cases were interviewed in order to evaluate how their projects were performed by using design indicators using the developed model, i.e., to indicate their level of satisfaction. This Chapter presents the details and discussions regarding of the 2 cases.

6.2 CASE STUDY 1: MINING AND METAL PROJECT1

This case example is an actual case from the construction industry, used to illustrate the model's capability to measure the design stage performance. For confidentiality reasons, detailed data about this project is not presented here. However, this project involves replacing some existing piping system, adding particle analyzers to the system and modifying the instrumentation and the expert system. The main aim of this project is to improve the grinding capabilities of certain material. The project was started in May 2007, and it is estimated to be completed by May 2010, with a budget of 10.1 Million. .Up until March 2009 the project is still on its design stage. The project suffered of cost overrun after 60 % of the engineering work is completed. The project went through Value Engineering exercise and its forecasted budget is $14 Million in Canadian Dollars, as shown in Figure 6.1. After 15% of the engineering was completed, the project experienced cost overrun and the project mangers decided to stop the work and re-design the project. The EPCM (Engineering, Procurement, and Construction Management) route is used to procure this project. However 25% of the procurement costs were considered as sunk costs.

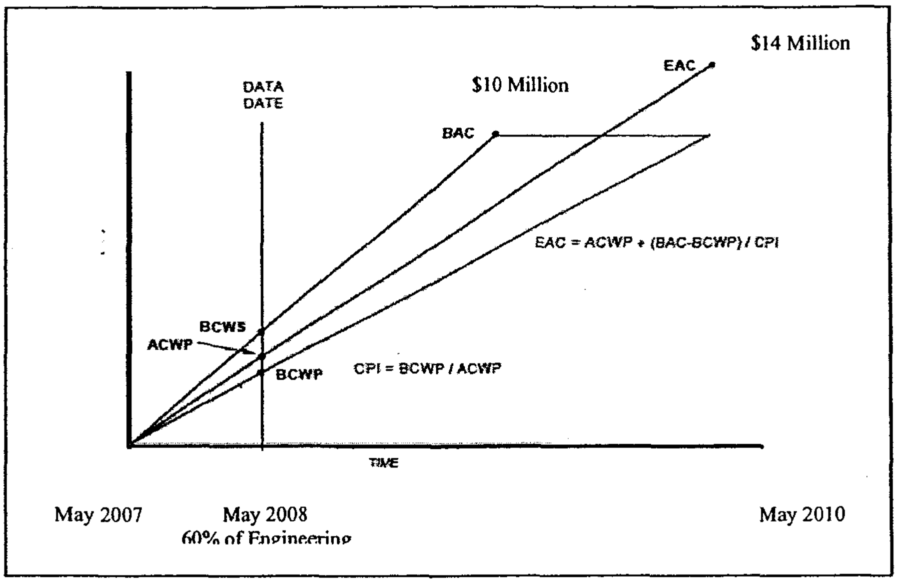


Figure 6. 1 Forecasting the estimate at completion

6.2.1 Case Study 1: Design Performance Data

The developed model is used to evaluate the performance of this project using the design performance indicators. As shown in Figure 6.1, this project is in its design stage, 25% of the engineering work is completed. The project is expected to finish by May 2010. The project manager was interviewed and participated in filling the scores for the indicators. Project performance data was gathered when 60% of the design work was completed and before the re-design decision was taken. Project performance data were entered into the developed model. The scores were entered into the database and the results are summarised in Table 6.1 and Figure 6.2.

Table 6. 1 Mining and Metal Project1Design Performance Indicators Scores

A	UNDERSTANDING CLIENT NEEDS	Score
A1	Seeking client needs	3
A2	Value management	2
A3	Alignment of project goals	3
A4	Client project brief	2
A5	End user collaboration	5
A6	Management of client expectation	2
A7	Whole life cost model integration	2
Average Score		3

B	DESIGN PROCESS	Score
B1	Implementation of environmental management	4
B2	implementation of health and safety procedures	1
B3	Change control Management	2
B4	resource plan	5
B5	documented and audited design process	1
B6	Formal design program	3
Average Score		3

C	INTEGRATION OF DESIGN WITH SUPPLY CHAIN	Score
C1	Integration of project knowledge	5
C2	Integration of Design data exchange	3
C3	The involvement of specialist design and construction expertise during the pre construction design process	1
C4	Benefit derived through design supply chain integration	3
C5	Project benefits from firm's management	1
Average Score		3

D	DESIGN QUALITY	Score
D1	Frequency of changes to the original plans & specifications	2
D2	Clarity and ease of plans & specifications	5
D3	No. of questions comes from contractor requesting clarification of plans & specifications	4
D4	Frequency of Architects and Engineers site visit to resolve problems	1
Average Score		3

Table 6. 1 Mining and Metal Project1Design Performance Indicators Scores (continued)

E	TIME AND COST MANAGEMENT	Score
E1	Cost estimate of design	1
E2	Cost impact of design change	2
E3	Cost impact of design errors	2
E4	Estimated time for design	2
E5	Time impact of design change	2
E6	Time impact of design errors	3
	Average Score	2

F	RISK	Score
F1	Defining risk assessment process	2
F2	Risk identification techniques	2
F3	Formal design program with all design team at the start of projects	2
F4	Risk Mitigation plan	3
F5	reviewing of Risk assessment undertaken	3
F6	Accuracy of risk	3
	Average Score	3

G	RE-USE OF DESIGN EXPERIENCES	Score
G1	use of recycled design	1
G2	Availability and accessibility of standards details from previous projects	3
G3	Design review and feedback	2
G4	Project reviews at completion	3
G5	Feed back of the result of the project completion reviews	1
G6	project publicity	2
	Average Score	2

H	INNOVATION	Score
H1	Technological innovation	1
H2	Process innovation	1
H3	Design sub phase for IndicatorH3	1
H4	Over all use of innovation on project	1
H5	Feedback of the innovative ideas	2
H6	New client inquiries based on the use of innovative solutions	2
	Average Score	1

Table 6. 1 Mining and Metal Project1Design Performance Indicators Scores (continued)

I	CLIENT SATISFACTION	Score
I1	Client satisfaction with the finished construction product	3
I2	Client satisfaction with time of the finished construction product	2
I3	Client satisfaction with cost of the finished construction	2
I4	*Obtaining and documenting project feedback from all clients on the* design service	3
I5	Obtaining and documented project feedback from all clients on the design product	2
I6	Obtaining and documenting project feedback from all end users on the design product	1
Average Score		2

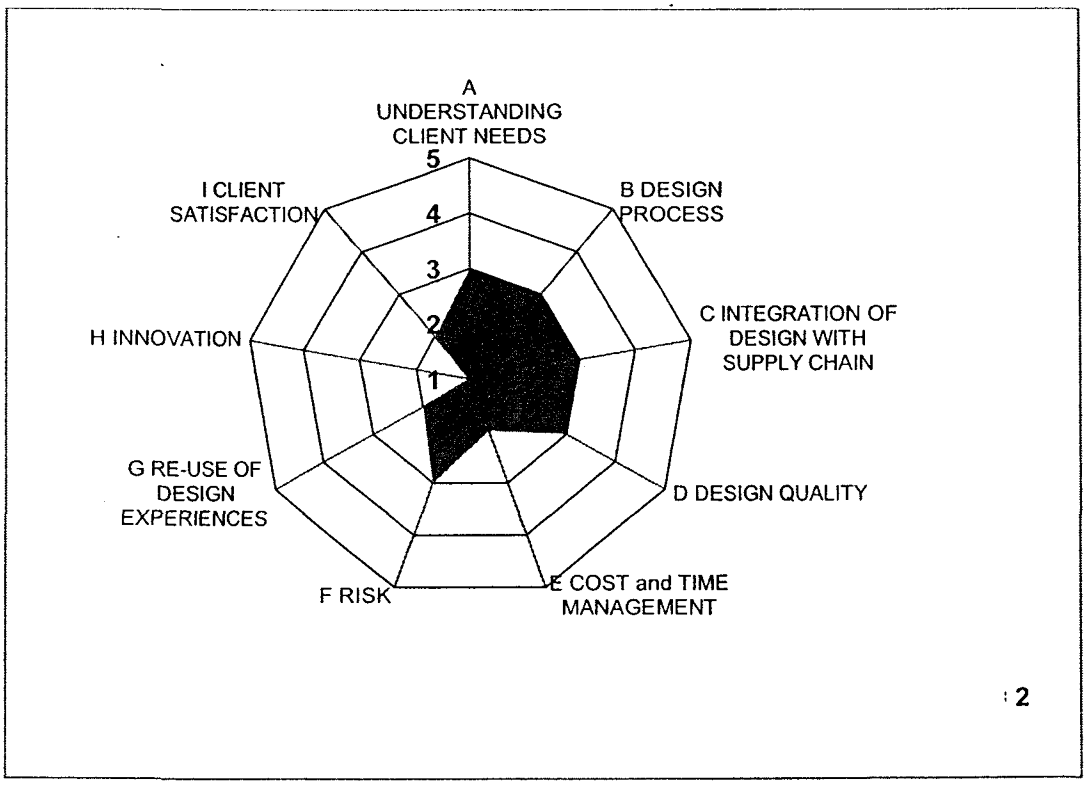


Figure 6. 2 Average Design Performance Scores

6.2.2 Case Study 1: Evaluation

The weighting procedure is applied to each indicator and the project design performance is evaluated using the developed model. The results that are presented in Figure 6.3 indicate that the project has an overall average performance in term of Understanding Clients Needs (Indicator A), Design Process (indicator B), Integration of Design team with Supply Chain (Indicator C), and Design Quality.

The indicator groups with the poorest performance index, Innovation (Indicator H), Cost and time management (Indicator E), Reuse of Design (Indicator G) and Client Satisfaction (Indicator I) are below the critical index line. Risk (Indicator F) is located on the critical line means attention is required. Indicators below the critical line e means that the project tends to run over cost, or tend slack behind schedule, or suffer of bad quality and not satisfying the client, action is required.

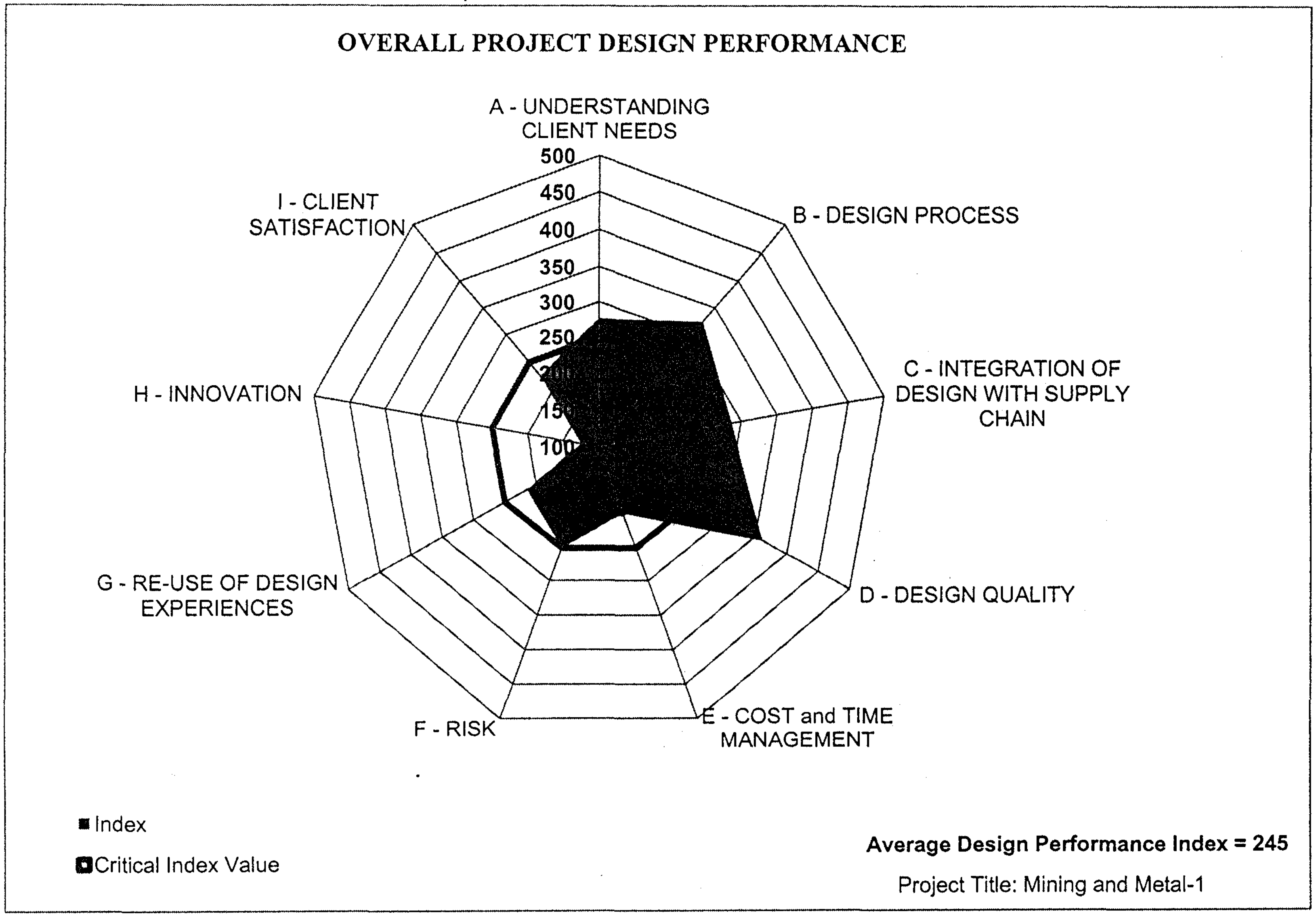


Figure 6. 3 Overall Design Performance Evaluation of the Mining and Metal Project 1

Cost and Time Management (Indicator E) is considered the second most important indicator as it constitute a weight of 0.154. Looking back to scores of this indicator group can determine the cause of the poor performance (see Figure 6.4). The Cost estimate of Design (Indicator E1) was recorded the lowest and poorest performance score. The final cost increased by more than 10% compared to the original budgeted cost. Time impact of design error is above the average only increased the cost of design by 5 -10% compared the initial estimate. Indicators E2, E3, E4, and E5 have a satisfied performance.

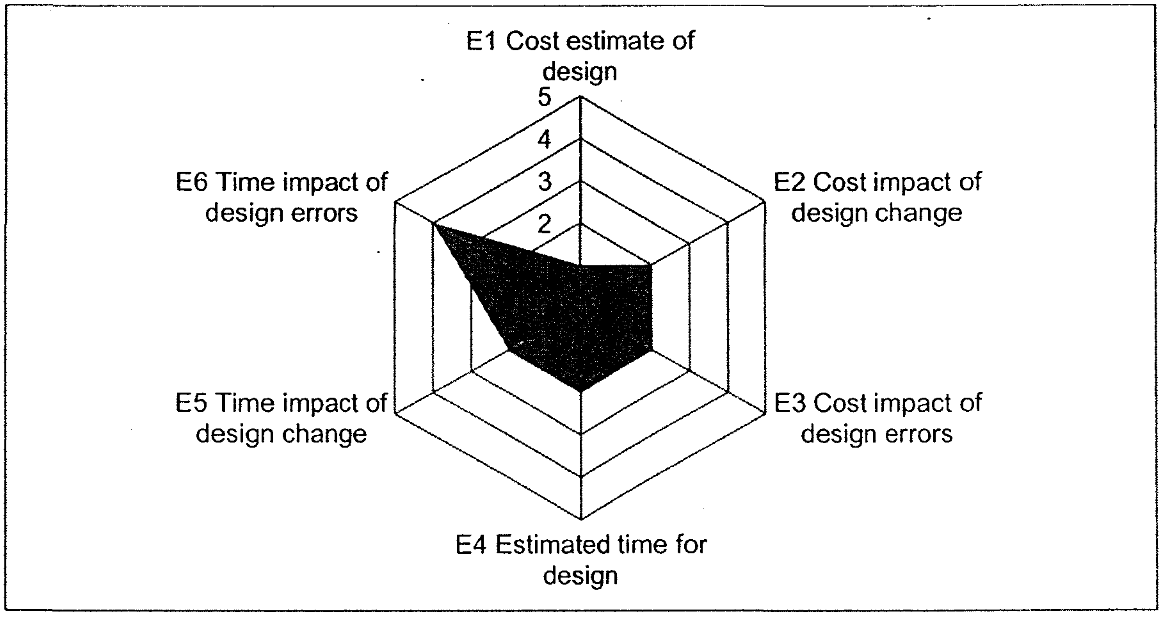


Figure 6. 4 Cost and Time Management Scores

For this project, an action is required to improve the design performance. To evaluate the best taken action, the AHP described in chapter 5 is used and the following steps were taken:

1) A hierarchy structure similar to the one shown in Figure 5.4 is developed. The hierarchy consists of three levels, the first level is the overall goal, the second level represents the nine indicators and the third level contains the available 3 alternatives.

2) The design and the project managers of this project compared the three actions with respect to each indicator. Table 6.2 presents the comparison of the alternatives with respect to each indicator.

3) Based on the pairwise comparison matrices, the weight of each alternative with respect to each indicator is calculated and presented in Table 6.3.

Table 6. 2 Comparison of the Alternatives with Respect to each indicator.

A- Understanding Client Needs				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	0.33	3.00	0.251
Major Changes	3.00	1.00	6.00	0.653
Minor Changes	0.33	0.17	1.00	0.096
CR = 0.02				

B- Design Process				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	2.00	3.00	0.539
Major Changes	0.50	1.00	2.00	0.297
Minor Changes	0.33	0.50	1.00	0.164
CR = 0.01				

Table 6. 2 Comparison of the Alternatives with Respect to each indicator (continued)

C- Integration of Design with Supply Chain				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	0.50	1.50	0.285
Major Changes	2.00	1.00	2.00	0.497
Minor Changes	0.67	0.50	1.00	0.218
CR = 0.02				

D- Design Quality				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	2.00	5.00	0.568
Major Changes	0.50	1.00	4.00	0.334
Minor Changes	0.20	0.25	1.00	0.098
CR = 0.02				

E- Time and Cost Management				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	5.00	9.00	0.748
Major Changes	0.20	1.00	3.00	0.180
Minor Changes	0.11	0.33	1.00	0.071
CR = 0.03				

F- Risk				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	2.00	3.00	0.539
Major Changes	0.50	1.00	2.00	0.297
Minor Changes	0.33	0.50	1.00	0.164
CR = 0.01				

G- Re use of design				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	0.20	0.17	0.082
Major Changes	5.00	1.00	0.50	0.343
Minor Changes	6.00	2.00	1.00	0.575
CR = 0.07				

Table 6. 2 Comparison of the Alternatives with Respect to each indicator (continued)

H- Innovation				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	0.14	0.13	0.062
Major Changes	7.00	1.00	0.50	0.354
Minor Changes	8.00	2.00	1.00	0.584
CR = 0.03				

I- Client Satisfaction				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	3.00	4.00	0.623
Major Changes	0.33	1.00	2.00	0.239
Minor Changes	0.25	0.50	1.00	0.137
CR = 0.02				

Table 6. 3 Alternatives Weights with respect to each Indicator

	Understanding Client Needs	Design Process	Integration of Design with Supply Chain
Redesign	0.25	0.54	0.285
Major Changes	0.65	0.30	0.497
Minor Changes	0.10	0.16	0.218

	Design Quality	Time and Cost Management	Risk
Redesign	0.568	0.748	0.539
Major Changes	0.334	0.180	0.297
Minor Changes	0.098	0.071	0.164

	Re use of design	Innovation	Client Satisfaction
Redesign	0.082	0.062	0.623
Major Changes	0.343	0.354	0.239
Minor Changes	0.575	0.584	0.137

Each alternative total weight is calculated using Equation 5 in chapter 5 section 5.2.5. The alternatives priorities are presented in Table 6.4.

Table 6.4 Alternatives Priorities

Alternative	Priority
Redesign	0.43
Major Design Changes	0.36
Minor Design Changes	0.21

Based on the analysis of this case example the, the best taken action is to re-design the project. In the real case the same decision was taken.

6.3 CASE STUDY 2: MINING AND METAL PROJECT2

This case example is an actual case from the construction industry. It involves modifying some existing conveyors and adding extra screening devices with higher capability. The main aim is to optimize the screening operation of certain material. Project name, type of material, design details was not available for confidentiality reasons. The starting date of this project was May 2007 and it is estimated to be completed by August 2009. Method of delivery is EPCM. The project original budget as estimated is $7.5 Million in Canadian Dollars. As shown in Figure 6.5, at 45 % of the engineering work, the project actual cost for work performed exceeded $7 million and the forecasted budget was estimated at $9.5 Million. The project manger had not taken any decision, the design continued. Now the design stage of this project is completed, and the construction stage is to start.

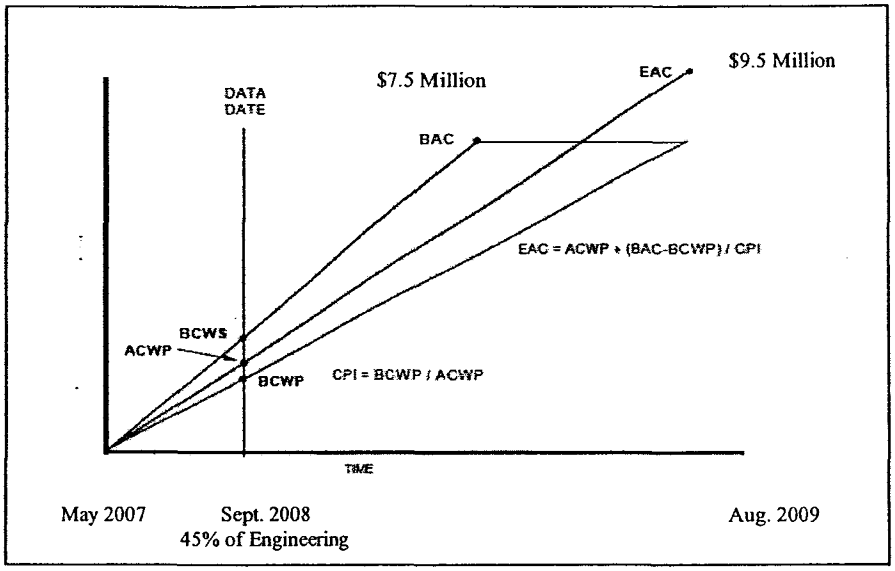


Figure 6.5 Forecasting the estimate at completion

6.3.1 Case Study 2: Design Performance Data

The design manager of this project was interviewed and participated in allocating the scores for the indicators. Project performance data was extracted when 45% of the engineering work was completed. This data is chosen to help the project manager to evaluate the main causes for the cost overrun and to take an action to overcome these problems. The scores were entered into the database and the results are summarized in Table 6.5. The average scores of the nine set of indicators are presented in Figure 6.6.

Table 6.5 Mining and Metal Project1Design Performance Indicators Scores

A	UNDERSTANDING CLIENT NEEDS	Score
A1	Seeking client needs	3
A2	Value management	2
A3	Alignment of project goals	2
A4	Client project brief	2
A5	End user collaboration	5
A6	Management of client expectation	2
A7	Whole life cost model integration	2
	Average Score	3

B	DESIGN PROCESS	Score
B1	Implementation of environmental management	4
B2	implementation of health and safety procedures	3
B3	Change control Management	3
B4	resource plan	5
B5	documented and audited design process	3
B6	Formal design program	4
	Average Score	4

C	INTEGRATION OF DESIGN WITH SUPPLY CHAIN	Score
C1	Integration of project knowledge	5
C2	Integration of Design data exchange	2
C3	The involvement of specialist design and construction expertise during the pre construction design process	1
C4	Benefit derived through design supply chain integration	5
C5	Project benefits from firm's management	1
	Average Score	3

D	DESIGN QUALITY	Score
D1	Frequency of changes to the original plans & specifications	2
D2	Clarity and ease of plans & specifications	5
D3	No. of questions comes from contractor requesting clarification of plans & specifications	4
D4	Frequency of Architects and Engineers site visit to resolve problems	2
	Average Score	3

Table 6.5 Mining and Metal Project1Design Performance Indicators Scores (Continued)

E	TIME AND COST MANAGEMENT	Score
E1	Cost estimate of design	1
E2	Cost impact of design change	2
E3	Cost impact of design errors	2
E4	Estimated time for design	2
E5	Time impact of design change	2
E6	Time impact of design errors	2
	Average Score	2

F	RISK	Score
F1	Defining risk assessment process	2
F2	Risk identification techniques	2
F3	Formal design program with all design team at the start of projects	2
F4	Risk Mitigation plan	2
F5	reviewing of Risk assessment undertaken	3
F6	Accuracy of risk	3
	Average Score	2

G	RE-USE OF DESIGN EXPERIENCES	Score
G1	use of recycled design	1
G2	Availability and accessibility of standards details from previous projects	3
G3	Design review and feedback	2
G4	Project reviews at completion	3
G5	Feed back of the result of the project completion reviews	1
G6	project publicity	2
	Average Score	2

H	INNOVATION	Score
H1	Technological innovation	1
H2	Process innovation	1
H3	Design sub phase for IndicatorH3	1
H4	Over all use of innovation on project	1
H5	Feedback of the innovative ideas	2
H6	New client inquiries based on the use of innovative solutions	2
	Average Score	1

Table 6.5 Mining and Metal Project1Design Performance Indicators Scores (Continued)

I	CLIENT SATISFACTION	Score
I1	Client satisfaction with the finished construction product	4
I2	Client satisfaction with time of the finished construction product	2
I3	Client satisfaction with cost of the finished construction	2
I4	Obtaining and documenting project feedback from all clients on the design service	2
I5	Obtaining and documented project feedback from all clients on the design product	2
I6	Obtaining and documenting project feedback from all end users on the design product	1
Average Score		2

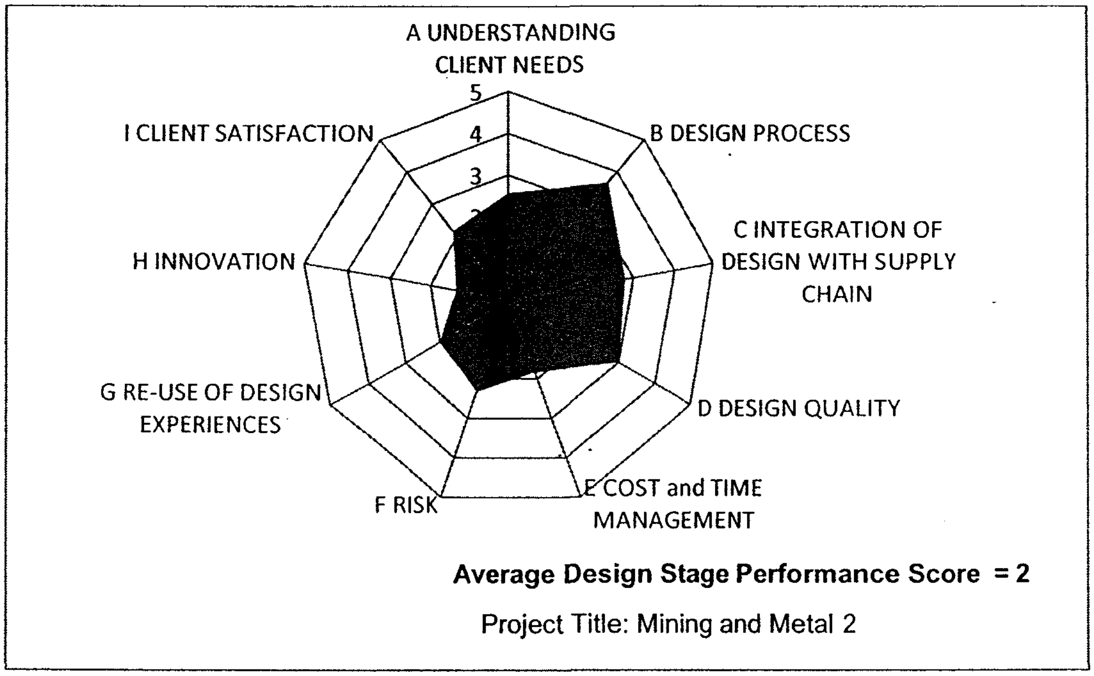


Figure 6.6 Average Design Stage Performance Score

6.3.2 Case Study 2: Evaluation

The design performance is evaluated using the developed model. The weight is applied to each indicator and the index values were calculated by multiplying each weight by the score of the indicator. The index values are presented in

Figure 6.7. The Radar chart indicates that the project has a good performance in term of Design Process (indicator B) and Design Quality (Indicator D). The chart also shows an average performance in term of Integration of Design team with Supply Chain (Indicator C). The project suffers of poor performance in term of Cost and time management (Indicator E), Risk (Indicator F), Reuse of Design (Indicator G), and Innovation (Indicator H). The chart alert that the project may not clearly understand and satisfy the client needs, however, both of these indicators are located on the critical index line.

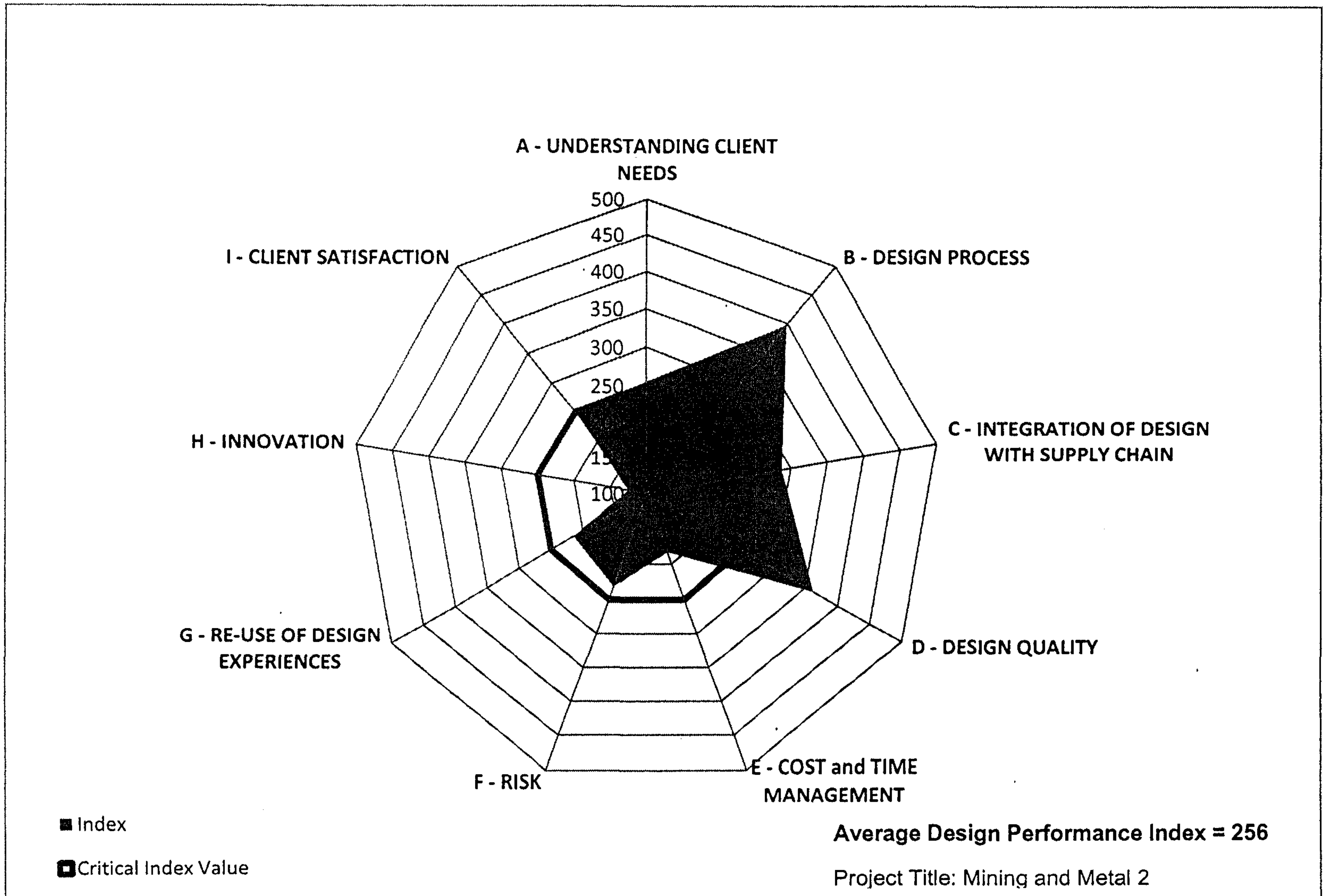


Figure 6.7 Overall Design Performance Evaluation of the Mining and Metal Project 2

Evaluating the level of importance of each indicator with respect to each decision criteria could help to determine the best action to take. However indicators with high weight, such as cost and time management, if they recorded a poor performance could lead the design team to start the designs from scratch. In this project, at 45% of the engineering work completed, the design manager has to evaluate and take an action in order to improve the performance of the design stage. The available alternatives are as following: 1) Redesign, 2) Major design changes, or 3) Minor design changes.

Since there is a poor performance in some areas, then the project manager has to evaluate and taken action, AHP analysis similar to the one described in the previous case were applied to this project. The design manager of this project compared the three actions with respect to each indicator. Table 6.6 presents the comparison of the alternatives with respect to each indicator.

Table 6.6 Comparison of the Alternatives with Respect to each indicator.

A- Understanding Client Needs				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	3.00	5.00	0.648
Major Changes	0.33	1.00	2.00	0.230
Minor Changes	0.20	0.50	1.00	0.122
CR = 0.00				

B- Design Process				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	0.33	3.00	0.260
Major Changes	3.00	1.00	5.00	0.633
Minor Changes	0.33	0.20	1.00	0.106
CR = 0.03				

Table 6.6 Comparison of the Alternatives with Respect to each indicator(continued)

C- Integration of Design with Supply Chain				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	0.50	3.00	0.320
Major Changes	2.00	1.00	4.00	0.557
Minor Changes	0.33	0.25	1.00	0.123
CR = 0.02				

D- Design Quality				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	2.00	4.00	0.557
Major Changes	0.50	1.00	3.00	0.320
Minor Changes	0.25	0.33	1.00	0.123
CR = 0.02				

E- Time and Cost Management				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	2.00	4.00	0.557
Major Changes	0.50	1.00	3.00	0.320
Minor Changes	0.25	0.33	1.00	0.123
CR = 0.02				

F- Risk				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	0.25	0.25	0.110
Major Changes	4.00	1.00	0.50	0.346
Minor Changes	4.00	2.00	1.00	0.544
CR = 0.05				

G- Re use of design				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	0.25	0.11	0.067
Major Changes	4.00	1.00	0.25	0.220
Minor Changes	9.00	4.00	1.00	0.713
CR = 0.03				

Table 6.6 Comparison of the Alternatives with Respect to each indicator(continued)

H- Innovation				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	0.14	0.13	0.062
Major Changes	7.00	1.00	0.50	0.354
Minor Changes	8.00	2.00	1.00	0.584
CR = 0.03				

I- Client Satisfaction				
	Re-design	Major Changes	Minor Changes	Weight
Re-design	1.00	0.13	0.14	0.062
Major Changes	8.00	1.00	2.00	0.584
Minor Changes	7.00	0.50	1.00	0.354
CR = 0.03				

Based on the pair comparison matrices, the weight of each alternative with respect to each indicator is calculated and presented in Table 6.7.

Table 6.7 Alternatives Weights with respect to each Indicator

	Understanding Client Needs	Design Process	Integration of Design with Supply Chain
Redesign	0.65	0.26	0.320
Major Changes	0.23	0.63	0.557
Minor Changes	0.12	0.11	0.123

	Design Quality	Time and Cost Management	Risk
Redesign	0.557	0.557	0.110
Major Changes	0.320	0.320	0.346
Minor Changes	0.123	0.123	0.544

	Re use of design	Innovation	Client Satisfaction
Redesign	0.067	0.062	0.062
Major Changes	0.220	0.354	0.584
Minor Changes	0.713	0.584	0.354

Each alternative total weight is calculated using Equation 5 in chapter 5 section 5.2.5. The alternatives priorities are presented in Table 6.8.

Table 6.8 Alternatives Priorities

Alternative	Priority
Redesign	0.31
Major Design Changes	0.41
Minor Design Changes	0.28

Based on the analysis of this case example, the best taken action is to go through major design changes, since it scored the highest weight.

6.4 SUMMARY

The aim of this chapter was to demonstrate the application of indicators to measure the performance of design activities and to establish the functionality and usability of the developed method. First, weights using the AHP method were estimated. Thirteen experts from the heavy construction sector were contacted and were asked to compare the design performance indicators in pairs. Pair-wise comparison matrices for estimating the weight were produced and covered in the present chapter.

This research implemented the indicators' weights for heavy construction projects on the developed model.

Two actual case studies drawn from the construction industry were analyzed using the developed model. The first case is replace piping system and the second is modifying and adding screening devices to a number of existing conveyors. The two cases were mining and metal projects and both were on their design stage. The design performance Indicators were used to measure the performance of the two cases. The result of the two cases highlighted areas of poor performance in the project and advised the design manager of the best action to take in order to improve the areas with poor performance. In the first case, the indicator groups with the poorest performance are index, Innovation (Indicator H), Cost and time management (Indicator E), Reuse of Design (Indicator G) and Client Satisfaction (Indicator I). However, the reason for the project bad performance was mainly related to cost and time management specifically, The Cost estimate of Design (Indicator E1), where the final cost increased by more than 10% compared to the original budgeted cost. In the second case study, the project suffers of poor performance in term of Cost and time management (Indicator E), Risk (Indicator F), Reuse of Design (Indicator G), and Innovation (Indicator H).

Also, the model alerted that the project may not clearly understand and satisfy the client needs; however, both of these indicators are located on the critical index line. An action is required. The model found that the design may go through a major design change in order to improve the areas with poor performance.

CHAPTER 7: CONCLUSIONS AND CONTRIBUTIONS

7.1 CONCLUSION

The present research provides a framework for measuring the performance of the design process in the Canadian Construction Industry. It focuses on developing a set of design performance indicators for the Canadian construction industry. These indicators can measure the degree of success of a project; they can predict, control, and measure design processes. In Canada, the detection of design and construction performance indicators is yet to be formulated and documented in assessing construction project performance across project phases.

An intensive literature review was conducted to acquire a good understanding of design and construction performance measurements. The literature review of this thesis focused on two aspects: 1) design performance measurement and 2) construction performance indicators. It was recognized that the current industry practices measure engineering and design performance during the detailed design stage of the project. The measures used were the production (the performance ratio of design work-hours per drawing) of design documents and the performance against schedule-measuring tools. The literature confirmed that the construction industry needs to develop a better understanding of the processes of design in order to measure the design performance. No research has been reported in the literature on the use of key performance indicators in Canadian construction particularly for the design stage of a project.

A framework for measuring design performance was proposed and the methods used were explained. The Analytic Hierarchy Process (AHP) method was used to calculate indicator weights. First, at the company level, global weights were estimated in order to compare and to rank different projects using the design performance indicators. Second, at the project level, along with the global weight method, the objective matrix method was used to measure the design performance of projects.

A web-based survey was structured, pretested, and distributed among professionals from the Canadian construction industry in order to identify design performance indicators. The significance and quantification of design performance indicators were determined using the SPSS 16.0 statistical package. The results from the questionnaire were used in the development of the design performance indicators. This study focused on using the identified set of design performance Indicators with heavy construction projects.

A design performance indicator model was proposed. The overall structure of the model is divided so as to be useful at two main levels, Company Level and Project Level. Both levels need to address company objectives. Company level indicators are concerned with the overall design performance of the company.

Project level indicators are used to monitor, to measure, and to improve performance. The overall aims of the model are the following: benchmarking against other companies, tracking the performance of the design activities, and improving the overall project design performance. The developed model was implemented using Macros in a Microsoft Access 2007 environment. The database was used to store and to retrieve design performance indicators, to fill in new project data, to fill in performance data in the form of a survey questionnaire, in order to track and to measure the performance of a project and finally to compare and to rank projects.

Two case studies were used to validate the viability of the developed design performance model. The cases were used to demonstrate the application of indicators to measure the performance of design activities. The design performance indicators and the developed model have proven to be useful tools for tracking, measuring, and benchmarking the performance of projects at the design stage.

In conclusion, the present research provided the first step in applying KPIs to monitor and to measure the performance of the design activities in the Canadian construction industry.

7.2 CONTRIBUTIONS

The main objective of the present research is to develop a set of performance indicators for design activities. Such a contribution enables design and construction companies to benchmark their performances at both the project level and the company level. The main contributions are as following:

1. The current practice for design performance measuring and design and construction key performance indicators were comprehensively reviewed. The review highlights the need for design measures other than just the financial data to measure the performance of the design stage of a project.

2. Two design Models were integrated in order to clarify the design sub-phase indicators that were addressed in this study to develop effective design performance measuring tools.

3. Design Key Performance Indicators were identified through a web based survey.

4. A method for measuring the design stage performance using the indicator weights is defined. The method includes the use of global weights in order to rank and compare construction projects and the use of objective matrices to measure the performance of a construction project.

5. A model for measuring the performance of the design stage at project level is introduced. The method of measurement can be applied at any stage of the design. Therefore, the model could be used as a tracking and controlling tool in the following ways:

   - The model can be used as a leading tool, since it enables the user to take action.
   - The model can be used as a lagging measurement tool to give an indication of how the overall design was performed.
   - The model allows the comparison of the performance of different projects.
   - Completing the information requested by the model results in the complete documentation of the design process.

7.3 LIMITATIONS

The limitations of this research can be described as follows:

- The sample size of 34 respondents may not be entirely representative of design and construction companies in Canada. Nevertheless, many attempts were made to increase the response rate within the time limits.
- Although the conducted design performance survey targeted the entire Canadian construction industry, this study was limited to the Montreal area and was limited to heavy construction type

- Comparison matrices used to assign indicator weights in this study are based on surveying 13 experts judgment from the heavy construction. In order to obtain more precise results, more experts should be involved.
- The model has been specifically designed to measure the performance of the design stage of a project. However, construction projects involve other stages such as construction, commissioning, and handover. The effect of the design performance measuring on these stages is not covered in this research.

7.4 FUTURE WORK

The following three areas are recommended for future development:

1. Investigation of design performance indicators

- Company level indicators need to be addressed in future work. The resulting indicators need to be investigated to establish a benchmarking tool to compare the design performance of one company against that of other companies at their design stages. This highlights the possibility of generating design performance benchmarking websites in order to benchmark the performance of design and construction companies across the Canadian construction industry.
- Internal design performance indicators differ from one company to another. However, more extensive studies should investigate the internal set of performance indicators across Canadian design and construction companies.

2. Expansion of the surveys of design performance indicators

- The identified set of design performance indicators needs to be tested in other Canadian regions and on other project types.
- The performance indicators should be identified and examined for other stages of a construction project.

3. Improvement of the model of design performance measuring
   - Exploring the possibilities of integrating the developed model with Construction Company measuring systems. This would enable a company to integrate its own internal DKPIs with the set of the identified design indicators. This could help to improve design and project performances, hence, improve the overall company performance.
   - Expansion of the developed design performance measuring model into a total project performance measuring system. This would require identifying performance indicators for all other project stages, consequently improving the model data base by including other project stages. However, this could provide a tool for measuring project performance for the Canadian construction industry.
   - Improving the developed model to include corrective action data based on the created performance reports.

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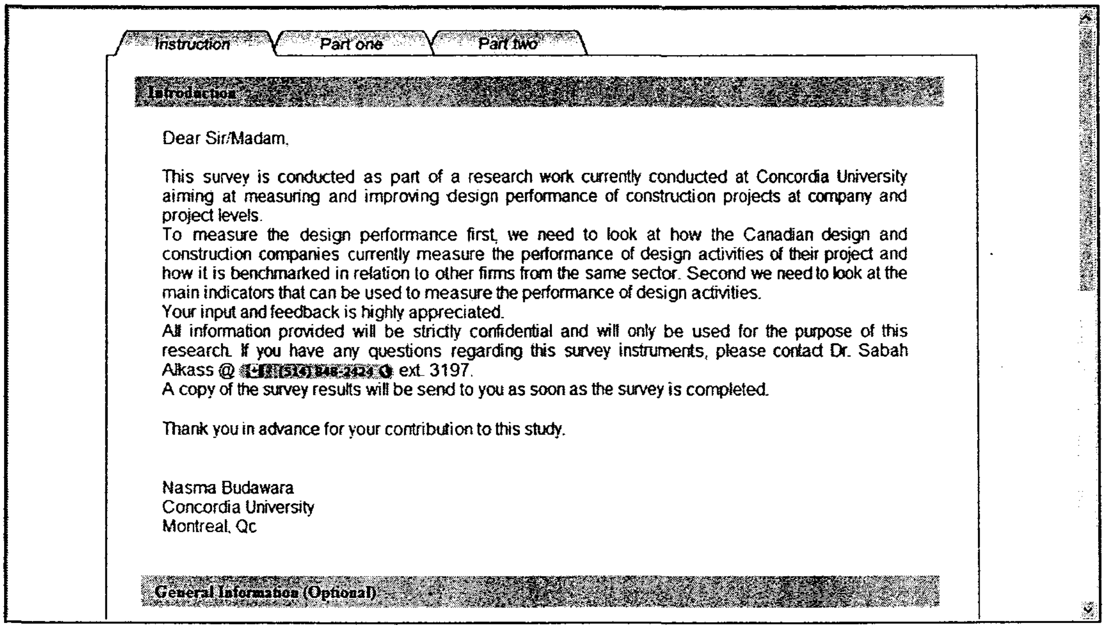
APPENDIX A: Design Performance Measurements Web- Base Survey



Instruction | Part one | Part two

Introduction

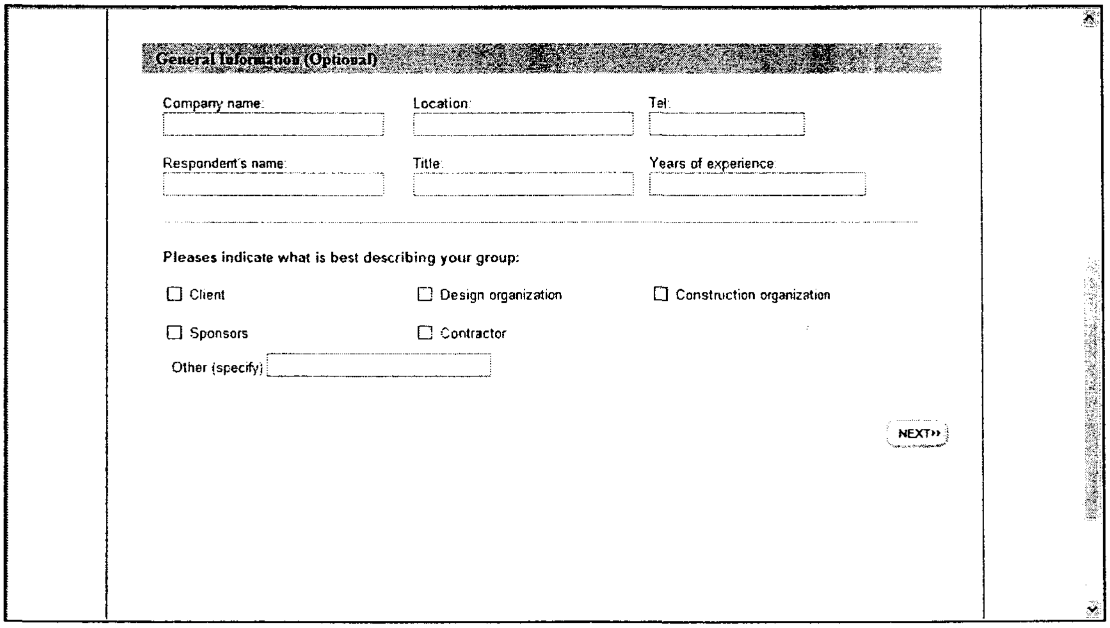
Dear Sir/Madam,

This survey is conducted as part of a research work currently conducted at Concordia University aiming at measuring and improving design performance of construction projects at company and project levels.
To measure the design performance first, we need to look at how the Canadian design and construction companies currently measure the performance of design activities of their project and how it is benchmarked in relation to other firms from the same sector. Second we need to look at the main indicators that can be used to measure the performance of design activities.
Your input and feedback is highly appreciated.
All information provided will be strictly confidential and will only be used for the purpose of this research. If you have any questions regarding this survey instruments, please contact Dr. Sabah Alkass @ [redacted] ext. 3197.
A copy of the survey results will be send to you as soon as the survey is completed.

Thank you in advance for your contribution to this study.

Nasma Budawara
Concordia University
Montreal, Qc

General Information (Optional)



General Information (Optional)

Company name: | Location: | Tel:

Respondent's name: | Title: | Years of experience:

Pleases indicate what is best describing your group:

☐ Client ☐ Design organization ☐ Construction organization

☐ Sponsors ☐ Contractor

Other (specify)

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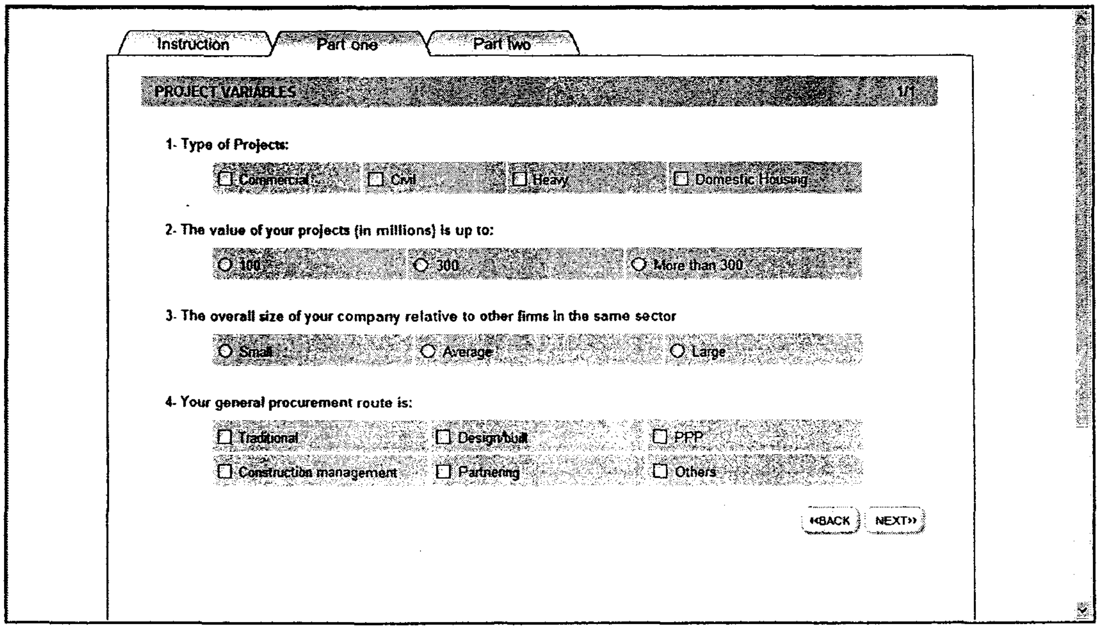
APPENDIX A: Design Performance Measurements Web- Base Survey (Continued)


Instruction | Part one | Part two

PROJECT VARIABLES 1/1

1- Type of Projects:

☐ Commercial ☐ Civil ☐ Heavy ☐ Domestic Housing

2- The value of your projects (in millions) is up to:

○ 100 ○ 300 ○ More than 300

3- The overall size of your company relative to other firms in the same sector

○ Small ○ Average ○ Large

4- Your general procurement route is:

☐ Traditional ☐ Design/built ☐ PPP

☐ Construction management ☐ Partnering ☐ Others

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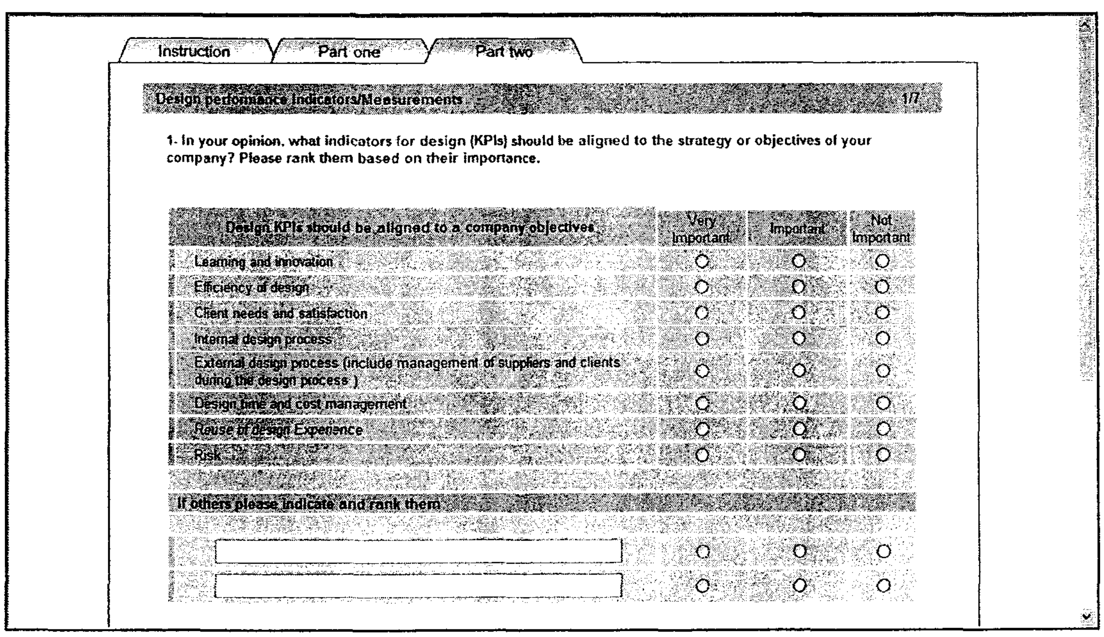
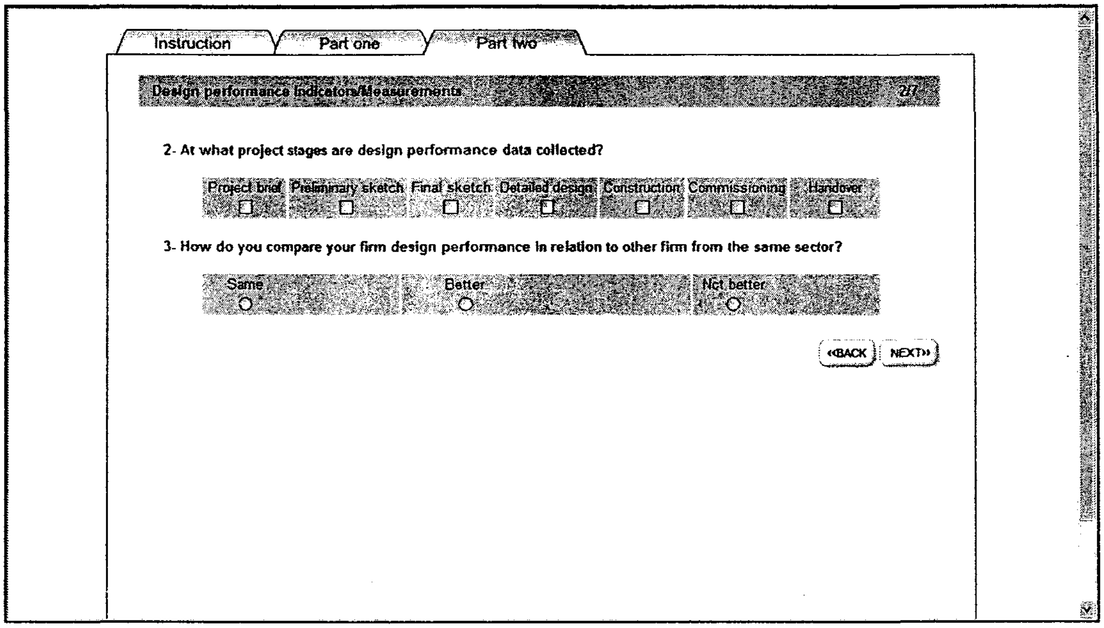

Instruction | Part one | Part two

Design performance Indicators/Measurements 1/7

1- In your opinion, what indicators for design (KPIs) should be aligned to the strategy or objectives of your company? Please rank them based on their importance.

Design KPIs should be aligned to a company objectives	Very important	Important	Not Important
Learning and innovation	○	○	○
Efficiency of design	○	○	○
Client needs and satisfaction	○	○	○
Internal design process	○	○	○
External design process (include management of suppliers and clients during the design process)	○	○	○
Design time and cost management	○	○	○
Reuse of design Experience	○	○	○
Risk	○	○	○
If others please indicate and rank them			
[ ]	○	○	○
[ ]	○	○	○

APPENDIX A: Design Performance Measurements Web- Base Survey (Continued)



Instruction | Part one | Part two

Design performance indicators/Measurements 2/7

2- At what project stages are design performance data collected?

Project brief	Preliminary sketch	Final sketch	Detailed design	Construction	Commissioning	Handover
☐	☐	☐	☐	☐	☐	☐

3- How do you compare your firm design performance in relation to other firm from the same sector?

Same	Better	Not better
○	○	○

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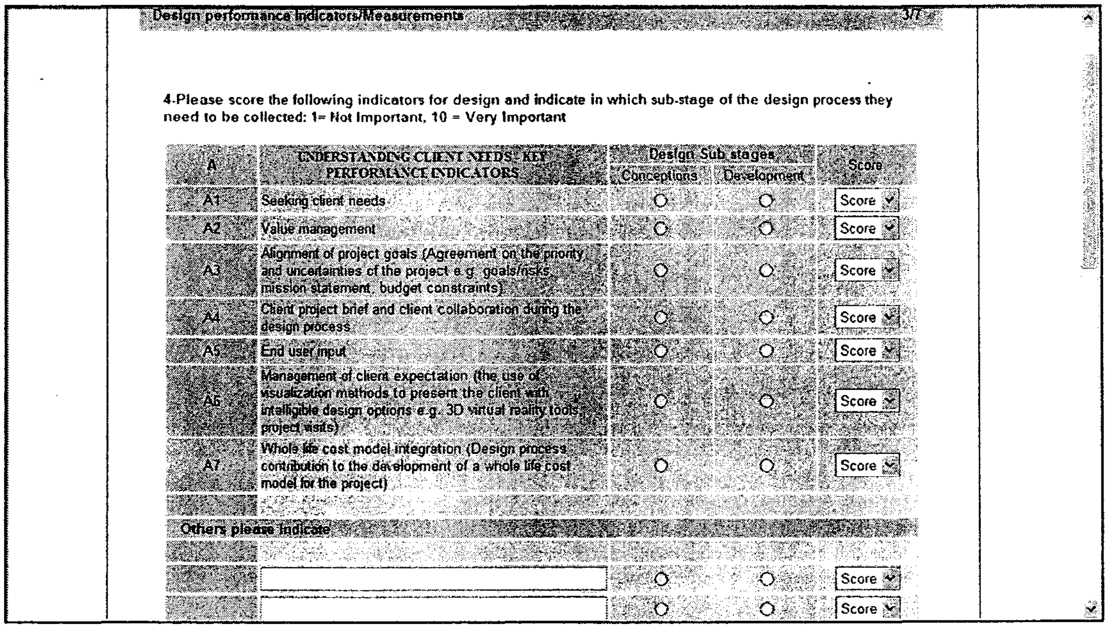
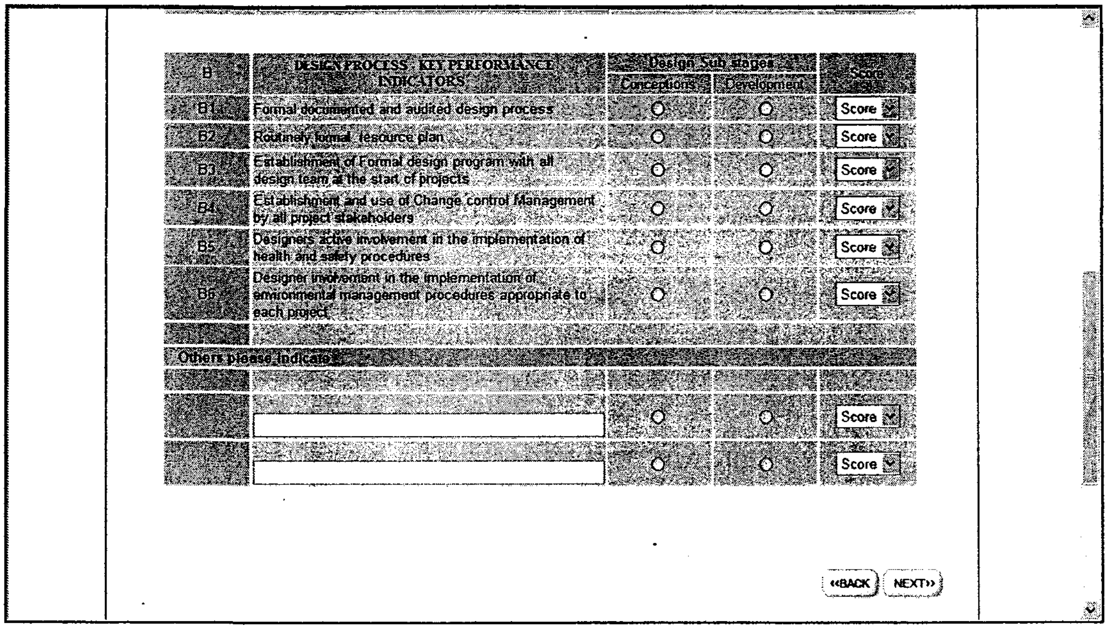


Design performance indicators/Measurements 3/7

4-Please score the following indicators for design and indicate in which sub-stage of the design process they need to be collected: 1= Not Important, 10 = Very Important

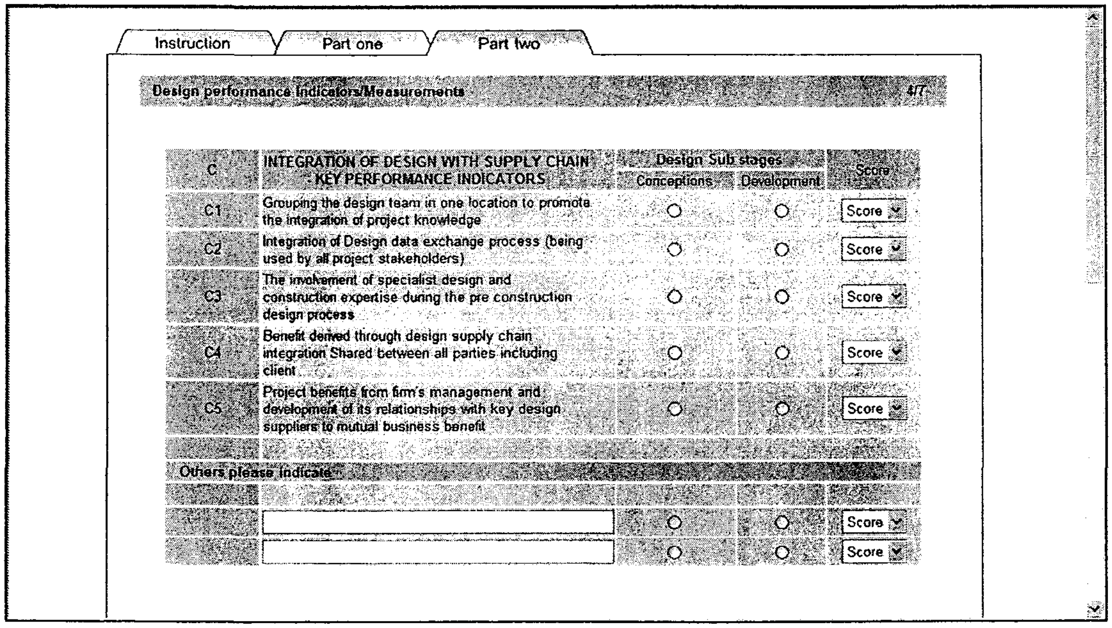
A	UNDERSTANDING CLIENT NEEDS: KEY PERFORMANCE INDICATORS	Design Sub stages: Conceptions	Development	Score
A1	Seeking client needs	○	○	Score
A2	Value management	○	○	Score
A3	Alignment of project goals (Agreement on the priority and uncertainties of the project e.g. goals/risks, mission statement, budget constraints)	○	○	Score
A4	Client project brief and client collaboration during the design process	○	○	Score
A5	End user input	○	○	Score
A6	Management of client expectation (the use of visualization methods to present the client with intelligible design options e.g. 3D virtual reality tools, project visits)	○	○	Score
A7	Whole life cost model integration (Design process contribution to the development of a whole life cost model for the project)	○	○	Score
Others please indicate				
		○	○	Score
		○	○	Score

APPENDIX A: Design Performance Measurements Web- Base Survey (Continued)



B	DESIGN PROCESS KEY PERFORMANCE INDICATORS	Design Sub stages		Score
		Conceptions	Development	
B1	Formal documented and audited design process	O	O	Score
B2	Routinely formal resource plan	O	O	Score
B3	Establishment of Formal design program with all design team at the start of projects	O	O	Score
B4	Establishment and use of Change control Management by all project stakeholders	O	O	Score
B5	Designers active involvement in the implementation of health and safety procedures	O	O	Score
B6	Designer involvement in the implementation of environmental management procedures appropriate to each project	O	O	Score
Others please indicate				
		O	O	Score
		O	O	Score

«BACK NEXT»

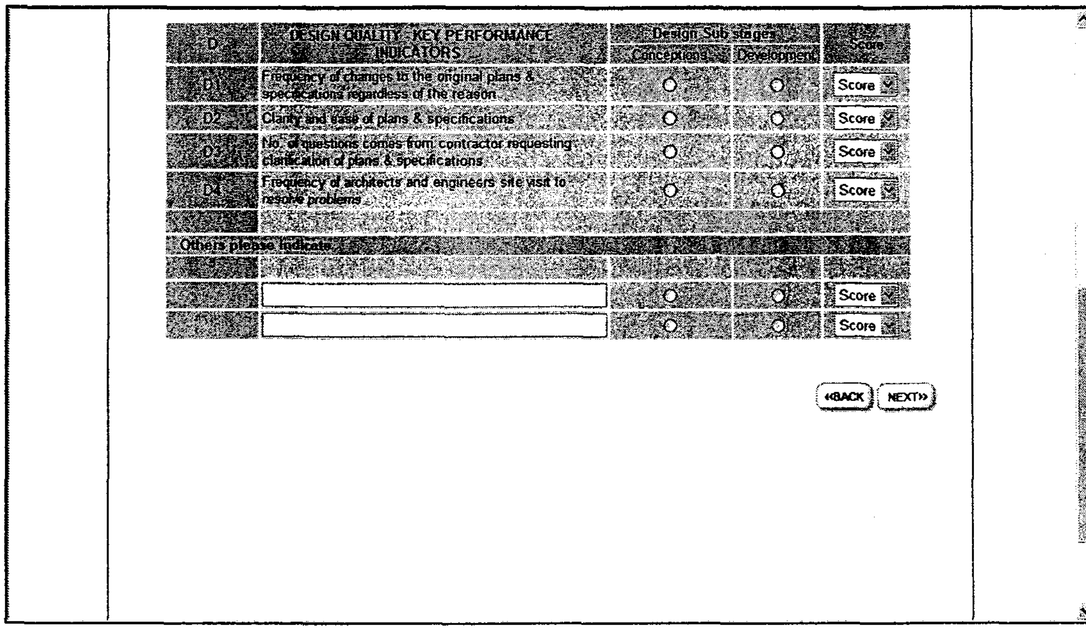


Instruction | Part one | Part two

Design performance Indicators/Measurements 4/7

C	INTEGRATION OF DESIGN WITH SUPPLY CHAIN KEY PERFORMANCE INDICATORS	Design Sub stages		Score
		Conceptions	Development	
C1	Grouping the design team in one location to promote the integration of project knowledge	O	O	Score
C2	Integration of Design data exchange process (being used by all project stakeholders)	O	O	Score
C3	The involvement of specialist design and construction expertise during the pre construction design process	O	O	Score
C4	Benefit derived through design supply chain integration Shared between all parties including client	O	O	Score
C5	Project benefits from firm's management and development of its relationships with key design suppliers to mutual business benefit	O	O	Score
Others please indicate				
		O	O	Score
		O	O	Score

APPENDIX A: Design Performance Measurements Web- Base Survey (Continued)



D	DESIGN QUALITY - KEY PERFORMANCE INDICATORS	Design Sub stages		Score
		Conceptions	Development	
D1	Frequency of changes to the original plans & specifications regardless of the reason	○	○	Score
D2	Clarity and ease of plans & specifications	○	○	Score
D3	No. of questions comes from contractor requesting clarification of plans & specifications	○	○	Score
D4	Frequency of architects and engineers site visit to resolve problems	○	○	Score
Others please indicate				
		○	○	Score
		○	○	Score

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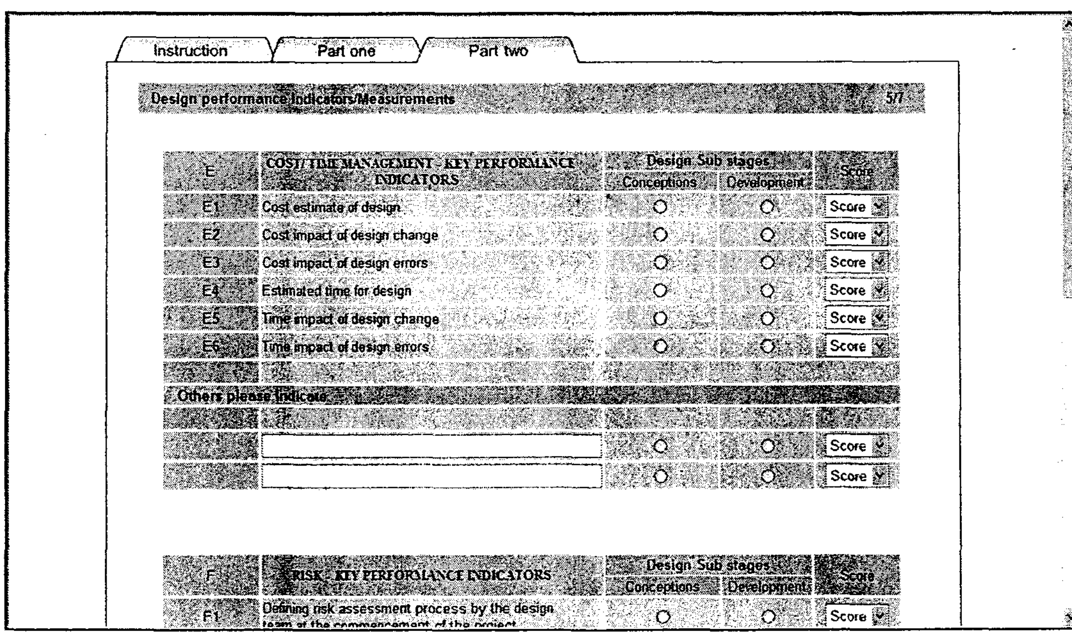

Instruction | Part one | Part two

Design performance Indicators/Measurements 5/7

E	COST/ TIME MANAGEMENT - KEY PERFORMANCE INDICATORS	Design Sub stages		Score
		Conceptions	Development	
E1	Cost estimate of design	○	○	Score
E2	Cost impact of design change	○	○	Score
E3	Cost impact of design errors	○	○	Score
E4	Estimated time for design	○	○	Score
E5	Time impact of design change	○	○	Score
E6	Time impact of design errors	○	○	Score
Others please indicate				
		○	○	Score
		○	○	Score

F	RISK - KEY PERFORMANCE INDICATORS	Design Sub stages		Score
		Conceptions	Development	
F1	Defining risk assessment process by the design team at the commencement of the project	○	○	Score

APPENDIX A: Design Performance Measurements Web- Base Survey (Continued)

F	RISK - KEY PERFORMANCE INDICATORS	Design Sub stages		Score
		Conceptions	Development	
F1	Defining risk assessment process by the design team at the commencement of the project	○	○	Score
F2	The use of formal risk identification techniques	○	○	Score
F3	Establishment of Formal design program with all design team at the start of projects	○	○	Score
F4	Risk Mitigation plan	○	○	Score
F5	Continues Monitoring and reviewing of Risk assessment undertaken	○	○	Score
F6	Accuracy of risk	○	○	Score
Others please indicate				
		○	○	Score
		○	○	Score

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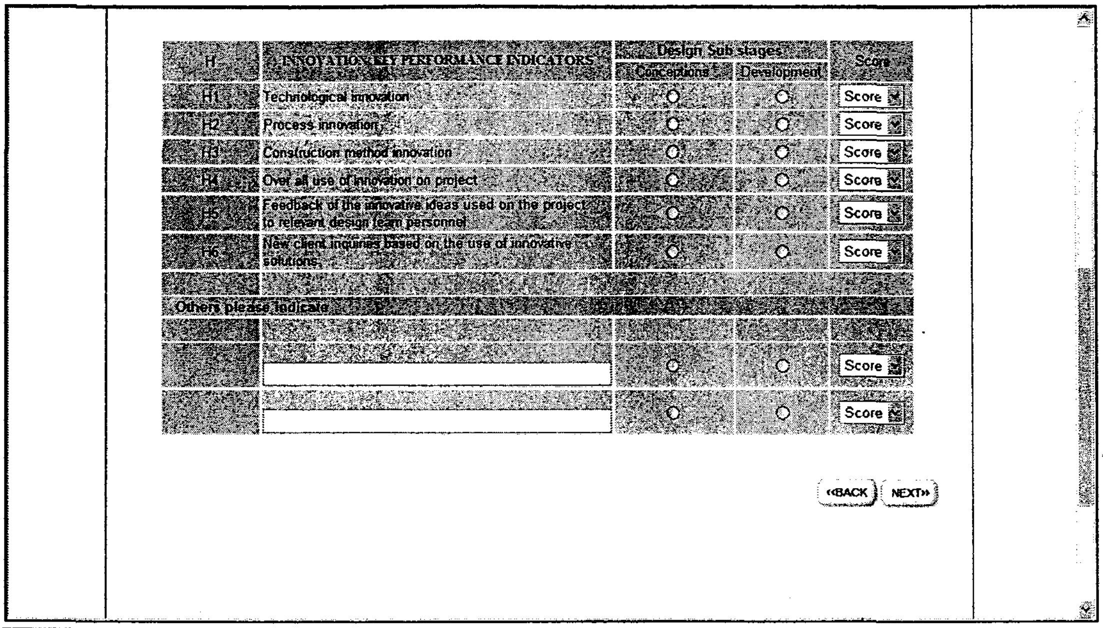
Instruction | Part one | Part two

Design performance Indicators/Measurements 6/7

G	RE-USE OF DESIGN KEY PERFORMANCE INDICATORS	Design Sub stages		Score
		Conceptions	Development	
G1	Benefit from the use of recycled design	○	○	Score
G2	Availability and accessibility of standards details/ specifications and/or innovative solutions from previous projects to relevant design personnel	○	○	Score
G3	Design review and feedback (design reviews being held and recorded at key project milestone, and integrated with on going project activities)	○	○	Score
G4	Project reviews at completion to identify factors might have affected successes or failure	○	○	Score
G5	Feed back of the result of the project completion reviews	○	○	Score
G6	project publicity (publications, presentations, awards, citations etc)	○	○	Score
Others please Indicate				
		○	○	Score
		○	○	Score

APPENDIX A: Design Performance Measurements Web- Base Survey (Continued)



H	INNOVATION KEY PERFORMANCE INDICATORS	Design Sub stages		Score
		Conceptions	Development	
H1	Technological innovation	○	○	Score
H2	Process innovation	○	○	Score
H3	Construction method innovation	○	○	Score
H4	Over all use of innovation on project	○	○	Score
H5	Feedback of the innovative ideas used on the project to relevant design team personnel	○	○	Score
H6	New client inquiries based on the use of innovative solutions	○	○	Score
Others please indicate				
		○	○	Score
		○	○	Score

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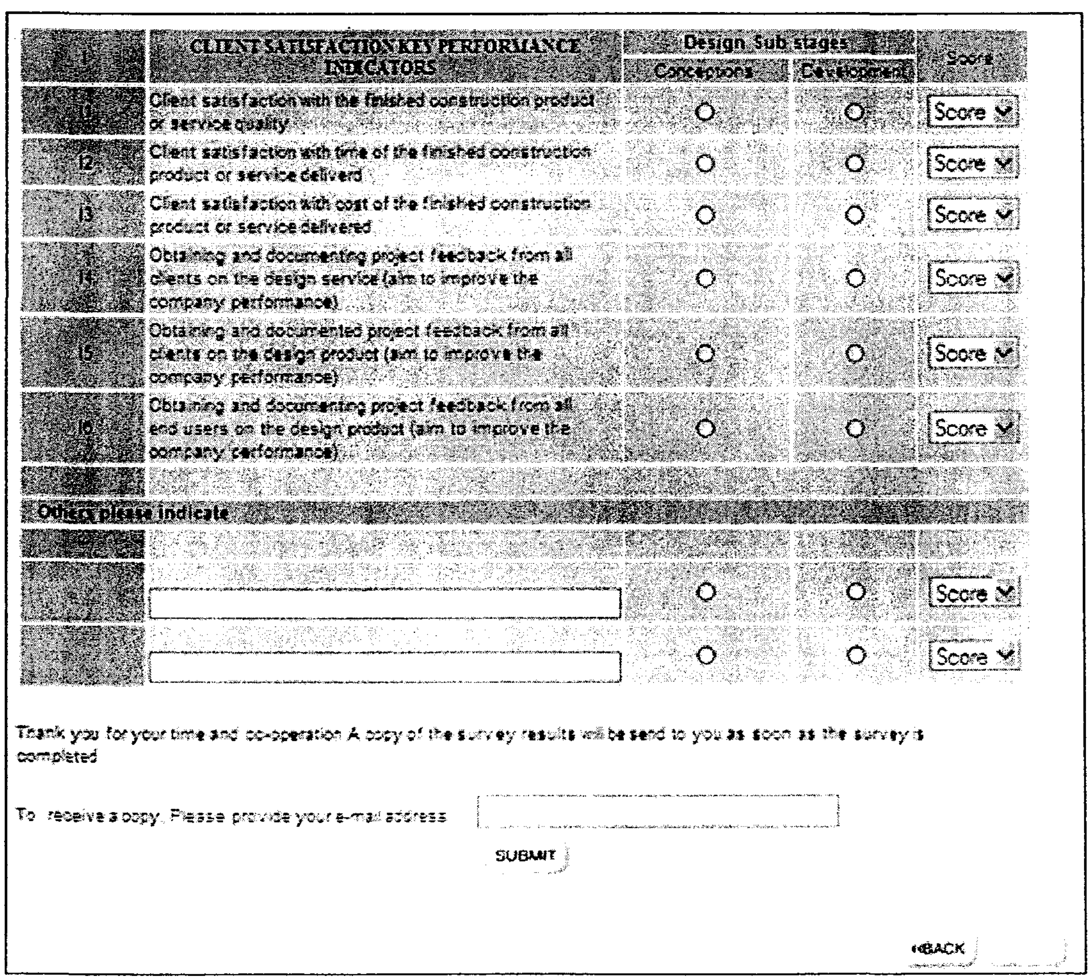

I	CLIENT SATISFACTION KEY PERFORMANCE INDICATORS	Design Sub stages		Score
		Conceptions	Development	
I1	Client satisfaction with the finished construction product or service quality	○	○	Score
I2	Client satisfaction with time of the finished construction product or service deliverd	○	○	Score
I3	Client satisfaction with cost of the finished construction product or service delivered	○	○	Score
I4	Obtaining and documenting project feedback from all clients on the design service (aim to improve the company performance)	○	○	Score
I5	Obtaining and documented project feedback from all clients on the design product (aim to improve the company performance)	○	○	Score
I6	Obtaining and documenting project feedback from all end users on the design product (aim to improve the company performance)	○	○	Score
Others please indicate				
		○	○	Score
		○	○	Score

Thank you for your time and co-operation A copy of the survey results will be send to you as soon as the survey is completed

To receive a copy. Please provide your e-mail address

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Appendix B: Design Performance Indicators' Data Summary

Variable		Items	N	Mean	Std. Deviation
A Client needs	A1	Seeking client needs	33	8.88	1.053
	A2	Value management	33	7.70	1.287
	A3	Alignment of project goals	32	8.25	1.437
	A4	Client project brief	33	8.09	1.284
	A5	End user collaboration	33	7.76	1.953
	A6	Management of client expectation	33	7.79	1.495
	A7	Whole life cost model integration	32	7.84	1.526
B Design Process	B1	implementation of environmental management	32	7.41	1.932
	B2	implementation of health and safety procedures	31	7.52	1.768
	B3	Change control Management	32	7.84	1.706
	B4	resource plan	32	8.09	1.855
	B5	documented and audited design process	32	8.16	1.462
	B6	Formal design program	32	7.94	1.625
C Design Integration with supply chain	C1	integration of project knowledge	32	7.72	1.727
	C2	Integration of Design data exchange	32	8.31	1.281
	C3	The involvement of specialist design and construction expertise during the pre construction design process	32	8.28	1.276
	C4	Benefit derived through design supply chain integration	31	7.71	1.755
	C5	Project benefits from firm's management	32	7.63	1.561
D Design Quality	D1	Frequency of changes to the original plans & specifications	32	6.94	2.169
	D2	Clarity and ease of plans & specifications	32	7.97	1.787
	D3	No. of questions comes from contractor requesting clarification of plans & specifications	31	7.19	1.939
	D4	Frequency of Architects and Engineers site visit to resolve problems	32	7.00	2.396
E Cost/Time Management	E1	Cost estimate of design	30	8.47	1.279
	E2	Cost impact of design change	30	8.43	1.455
	E3	Cost impact of design errors	30	7.97	1.650
	E4	Estimated time for design	30	7.53	1.961
	E5	Time impact of design change	30	8.07	1.799
	E6	Time impact of design errors	30	8.00	1.948
F Risk	F1	Defining risk assessment process	31	7.35	1.762
	F2	risk identification techniques	31	7.74	1.437
	F3	Formal design program with all design team at the start of projects	31	8.00	1.592
	F4	Risk Mitigation plan	30	7.77	1.331
	F5	reviewing of Risk assessment undertaken	30	7.87	1.306
	F6	Accuracy of risk	31	7.48	1.568

Appendix B: Design Performance Indicators' Data Summary (continued)

Variable		Items	N	Mean	Std. Deviation
G Re-use of Design Experiences	G1	use of recycled design	31	6.97	1.581
	G2	Availability and accessibility of standards details from previous projects	32	8.03	1.379
	G3	Design review and feedback	32	8.31	1.575
	G4	Project reviews at completion	31	7.45	1.670
	G5	Feed back of the result of the project completion reviews	32	7.81	1.786
	G6	project publicity	32	6.31	2.132
H *Innovation*	H1	Technological innovation	32	7.28	1.631
	H2	Process innovation	32	7.34	1.825
	H3	Design sub phase for IndicatorH3	32	7.84	1.505
	H4	*Over all use of innovation on project*	*32*	*7.19*	*1.447*
	H5	Feedback of the innovative ideas	31	7.16	1.753
	H6	New client inquiries based on the use of innovative solutions	32	7.53	1.606
I Client satisfaction	I1	Client satisfaction with the finished construction product	30	8.43	1.654
	I2	Client satisfaction with time of the finished construction product	30	8.03	1.732
	I3	Client satisfaction with cost of the finished construction	30	8.43	1.406
	I4	Obtaining and documenting project feedback from all clients on the design service	30	7.40	2.027
	I5	Obtaining and documented project feedback from all clients on the design product	30	7.70	1.896
	I6	Obtaining and documenting project feedback from all end users on the design product	30	7.20	2.203

APPENDIX B-1: Summary of data by organization and Project typ

	Case Summaries																
	Mean	Organization Types															
		Design Organisation			Construction Organisation		Contractor			Mix				Total			
		ProjectTypes			ProjectTypes		ProjectTypes			ProjectTypes				ProjectTypes			
		Heavy	Mix	T	Commercial	Total	Heavy	Mix	Total	Commercial	Heavy	Mix	Total	Commercial	Heavy	Mix	Total
A1	Seeking client needs	9.57	8.67	9.06	9.50	9.50	9.00	6.00	8.00	9.33	9.00	9.00	9.14	9.40	9.36	8.50	9.00
A2	Value management	8.00	7.33	7.63	9.00	9.00	8.50	6.00	7.67	7.67	8.00	7.50	7.71	8.20	8.09	7.25	7.75
A3	Alignment of project goals	8.57	7.33	7.88	10.00	10.00	9.50		9.50	9.33	9.00	7.00	8.57	9.60	8.82	7.27	8.33
A4	Client project brief	8.00	7.67	7.81	9.00	9.00	8.00	8.00	8.00	8.33	8.50	8.50	8.43	8.60	8.09	7.83	8.07
A5	End user collaboration	8.00	8.00	8.00	6.00	6.00	8.00	5.00	7.00	8.00	9.00	9.00	8.57	7.20	8.18	7.92	7.89
A6	Management of client expectation	8.71	7.11	7.81	6.00	6.00	9.00	9.00	9.00	7.33	9.50	8.50	8.29	6.80	8.91	7.50	7.93
A7	Whole life cost model integration	8.00	7.56	7.75	9.50	9.50	8.00		8.00	6.67	9.00	8.00	7.71	7.80	8.18	7.64	7.89
B1	implementation of environmental management	8.29	6.22	7.13	9.00	9.00	9.50		9.50	7.67	9.00	5.00	7.29	8.20	8.64	6.00	7.48
B2	implementation of health and safety procedures	7.29	8.22	7.81	6.50	6.50	8.00		8.00	9.00	8.00	5.00	8.00	8.00	7.55	7.90	7.77
B3	Change control Management	7.86	7.78	7.81	9.00	9.00	9.00		9.00	7.67	8.50	4.50	7.00	8.20	8.18	7.18	7.78
B4	resource plan	7.71	8.44	8.13	9.00	9.00	9.00		9.00	9.33	9.00	7.50	8.71	9.20	8.18	8.27	8.41
B5	documented and audited design process	8.57	8.00	8.25	9.00	9.00	8.50		8.50	8.00	8.00	6.00	7.43	8.40	8.45	7.64	8.11
B6	Formal design program	8.57	7.78	8.13	9.00	9.00	8.50		8.50	8.00	7.50	6.00	7.29	8.40	8.36	7.45	8.00
C1	integration of project knowledge	8.86	6.44	7.50	8.50	8.50	8.50		8.50	8.33	8.50	7.00	8.00	8.40	8.73	6.55	7.78
C2	Integration of Design data exchange	8.43	8.22	8.31	10.00	10.00	9.00		9.00	8.67	8.50	7.50	8.29	9.20	8.55	8.09	8.48
C3	The involvement of specialist design and construction expertise during the pre construction design process	8.71	7.89	8.25	8.00	8.00	8.50		8.50	9.00	7.50	8.50	8.43	8.60	8.45	8.00	8.30
C4	Benefit derived through design supply chain integration	7.71	8.44	8.13	9.00	9.00	8.50		8.50	6.67	8.50	6.00	7.17	7.60	8.00	8.20	8.00
C5	Project benefits from firm's management	8.29	6.89	7.50	8.50	8.50	8.50		8.50	7.33	8.50	7.50	7.71	7.80	8.36	7.00	7.70
D1	Frequency of changes to the original plans & specifications	7.57	6.67	7.06	3.50	3.50	8.50		8.50	9.00	5.50	9.00	8.00	6.80	7.36	7.09	7.15
D2	Clarity and ease of plans & specifications	9.00	7.00	7.88	8.50	8.50	9.00		9.00	8.00	9.00	5.00	7.43	8.20	9.00	6.64	7.89
D3	No. of questions comes from contractor requesting clarification of plans & specifications	6.86	7.11	7.00	6.50	6.50	8.50		8.50	6.67	8.00	4.00	6.67	6.60	7.36	6.80	7.00
D4	Frequency of Architects and Engineers site visit to resolve problems	7.57	7.44	7.50	4.00	4.00	9.50		9.50	7.67	7.50	3.50	6.43	6.20	7.91	6.73	7.11
E1	Cost estimate of design	8.14	8.44	8.31	8.50	8.50	10.00		10.00	8.33	8.50		8.40	8.40	8.55	8.44	8.48
E2	Cost impact of design change	8.14	8.11	8.13	10.00	10.00	10.00		10.00	8.00	9.00		8.40	8.80	8.64	8.11	8.48
E3	Cost impact of design errors	8.29	6.78	7.44	9.00	9.00	10.00		10.00	8.67	8.50		8.60	8.80	8.64	6.78	8.00
E4	Estimated time for design	8.57	6.44	7.38	8.50	8.50	10.00		10.00	7.33	7.50		7.40	7.80	8.64	6.44	7.68
E5	Time impact of design change	7.86	7.22	7.50	9.00	9.00	10.00		10.00	8.33	8.00		8.20	8.60	8.27	7.22	7.96
E6	Time Impact of design errors	8.71	6.78	7.63	8.50	8.50	10.00		10.00	8.33	8.00		8.20	8.40	8.82	6.78	8.00
F1	Defining risk assessment process	8.00	6.89	7.38	8.50	8.50	9.00		9.00	7.67	7.50	1.00	6.50	8.00	8.09	6.30	7.38
F2	risk identification techniques	7.57	7.22	7.38	10.00	10.00	9.00		9.00	8.67	7.50	5.00	7.67	9.20	7.82	7.00	7.77
F3	Formal design program with all design team at the start of projects	8.43	7.44	7.88	9.00	9.00	9.00		9.00	8.00	8.00	4.00	7.33	8.40	8.45	7.10	7.92
F4	Risk Mitigation plan	7.86	7.00	7.38	10.00	10.00	8.50		8.50	8.67	7.50		8.20	9.20	7.91	7.00	7.84
F5	reviewing of Risk assessment undertaken	7.86	7.44	7.63	8.50	8.50	9.00		9.00	8.67	8.00		8.40	8.60	8.09	7.44	7.96
F6	Accuracy of risk	7.57	7.11	7.31	8.50	8.50	9.00		9.00	8.00	8.00	8.00	8.00	8.20	7.91	7.20	7.69
G1	use of recycled design	7.57	6.38	6.93	5.50	5.50	7.50		7.50	8.33	7.50	5.50	7.29	7.20	7.55	6.20	6.96
G2	Availability and accessibility of standards details from previous projects	8.57	7.33	7.88	8.00	8.00	9.50		9.50	7.67	8.00	6.50	7.43	7.80	8.64	7.18	7.89
G3	Design review and feedback	8.57	8.44	8.50	8.00	8.00	9.50		9.50	8.00	8.50	6.50	7.71	8.00	8.73	8.09	8.33
G4	Project reviews at completion	7.86	6.78	7.25	9.00	9.00	9.50		9.50	7.67	9.00	6.00	7.83	8.20	8.36	6.70	7.69
G5	Feed back of the result of the project completion reviews	8.29	6.89	7.50	8.50	8.50	9.00		9.00	9.33	9.00	6.00	8.29	9.00	8.55	6.73	7.89
G6	project publicity	6.57	5.33	5.88	7.50	7.50	7.00		7.00	6.33	8.00	7.00	7.00	6.80	6.91	5.64	6.37
H1	Technological innovation	7.71	6.22	6.88	9.00	9.00	8.00		8.00	7.67	8.00	5.50	7.14	8.20	7.82	6.09	7.19
H2	Process innovation	7.714	6.778	7.188	9.000	9.000	8.500		8.500	8.667	8.000	3.500	7.000	8.800	7.909	6.182	7.370
H3	Design sub phase for IndicatorH3	7.71	7.78	7.75	9.00	9.00	9.00		9.00	8.00	8.00	5.50	7.29	8.40	8.00	7.36	7.81
H4	Over all use of innovation on project	7.71	7.00	7.31	6.50	6.50	8.50		8.50	7.67	8.00	5.00	7.00	7.20	7.91	6.64	7.26
H5	Feedback of the innovative ideas	7.71	6.67	7.13	7.50	7.50	8.00		8.00	7.33	8.00	6.00	7.33	7.40	7.82	6.60	7.27
H6	New client inquiries based on the use of innovative solutions	8.43	6.22	7.19	7.00	7.00	8.50		8.50	7.33	9.00	7.00	7.71	7.20	8.55	6.36	7.41
I1	Client satisfaction with the finished construction product	9.14	6.89	7.88	10.00	10.00	9.50		9.50	7.67	10.00	10.00	8.60	8.60	9.30	7.20	8.32
I2	Client satisfaction with time of the finished construction product	8.57	7.11	7.75	10.00	10.00	10.00		10.00	7.67	10.00	5.00	7.60	8.60	9.00	6.90	8.08
I3	Client satisfaction with cost of the finished construction	8.86	7.78	8.25	9.00	9.00	10.00		10.00	8.67	10.00	7.00	8.60	8.80	9.20	7.70	8.52
I4	Obtaining and documenting project feedback from all clients on the design service	8.00	6.44	7.13	8.50	8.50	10.00		10.00	8.00	9.00	2.00	7.00	8.20	8.50	6.00	7.44
I5	Obtaining and documented project feedback from all clients on the design product	8.00	7.11	7.50	8.50	8.50	10.00		10.00	8.00	9.00	4.00	7.40	8.20	8.50	6.80	7.76
I6	Obtaining and documenting project feedback from all end users on the design product	8.14	6.00	6.94	7.50	7.50	9.50		9.50	8.00	9.00	4.00	7.40	7.80	8.50	5.80	7.28

APPENDIX B-2: Summary of Data by Years of Experience

Multiple Comparisons

LSD

Dependent Variable	Mean Difference (I-J) 1-15 years vs 16-30 years	1-15 years vs 31-45 years	16-30 years vs 1-15 years	16-30 years vs 31-45 years	31-45 years vs 1-15 years	31-45 years vs 16-30 years	Std. Error 1-15 years vs 16-30 years	1-15 years vs 31-45 years	16-30 years vs 1-15 years	16-30 years vs 31-45 years	31-45 years vs 1-15 years	31-45 years vs 16-30 years	Sig. 1-15 years vs 16-30 years	1-15 years vs 31-45 years	16-30 years vs 1-15 years	16-30 years vs 31-45 years	31-45 years vs 1-15 years	31-45 years vs 16-30 years
Seeking client needs	.183	.311	-.183	.128	-.311	-.128	.378	.414	.378	.314	.414	.314	.829	.456	.829	.684	.456	.684
Value management	.540	.311	-.540	-.228	-.311	.228	.502	.553	.502	.418	.553	.418	.286	.579	.286	.588	.579	.588
Alignment of project goals	1.214*	.400	-1.214*	-.814	-.400	.814	.520	.572	.520	.434	.572	.434	.024	.466	.024	.067	.466	.067
Client project brief	1.317*	1.089	-1.317*	-.228	-1.089	.228	.502	.553	.502	.418	.553	.418	.012	.054	.012	.588	.054	.588
End user collaboration	-.087	-.044	.087	.043	.044	-.043	.702	.772	.702	.586	.772	.586	.901	.854	.901	.942	.854	.942
Management of client expectation	1.190	.333	-1.190	-.857	-.333	.857	.562	.618	.562	.468	.618	.468	.039	.582	.039	.074	.582	.074
Whole life cost model integration	.762	.733	-.762	-.029	-.733	.029	.618	.677	.618	.514	.677	.514	.222	.284	.222	.856	.284	.856
implementation of environmental management	2.167*	.867	-2.167*	-1.300*	-.867	1.300*	.632	.696	.632	.528	.696	.528	.001	.219	.001	.017	.219	.017
implementation of health and safety procedures	.683	1.111	-.683	.429	-1.111	-.429	.661	.727	.661	.552	.727	.552	.307	.133	.307	.441	.133	.441
Change control Management	1.389*	.489	-1.389*	-.900	-.489	.900	.573	.630	.573	.478	.630	.478	.018	.442	.018	.066	.442	.066
resource plan	.746	2.289*	-.746	1.543*	-2.289*	-1.543*	.657	.723	.657	.548	.723	.548	.261	.003	.261	.007	.003	.007
documented and audited design process	.464	-.044	-.464	-.529	.044	.529	.573	.631	.573	.479	.631	.479	.403	.944	.403	.275	.944	.275
Formal design program	1.103	1.089	-1.103	-.014	-1.089	.014	.584	.643	.584	.486	.643	.486	.085	.087	.085	.877	.087	.877
integration of project knowledge	.714	-.600	-.714	-1.314*	.600	1.314*	.651	.716	.651	.543	.716	.543	.278	.406	.278	.018	.406	.018
Integration of Design data exchange	.603	.889	-.603	.286	-.889	-.286	.447	.492	.447	.373	.492	.373	.163	.077	.163	.447	.077	.447
The involvement of specialist design and construction expertise during the pre construction design process	-.317	-.389	.317	.029	.389	-.029	.494	.543	.494	.412	.543	.412	.823	.587	.823	.846	.587	.846
Benefit derived through design supply chain integration	.844	1.444	-.844	.600	-1.444	-.600	.706	.779	.706	.591	.779	.591	.166	.070	.166	.402	.070	.402
Project benefits from firm's management	1.262*	.533	-1.262*	-.729	-.533	.729	.620	.682	.620	.516	.682	.516	.047	.438	.047	.166	.438	.166
Frequency of changes to the original plans & specifications	1.127*	1.356	-1.127*	.228	-1.356	-.228	.606	.665	.606	.725	.665	.725	.200	.162	.200	.754	.162	.754
Clarity and ease of plans & specifications	-.032	-.289	.032	-.257	.289	.257	.647	.712	.647	.541	.712	.541	.861	.667	.861	.636	.667	.636
No. of questions comes from contractor requesting clarification of plans & specifications	.952	-.333	-.952	-1.286*	.333	1.286*	.717	.789	.717	.599	.789	.599	.180	.675	.180	.037	.675	.037
Frequency of Architects and Engineers site visit to resolve problems	1.127*	-1.044	-1.127*	-2.171*	1.044	2.171*	.798	.878	.798	.667	.878	.667	.164	.240	.164	.002	.240	.002
Cost estimate of design	-.087	.356	.087	.443	-.356	-.443	.517	.568	.517	.431	.568	.431	.866	.535	.866	.310	.535	.310
Cost impact of design change	.603	.689	-.603	.086	-.689	-.086	.572	.629	.572	.477	.629	.477	.286	.279	.286	.658	.279	.658
Cost impact of design errors	1.024	.667	-1.024	-.357	-.667	.357	.662	.729	.662	.553	.729	.553	.128	.365	.128	.521	.365	.521
Estimated time for design	1.476	.133	-1.476	-1.343*	-.133	1.343*	.762	.838	.762	.636	.838	.636	.058	.874	.058	.040	.874	.040
Time impact of design change	.730	.044	-.730	-.686	-.044	.686	.746	.820	.746	.623	.820	.623	.332	.867	.332	.276	.867	.276
Time impact of design errors	1.460	.689	-1.460	-.771	-.689	.771	.774	.852	.774	.647	.852	.647	.065	.423	.065	.238	.423	.238
Defining risk assessment process	.643	.400	-.643	-.243	-.400	.243	.514	.565	.514	.429	.565	.429	.217	.462	.217	.574	.462	.574
risk identification techniques	1.167*	1.067	-1.167*	-.100	-1.067*	.100	.491	.541	.491	.410	.541	.410	.022	.064	.022	.806	.064	.806
Formal design program with all design team at the start of projects	.913	-.044	-.913	-.957*	.044	.957*	.570	.627	.570	.476	.627	.476	.115	.944	.115	.050	.944	.050
Risk Mitigation plan	1.056*	1.156*	-1.056*	.100	-1.156*	-.100	.473	.521	.473	.395	.521	.395	.030	.031	.030	.801	.031	.801
reviewing of Risk assessment undertaken	.111	.911	-.111	.800*	-.911	-.800*	.475	.523	.475	.397	.523	.397	.618	.066	.618	.048	.066	.048
Accuracy of risk	.976	1.733*	-.976	.757	-1.733*	-.757	.579	.634	.579	.484	.634	.484	.086	.009	.086	.124	.009	.124
use of recycled design	.040	.311	-.040	.271	-.311	-.271	.587	.646	.587	.490	.646	.490	.946	.832	.946	.563	.832	.563
Availability and accessibility of standards details from previous projects	-.214	-.800	.214	-.586	.800	.586	.442	.486	.442	.369	.486	.369	.630	.106	.630	.116	.106	.116
Design review and feedback	-.786	-.400	.786	.386	.400	-.386	.580	.650	.580	.483	.650	.483	.169	.541	.169	.436	.541	.436
Project reviews at completion	.754	1.511*	-.754	.757	-1.511*	-.757	.645	.710	.645	.539	.710	.539	.246	.036	.246	.166	.036	.166
Feed back of the result of the project completion reviews	1.238	.867	-1.238	-.371	-.867	.371	.673	.741	.673	.562	.741	.562	.072	.246	.072	.512	.246	.512
project publicity	1.460	.089	-1.460	-1.371*	-.089	1.371*	.808	.890	.808	.675	.890	.675	.077	.821	.077	.046	.821	.046
Technological innovation	1.222*	1.222	-1.222*	.000	-1.222	.000	.578	.636	.578	.483	.636	.483	.040	.061	.040	1.000	.061	1.000
Process innovation	.7143	.8000	-.7143	-.1143	-.8000	.1143	.5478	.6456	.5478	.4808	.6456	.4808	.230	.356	.230	.817	.356	.817
Design sub phase for Indicator H3	.913	.556	-.913	-.357	-.556	.357	.515	.567	.515	.430	.567	.430	.063	.332	.063	.411	.332	.411
Over all use of innovation on project	1.214*	.600	-1.214*	-.614	-.600	.614	.503	.553	.503	.420	.553	.420	.018	.283	.018	.150	.283	.150
Feedback of the innovative ideas	1.619*	1.733*	-1.619*	.114	-1.733*	-.114	.673	.741	.673	.562	.741	.562	.020	.023	.020	.640	.023	.640
New client inquiries based on the use of innovative solutions	.270	-.844	-.270	-1.114*	.844	1.114*	.637	.701	.637	.532	.701	.532	.674	.234	.674	.041	.234	.041
Client satisfaction with the finished construction product	1.437*	.422	-1.437*	-1.014	-.422	1.014	.616	.679	.616	.514	.679	.514	.024	.636	.024	.064	.636	.064
Client satisfaction with time of the finished construction product	1.103*	.689	-1.103*	-.414	-.689	.414	.624	.687	.624	.521	.687	.521	.063	.321	.063	.431	.321	.431
Client satisfaction with cost of the finished construction product	.532	.289	-.532	-.243	-.289	.243	.492	.542	.492	.411	.542	.411	.266	.566	.266	.667	.566	.667
Obtaining and documenting project feedback from all clients on the design service	.754	.511	-.754	-.243	-.511	.243	.748	.824	.748	.625	.824	.625	.316	.636	.316	.699	.636	.699
Obtaining and documented project feedback from all clients on the design product	1.302*	-.356	-1.302*	-1.657*	.356	1.657*	.665	.730	.665	.583	.730	.583	.068	.617	.068	.004	.617	.004
Obtaining and documenting project feedback from all end users on the design product	1.387*	.311	-1.387*	-1.086	-.311	1.086	.832	.915	.832	.696	.915	.696	.100	.735	.100	.125	.735	.125

Dependent Variable	95% Confidence Interval: Lower Bound 1-15 years vs 16-30 years	1-15 years vs 31-45 years	16-30 years vs 1-15 years	16-30 years vs 31-45 years	31-45 years vs 1-15 years	31-45 years vs 16-30 years	Upper Bound 1-15 years vs 16-30 years	1-15 years vs 31-45 years	16-30 years vs 1-15 years	16-30 years vs 31-45 years	31-45 years vs 1-15 years	31-45 years vs 16-30 years
Seeking client needs	-.67	-.52	-.94	-.80	-1.14	-.76	.94	1.14	.67	.76	.62	.50
Value management	-.47	-.80	-1.66	-1.87	-1.42	-.01	1.66	1.42	.47	.81	.80	1.07
Alignment of project goals	.17	-.75	-2.26	-1.09	-1.56	-.06	2.26	1.65	-.17	.06	.75	1.09
Client project brief	.31	-.02	-2.33	-1.07	-2.20	-.01	2.33	2.20	-.31	.01	.02	1.07
End user collaboration	-1.50	-1.60	-1.32	-1.13	-1.81	-1.22	1.32	1.81	1.50	1.22	1.60	1.13
Management of client expectation	.06	-.81	-2.32	-1.80	-1.58	-.06	2.32	1.58	-.06	.06	.81	1.80
Whole life cost model integration	-.44	-.63	-2.00	-1.06	-2.06	-1.00	2.00	2.06	.46	1.00	.63	1.06
implementation of environmental management	.80	-.53	-3.44	-2.36	-2.26	.24	3.44	2.26	-.80	-.24	.53	2.36
implementation of health and safety procedures	-.65	-.35	-2.01	-.66	-2.57	-1.54	2.01	2.57	.65	1.54	.35	.66
Change control Management	.24	-.79	-2.84	-1.66	-1.76	-.06	2.84	1.76	-.24	.06	.79	1.66
resource plan	-.57	.64	-2.07	.44	-3.74	-2.84	2.07	3.74	.57	2.84	-.64	-.44
documented and audited design process	-.87	-1.31	-1.84	-1.49	-1.22	-.43	1.84	1.22	.87	.43	1.31	1.49
Formal design program	-.07	-.20	-2.28	-1.00	-2.36	-.07	2.28	2.36	.07	.07	.20	1.00
integration of project knowledge	-.58	-2.04	-2.02	-2.41	-.64	.22	2.02	.64	.58	-.22	2.04	2.41
Integration of Design data exchange	-.29	-.10	-1.60	-.46	-1.88	-1.04	1.60	1.88	.29	1.04	.10	.46
The involvement of specialist design and construction expertise during the pre construction design process	-1.31	-1.36	-.67	-.80	-.80	-.86	.67	.80	1.31	.86	1.36	.80
Benefit derived through design supply chain integration	-.46	-.12	-2.37	-.66	-3.01	-1.66	2.37	3.01	.46	1.66	.12	.66
Project benefits from firm's management	.02	-.64	-2.61	-1.77	-1.80	-.31	2.51	1.80	-.02	.31	.84	1.77
Frequency of changes to the original plans & specifications	-.62	-.56	-2.87	-1.23	-3.28	-1.69	2.87	3.28	.62	1.69	.56	1.23
Clarity and ease of plans & specifications	-1.33	-1.72	-1.27	-1.34	-1.14	-.63	1.27	1.14	1.33	.83	1.72	1.34
No. of questions comes from contractor requesting clarification of plans & specifications	-.48	-1.52	-2.36	-2.48	-1.25	.04	2.36	1.25	.48	-.04	1.82	2.48
Frequency of Architects and Engineers site visit to resolve problems	-.48	-2.61	-2.73	-3.51	-.72	.83	2.73	.72	.44	-.83	2.81	3.51
Cost estimate of design	-1.13	-.79	-.85	-.42	-1.60	-1.31	.85	1.50	1.13	1.31	.79	.42
Cost impact of design change	-.65	-.57	-1.75	-.87	-1.85	-1.04	1.75	1.85	.85	1.04	.57	.87
Cost impact of design errors	-.31	-.80	-2.36	-1.47	-2.13	-.75	2.35	2.13	.31	.75	.60	1.47
Estimated time for design	-.06	-1.55	-3.01	-2.62	-4.82	.06	3.01	1.82	.06	-.06	1.55	2.62
Time impact of design change	-.77	-1.60	-2.23	-1.64	-1.88	-.57	2.23	1.88	.77	.57	1.60	1.84
Time impact of design errors	-.10	-1.02	-3.02	-2.07	-2.40	-.53	3.02	2.40	.10	.53	1.02	2.07
Defining risk assessment process	-.39	-.74	-1.87	-1.10	-1.54	-.82	1.87	1.54	.38	.82	.74	1.10
risk identification techniques	.18	-.02	-2.15	-.92	-2.15	-.72	2.15	2.15	-.18	.72	.02	.92
Formal design program with all design team at the start of projects	-.23	-1.30	-2.06	-1.81	-1.21	.00	2.06	1.21	.23	.00	1.30	1.81
Risk Mitigation plan	.10	.11	-3.01	-.66	-2.20	-.69	2.01	2.20	-.10	.69	-.11	.66
reviewing of Risk assessment undertaken	-.64	-.14	-1.67	.00	-1.86	-1.60	1.67	1.86	.84	1.60	.14	.00
Accuracy of risk	-.18	.46	-2.14	-.22	-3.01	-1.73	2.14	3.01	.18	1.73	-.46	.22
use of recycled design	-1.14	-.66	-1.32	-.71	-1.81	-1.26	1.22	1.81	1.14	1.26	.86	.71
Availability and accessibility of standards details from previous projects	-1.10	-1.78	-.67	-1.33	-.16	-.16	.67	.16	1.10	.16	1.76	1.33
Design review and feedback	-1.97	-1.71	-.40	-.80	-.81	-1.36	.40	.81	1.87	1.36	1.71	.80
Project reviews at completion	-.54	.06	-2.05	-.33	-2.94	-1.84	2.05	2.94	.54	1.84	-.06	.33
Feed back of the result of the project completion reviews	-.11	-.62	-2.58	-1.50	-2.36	-.76	2.58	2.36	.11	.76	.62	1.50
project publicity	-.16	-1.70	-3.06	-2.73	-1.86	.01	3.06	1.86	.16	-.01	1.70	2.73
Technological innovation	.06	-.06	-2.34	-.87	-2.50	-.87	2.34	2.50	-.06	.87	.06	.87
Process innovation	-.467	-.700	-1.896	-1.101	-1.800	-.472	1.896	1.800	.467	.472	.700	1.101
Design sub phase for Indicator H3	-.12	-.56	-1.96	-1.22	-1.70	-.51	1.95	1.70	.12	.51	.56	1.22
Over all use of innovation on project	.20	-.51	-2.22	-1.40	-1.71	-.23	2.22	1.71	-.20	.23	.51	1.40
Feedback of the innovative ideas	.27	.34	-2.97	-1.02	-3.22	-1.24	2.97	3.22	-.27	1.24	-.24	1.02
New client inquiries based on the use of innovative solutions	-1.01	-2.25	-1.55	-2.16	-.56	.04	1.55	.56	1.01	-.04	2.25	2.16
Client satisfaction with the finished construction product	.20	-.64	-2.67	-2.06	-1.78	-.02	2.67	1.78	-.20	.02	.84	2.06
Client satisfaction with time of the finished construction product	-.15	-.66	-2.36	-1.40	-2.07	-.63	2.36	2.07	.15	.63	.66	1.40
Client satisfaction with cost of the finished construction product	-.40	-.60	-1.62	-1.07	-1.36	-.56	1.62	1.36	.40	.56	.60	1.07
Obtaining and documenting project feedback from all clients on the design service	-.75	-1.14	-2.26	-1.50	-2.17	-1.01	2.26	2.17	.75	1.01	1.14	1.50
Obtaining and documented project feedback from all clients on the design product	-.63	-1.62	-2.89	-2.77	-1.11	.86	2.89	1.11	.63	-.66	1.62	2.77
Obtaining and documenting project feedback from all end users on the design product	-.28	-1.53	-3.07	-2.46	-2.15	-.31	3.07	2.15	.28	.31	1.63	2.46

* The mean difference is significant at the 0.05 level.

APPENDIX C: Ranking of the Design Performance Indicators

APPENDIX C-1:

Mean And Level of Importance of the Design Indicators For Commercial Projects

ID	Design Performance Indicator for Commercial Projects	Mean	Rank
F	**RISKS**	**8.60**	**9**
F1	Defining risk assessment process	8.00	2
F2	Risk identification techniques	9.20	6
F3	Formal design program with all design team at the start of projects	8.40	4
F4	Risk Mitigation plan	9.20	6
F5	reviewing of Risk assessment undertaken	8.60	5
F6	Accuracy of risk	8.20	3
E	**COST and TIME MANAGEMENT**	**8.47**	**8**
E1	Cost estimate of design	8.40	4
E2	Cost impact of design change	8.80	6
E3	Cost impact of design errors	8.80	6
E4	Estimated time for design	7.80	3
E5	Time impact of design change	8.60	5
E6	Time impact of design errors	8.40	4
B	**DESIGN PROCESS**	**8.40**	**7**
B1	Implementation of environmental management	8.20	4
B2	Implementation of health and safety procedures	8.00	3
B3	Change control Management	8.20	4
B4	Resource plan	9.20	6
B5	Documented and audited design process	8.40	5
B6	Formal design program	8.40	5
I	**CLIENT SATISFACTION**	**8.37**	**6**
I1	Client satisfaction with the finished construction product	8.60	5
I2	Client satisfaction with time of the finished construction product	8.60	5
I3	Client satisfaction with cost of the finished construction	8.80	6
I4	Obtaining and documenting project feedback from all clients on the design service	8.20	4
I5	Obtaining and documented project feedback from all clients on the design product	8.20	4
I6	Obtaining and documenting project feedback from all end users on the design product	7.80	3
C	**INTEGRATION OF DESIGN WITH SUPPLY CHAIN**	**8.32**	**5**
C1	integration of project knowledge	8.40	3
C2	Integration of Design data exchange	9.20	5
C3	The involvement of specialist design and construction expertise during the pre construction design process	8.60	4
C4	Benefit derived through design supply chain integration	7.60	1
C5	integration of project knowledge	7.80	2

APPENDIX C-1 (continued)

ID	Design Performance Indicator for Commercial Projects	Mean	Rank
A	**UNDERSTANDING CLIENT NEEDS**	**8.23**	**4**
A1	Seeking client needs	9.40	6
A2	Value management	8.20	4
A3	Alignment of project goals	9.60	7
A4	Client project brief	8.60	5
A5	End user collaboration	7.20	2
A6	Management of client expectation	6.80	1
A7	Whole life cost model integration	7.80	3
H	**INNOVATION**	**7.87**	**3**
H1	Technological innovation	8.20	4
H2	Process innovation	8.80	6
H3	Design sub phase for IndicatorH3	8.40	5
H4	Over all use of innovation on project	7.20	2
H5	Feedback of the innovative ideas	7.40	3
H6	New client inquiries based on the use of innovative solutions	7.20	2
G	**RE-USE OF DESIGN EXPERIENCES**	**7.83**	**2**
G1	use of recycled design	7.20	2
G2	Availability and accessibility of standards details from previous projects	7.80	3
G3	Design review and feedback	8.00	4
G4	Project reviews at completion	8.20	5
G5	Feed back of the result of the project completion reviews	9.00	6
G6	project publicity	6.80	1
D	DESIGN QUALITY	6.95	1
D1	Frequency of changes to the original plans & specifications	6.80	3
D2	Clarity and ease of plans & specifications	8.20	4
D3	No. of questions comes from contractor requesting clarification of plans & specifications	6.60	2
D4	Frequency of Architects and Engineers site visit to resolve problems	6.20	1

APPENDIX C-2:

Mean and Level Of Importance of the Design Indicators For Heavy Projects

ID	Design Performance Indicator for Heavy Projects	Mean	Rank
I	**CLIENT SATISFACTION**	**8.55**	**9**
I1	Client satisfaction with the finished construction product	9.08	6
I2	Client satisfaction with time of the finished construction product	8.62	4
I3	Client satisfaction with cost of the finished construction	9	5
I4	Obtaining and documenting project feedback from all clients on the design service	8.08	1
I5	Obtaining and documented project feedback from all clients on the design product	8.38	3
I6	Obtaining and documenting project feedback from all end users on the design product	8.15	2
E	**COST and TIME MANAGEMENT**	**8.50**	**8**
E1	Cost estimate of design	8.43	5
E2	Cost impact of design change	8.71	6
E3	Cost impact of design errors	8.43	5
E4	Estimated time for design	8.36	4
E5	Time impact of design change	8.36	4
E6	Time impact of design errors	8.71	6
A	**UNDERSTANDING CLIENT NEEDS**	**8.33**	**7**
A1	Seeking client needs	9.07	7
A2	Value management	8	4
A3	Alignment of project goals	8.57	6
A4	Client project brief	8.07	5
A5	End user collaboration	7.93	3
A6	Management of client expectation	8.57	6
A7	Whole life cost model integration	8.07	5
C	**INTEGRATION OF DESIGN WITH SUPPLY CHAIN**	**8.23**	**6**
C1	integration of project knowledge	8.5	5
C2	Integration of Design data exchange	8.29	3
C3	The involvement of specialist design and construction expertise during the pre construction design process	8.36	4
C4	Benefit derived through design supply chain integration	7.71	2
C5	integration of project knowledge	8.29	3
B	**DESIGN PROCESS**	**8.05**	**5**
B1	implementation of environmental management	8.43	5
B2	implementation of health and safety procedures	7.29	1
B3	Change control Management	8.14	3
B4	resource plan	7.64	2
B5	documented and audited design process	8.5	6
B6	Formal design program	8.29	4

APPENDIX C-2: (continued)

ID	Design Performance Indicator for Commercial Projects	Mean	Rank
G	**RE-USE OF DESIGN EXPERIENCES**	**8.01**	**4**
G1	use of recycled design	7.5	3
G2	Availability and accessibility of standards details from previous projects	8.64	6
G3	Design review and feedback	8.64	6
G4	Project reviews at completion	7.86	4
G5	Feed back of the result of the project completion reviews	8.5	5
G6	project publicity	6.93	2
F	**RISK**	**7.98**	**3**
F1	Defining risk assessment process	7.93	4
F2	risk identification techniques	7.93	4
F3	Formal design program with all design team at the start of projects	8.43	6
F4	Risk Mitigation plan	7.71	2
F5	reviewing of Risk assessment undertaken	8.07	5
F6	Accuracy of risk	7.79	3
H	**INNOVATION**	**7.88**	**2**
H1	Technological innovation	7.71	2
H2	Process innovation	7.857	4
H3	Design sub phase for IndicatorH3	8.07	5
H4	Over all use of innovation on project	7.79	3
H5	Feedback of the innovative ideas	7.57	1
H6	New client inquiries based on the use of innovative solutions	8.29	6
D	**DESIGN QUALITY**	**7.72**	**1**
D1	Frequency of changes to the original plans & specifications	7.29	1
D2	Clarity and ease of plans & specifications	8.64	4
D3	No. of questions comes from contractor requesting clarification of plans & specifications	7.57	3
D4	Frequency of Architects and Engineers site visit to resolve problems	7.36	2

APPENDIX D: Pairwise Comparison Matrices

APPEDIX D-1: Consistency Ratios for the Pairwise Comparison Matrices

Main Indicators- Matrix(9X9)

Matrix No.	Max eignvalue Lamtha	Consistency Index CI	Random Index RI	Consistency Ratio CR <0.1
1	9.7341	0.0918	1.45	0.0633
2	10.0400	0.1300	1.45	0.0897
3	9.6998	0.0875	1.45	0.0603
4	9.7923	0.0990	1.45	0.0683
5	9.9334	0.1167	1.45	0.0805
6	9.9646	0.1206	1.45	0.0832
7	10.0995	0.1374	1.45	0.0948
8	10.0439	0.1305	1.45	0.0900
9	9.6579	0.0822	1.45	0.0567
10	9.6335	0.0792	1.45	0.0546
11	9.5303	0.0663	1.45	0.0457
12	9.4179	0.0522	1.45	0.0360
13	9.6090	0.0761	1.45	0.0525

Indicator A- Understanding Client Needs (Matrix 7X7)

Matrix No.	Max eignvalue	Consistency Index	Random Index	Consistency Ratio
	Lamtha	CI	RI	CR <0.1
1	7.6424	0.1071	1.32	0.0811
2	7.3931	0.0655	1.32	0.0496
3	7.6616	0.1103	1.32	0.0835
4	7.6355	0.1059	1.32	0.0802
5	7.5378	0.0896	1.32	0.0679
6	7.4815	0.0803	1.32	0.0608
7	7.3506	0.0584	1.32	0.0443
8	7.5989	0.0998	1.32	0.0756
9	7.3690	0.0615	1.32	0.0466
10	7.3364	0.0561	1.32	0.0425
11	7.4340	0.0723	1.32	0.0548
12	7.6245	0.1041	1.32	0.0788
13	7.3381	0.0563	1.32	0.0427

Indicator B- Design Process (Matrix 6X6)

Matrix No.	Max eignvalue	Consistency Index	Random Index	Consistency Ratio
	Lamtha	CI	RI	CR <0.1
1	6.4701	0.0940	1.24	0.0758
2	6.4465	0.0893	1.24	0.0720
3	6.4190	0.0838	1.24	0.0676
4	6.4637	0.0927	1.24	0.0748
5	6.4719	0.0944	1.24	0.0761
6	6.3044	0.0609	1.24	0.0491
7	6.5763	0.1153	1.24	0.0930
8	6.3871	0.0774	1.24	0.0624
9	6.3717	0.0743	1.24	0.0600
10	6.3844	0.0769	1.24	0.0620
11	6.4538	0.0908	1.24	0.0732
12	6.5067	0.1013	1.24	0.0817
13	6.4388	0.0878	1.24	0.0708

Indicator C- Integration of Design team with supply chain (Matrix 5X5)

Matrix No.	Max eignvalue	Consistency Index	Random Index	Consistency Ratio
	Lamtha	CI	RI	CR <0.1
1	5.0975	0.0244	1.12	0.0218
2	5.3155	0.0789	1.12	0.0704
3	5.1915	0.0479	1.12	0.0427
4	5.2034	0.0508	1.12	0.0454
5	5.2193	0.0548	1.12	0.0489
6	5.3311	0.0828	1.12	0.0739
7	5.1170	0.0293	1.12	0.0261
8	5.1698	0.0424	1.12	0.0379
9	5.3782	0.0945	1.12	0.0844
10	5.3470	0.0867	1.12	0.0775
11	5.4234	0.1059	1.12	0.0945
12	5.4076	0.1019	1.12	0.0910
13	5.3989	0.0997	1.12	0.0890

Indicator D- Design Quality(Matrix 4X4)

Matrix No.	Max eignvalue	Consistency Index	Random Index	Consistency Ratio
	Lamtha	CI	RI	CR <0.1
1	4.1648	0.0549	0.90	0.0610
2	4.1346	0.0449	0.90	0.0499
3	4.1427	0.0476	0.90	0.0528
4	4.1923	0.0641	0.90	0.0712
5	4.1528	0.0509	0.90	0.0566
6	4.0460	0.0153	0.90	0.0170
7	4.1182	0.0394	0.90	0.0438
8	4.0247	0.0082	0.90	0.0092
9	4.0328	0.0109	0.90	0.0122
10	4.0802	0.0267	0.90	0.0297
11	4.1756	0.0585	0.90	0.0650
12	4.2433	0.0811	0.90	0.0901
13	4.1648	0.0549	0.90	0.0610

Indicator E- Cost and Time Management (Matrix 6X6)

Matrix No.	Max eignvalue	Consistency Index	Random Index	Consistency Ratio
	Lamtha	CI	RI	CR <0.1
1	6.3627	0.0725	1.24	0.0585
2	6.4437	0.0887	1.24	0.0716
3	6.5376	0.1075	1.24	0.0867
4	6.3535	0.0707	1.24	0.0570
5	6.4582	0.0916	1.24	0.0739
6	6.3686	0.0737	1.24	0.0594
7	6.3506	0.0701	1.24	0.0566
8	6.1123	0.0225	1.24	0.0181
9	6.4582	0.0916	1.24	0.0739
10	6.5376	0.1075	1.24	0.0867
11	6.4647	0.0929	1.24	0.0750
12	6.5373	0.1075	1.24	0.0867
13	6.4401	0.0880	1.24	0.0710

Indicator F- Risk (Matrix 6X6)

Matrix No.	Max eignvalue	Consistency Index	Random Index	Consistency Ratio
	Lamtha	CI	RI	CR <0.1
1	6.3405	0.0681	1.24	0.0549
2	6.5412	0.1082	1.24	0.0873
3	6.4529	0.0906	1.24	0.0731
4	6.4551	0.0910	1.24	0.0734
5	6.3093	0.0619	1.24	0.0499
6	6.3405	0.0681	1.24	0.0549
7	6.3981	0.0796	1.24	0.0642
8	6.2275	0.0455	1.24	0.0367
9	6.0545	0.0109	1.24	0.0088
10	6.3479	0.0696	1.24	0.0561
11	6.5103	0.1021	1.24	0.0823
12	6.4853	0.0971	1.24	0.0783
13	6.4687	0.0937	1.24	0.0756

Indicator G- Reuse of Design (Matrix 6X6)

Matrix No.	Max eignvalue	Consistency Index	Random Index	Consistency Ratio
	Lamtha	CI	RI	CR <0.1
1	6.4614	0.0923	1.24	0.0744
2	6.5533	0.1107	1.24	0.0892
3	6.4892	0.0978	1.24	0.0789
4	6.3670	0.0734	1.24	0.0592
5	6.4269	0.0854	1.24	0.0689
6	6.4834	0.0967	1.24	0.0780
7	6.5747	0.1149	1.24	0.0927
8	6.5341	0.1068	1.24	0.0861
9	6.5370	0.1074	1.24	0.0866
10	6.5440	0.1088	1.24	0.0877
11	6.5047	0.1009	1.24	0.0814
12	6.3107	0.0621	1.24	0.0501
13	6.5354	0.1071	1.24	0.0864

Indicator H- Innovation (Matrix 6X6)

Matrix No.	Max eignvalue	Consistency Index	Random Index	Consistency Ratio
	Lamtha	CI	RI	CR <0.1
1	6.1954	0.0391	1.24	0.0315
2	6.3002	0.0600	1.24	0.0484
3	6.0547	0.0109	1.24	0.0088
4	6.1648	0.0330	1.24	0.0266
5	6.4350	0.0870	1.24	0.0702
6	6.1225	0.0245	1.24	0.0198
7	6.1871	0.0374	1.24	0.0302
8	6.3691	0.0738	1.24	0.0595
9	6.2780	0.0556	1.24	0.0448
10	6.3965	0.0793	1.24	0.0639
11	6.4428	0.0886	1.24	0.0714
12	6.4028	0.0806	1.24	0.0650
13	6.3327	0.0665	1.24	0.0537

Indicator I- Client satisfactions (Matrix 6X6)

Matrix No.	Max eignvalue	Consistency Index	Random Index	Consistency Ratio
	Lamtha	CI	RI	CR <0.1
1	6.2068	0.0414	1.24	0.0333
2	6.2065	0.0413	1.24	0.0333
3	6.1599	0.0320	1.24	0.0258
4	6.2713	0.0543	1.24	0.0438
5	6.2057	0.0411	1.24	0.0332
6	6.1808	0.0362	1.24	0.0292
7	6.1599	0.0320	1.24	0.0258
8	6.2574	0.0515	1.24	0.0415
9	6.2040	0.0408	1.24	0.0329
10	6.1670	0.0334	1.24	0.0269
11	6.4159	0.0832	1.24	0.0671
12	6.4137	0.0827	1.24	0.0667
13	6.2647	0.0529	1.24	0.0427

APPENDIX D-2: Main outcome of pairwise comparison Matrices

(Design Stage Indicator weights based on 13 experts)

Indicator	WEIGHT													Average
	1	2	3	4	5	6	7	8	9	10	11	12	13	Weight
A	0.1693	0.1699	0.1340	0.1397	0.1087	0.1567	0.1701	0.1610	0.1555	0.1414	0.1414	0.1247	0.1224	0.146
B	0.1148	0.1153	0.1213	0.1126	0.0990	0.1116	0.1199	0.1134	0.0860	0.0835	0.0835	0.1334	0.0909	0.107
C	0.1471	0.1381	0.1416	0.1390	0.1408	0.1349	0.0910	0.1547	0.1619	0.1599	0.1599	0.1079	0.0917	0.136
D	0.0468	0.0497	0.0457	0.0486	0.0553	0.0490	0.0552	0.0542	0.0591	0.0559	0.0559	0.0820	0.0995	0.058
E	0.1471	0.1593	0.1753	0.1634	0.1622	0.1641	0.1631	0.1456	0.1392	0.1280	0.1280	0.1656	0.1674	0.154
F	0.0639	0.0644	0.0629	0.0590	0.0794	0.0712	0.0713	0.0727	0.0924	0.0793	0.0793	0.0745	0.1021	0.075
G	0.1043	0.1013	0.1014	0.0987	0.0981	0.1019	0.1147	0.0966	0.0896	0.0976	0.0976	0.0912	0.0956	0.099
H	0.0562	0.0567	0.0554	0.0527	0.0604	0.0584	0.0601	0.0656	0.0774	0.0856	0.0856	0.0732	0.0806	0.067
I	0.1505	0.1452	0.1623	0.1863	0.1960	0.1520	0.1547	0.1362	0.1389	0.1687	0.1687	0.1476	0.1497	0.158
A1	0.2480	0.2416	0.2131	0.1974	0.1794	0.2351	0.1369	0.2430	0.1993	0.1677	0.1637	0.1693	0.2051	0.200
A2	0.1144	0.1333	0.1153	0.1349	0.1237	0.1075	0.1444	0.1260	0.1160	0.1115	0.1506	0.1565	0.1520	0.130
A3	0.2179	0.1499	0.2090	0.2274	0.2439	0.2201	0.1903	0.1779	0.2287	0.2018	0.1837	0.2189	0.1847	0.204
A4	0.1076	0.1088	0.1166	0.1152	0.1301	0.1036	0.1366	0.1241	0.1211	0.1377	0.1352	0.1286	0.1240	0.122
A5	0.1025	0.1428	0.1303	0.1130	0.1118	0.1075	0.1489	0.1111	0.1017	0.1213	0.1352	0.1182	0.1138	0.120
A6	0.1019	0.1095	0.0991	0.0970	0.0993	0.1136	0.0940	0.1061	0.1121	0.1088	0.1237	0.0939	0.1108	0.105
A7	0.1076	0.1141	0.1166	0.1152	0.1118	0.1126	0.1489	0.1118	0.1211	0.1511	0.1079	0.1147	0.1097	0.119
B1	0.1861	0.1449	0.1680	0.1569	0.1849	0.1725	0.2045	0.1833	0.1821	0.1241	0.1641	0.1924	0.1452	0.170
B2	0.0645	0.1010	0.0666	0.0690	0.0658	0.0488	0.0650	0.0502	0.0521	0.0696	0.0589	0.0641	0.0730	0.065
B3	0.1181	0.1357	0.1260	0.1393	0.1227	0.0995	0.1157	0.1168	0.1174	0.1384	0.1158	0.1209	0.1279	0.123
B4	0.3423	0.2274	0.3262	0.3419	0.3055	0.3918	0.3401	0.3425	0.3625	0.3434	0.3545	0.3049	0.3432	0.333
B5	0.1534	0.2015	0.1711	0.1525	0.1695	0.1469	0.1620	0.1755	0.1607	0.1826	0.1696	0.1678	0.1819	0.169
B6	0.1356	0.1895	0.1421	0.1404	0.1516	0.1405	0.1127	0.1316	0.1253	0.1420	0.1370	0.1499	0.1288	0.141

Indicator	WEIGHT													Average Weight
	1	2	3	4	5	6	7	8	9	10	11	12	13	
C2	0.2196	0.2442	0.1641	0.2486	0.2504	0.2098	0.2849	0.2131	0.2068	0.2455	0.2531	0.2066	0.2115	0.228
C3	0.2251	0.1812	0.1974	0.2125	0.1936	0.1460	0.2163	0.2177	0.2818	0.1419	0.1813	0.2178	0.1463	0.197
C4	0.1216	0.1157	0.1098	0.1181	0.1143	0.1070	0.1447	0.1066	0.1016	0.1244	0.1189	0.1434	0.1124	0.118
C5	0.1918	0.1865	0.1697	0.1681	0.1886	0.1876	0.1091	0.1623	0.1486	0.1622	0.0901	0.1817	0.1830	0.164
D1	0.2770	0.1916	0.1732	0.1796	0.1977	0.2815	0.3238	0.1367	0.1414	0.1475	0.3120	0.1916	0.2770	0.22
D2	0.4358	0.5472	0.5327	0.5647	0.5509	0.4692	0.3944	0.5643	0.5402	0.5042	0.3597	0.5472	0.4358	0.50
D3	0.1254	0.1251	0.1387	0.1069	0.1316	0.1242	0.1704	0.1554	0.1592	0.1844	0.1465	0.1251	0.1254	0.14
D4	0.1617	0.1361	0.1554	0.1488	0.1199	0.1251	0.1114	0.1437	0.1592	0.1639	0.1818	0.1361	0.1617	0.15
E1	0.1609	0.1744	0.1742	0.1783	0.1753	0.1799	0.1632	0.1617	0.1753	0.1548	0.1543	0.1550	0.1741	0.168
E2	0.2624	0.2795	0.2615	0.2625	0.2617	0.2619	0.2355	0.2892	0.2617	0.2796	0.2614	0.2798	0.2794	0.267
E3	0.1612	0.1583	0.1551	0.1783	0.1577	0.1610	0.1632	0.1617	0.1577	0.1656	0.1755	0.1550	0.1510	0.162
E4	0.1067	0.0921	0.1061	0.0816	0.1063	0.0955	0.1143	0.1170	0.1063	0.1028	0.1094	0.1027	0.0923	0.103
E5	0.1649	0.1548	0.1713	0.1613	0.1615	0.1610	0.1820	0.1654	0.1615	0.1588	0.1612	0.1692	0.1623	0.164
E6	0.1439	0.1409	0.1318	0.1381	0.1377	0.1408	0.1417	0.1050	0.1377	0.1384	0.1381	0.1383	0.1409	0.136
F1	0.1489	0.1714	0.1738	0.1478	0.1664	0.1489	0.1707	0.1802	0.1501	0.1751	0.1701	0.1314	0.1437	0.160
F2	0.1802	0.1877	0.1958	0.1941	0.1976	0.1802	0.1808	0.1802	0.1652	0.1789	0.1629	0.1765	0.2063	0.184
F3	0.1615	0.1616	0.1549	0.1496	0.1539	0.1615	0.1785	0.1213	0.1890	0.1418	0.1620	0.1612	0.1528	0.158
F4	0.1802	0.1610	0.1829	0.2221	0.1976	0.1802	0.1570	0.2010	0.1652	0.1661	0.1591	0.1765	0.1841	0.179
F5	0.1802	0.1748	0.1772	0.1571	0.1809	0.1802	0.1680	0.1802	0.1652	0.1789	0.2014	0.1626	0.1702	0.175
F6	0.1489	0.1436	0.1154	0.1293	0.1035	0.1489	0.1451	0.1372	0.1652	0.1593	0.1445	0.1917	0.1429	0.144
G1	0.0629	0.0624	0.0584	0.0662	0.0551	0.0616	0.0681	0.0564	0.0631	0.0551	0.0727	0.1116	0.0698	0.066
G2	0.1979	0.1877	0.1962	0.1792	0.1985	0.2020	0.1764	0.1978	0.2147	0.1883	0.1540	0.1599	0.1965	0.188
G3	0.2040	0.2270	0.2026	0.2139	0.2047	0.2082	0.2159	0.2149	0.1892	0.2278	0.2018	0.1678	0.2027	0.206
G4	0.2499	0.2533	0.2671	0.2583	0.2503	0.2487	0.2545	0.2442	0.2474	0.2674	0.2629	0.2840	0.2491	0.257
G5	0.2406	0.2223	0.2252	0.2418	0.2417	0.2374	0.2191	0.2166	0.2397	0.2178	0.2361	0.2267	0.2390	0.231
G6	0.0447	0.0474	0.0505	0.0406	0.0496	0.0422	0.0661	0.0701	0.0459	0.0436	0.0726	0.0499	0.0428	0.051

Indicator	WEIGHT													Average Weight
	1	2	3	4	5	6	7	8	9	10	11	12	13	
H2	0.1788	0.1984	0.1823	0.1997	0.2068	0.1598	0.1774	0.2137	0.1746	0.1719	0.2185	0.1555	0.1470	0.183
H3	0.2132	0.1852	0.1657	0.2068	0.1983	0.2417	0.2228	0.1861	0.2127	0.2298	0.1847	0.2281	0.2136	0.207
H4	0.1618	0.1453	0.1823	0.1645	0.1731	0.1573	0.1765	0.1372	0.1718	0.1628	0.1741	0.1643	0.1803	0.165
H5	0.1618	0.1435	0.1823	0.1127	0.1188	0.1573	0.1221	0.1603	0.1580	0.1686	0.1590	0.1549	0.1803	0.152
H6	0.1058	0.1017	0.1051	0.1165	0.1039	0.0818	0.0887	0.1008	0.0944	0.0950	0.0929	0.0995	0.1040	0.099
I1	0.2751	0.2872	0.3115	0.2485	0.3073	0.2779	0.3115	0.2350	0.2968	0.2886	0.2860	0.3048	0.2910	0.286
I2	0.1620	0.1597	0.1580	0.1706	0.1587	0.1636	0.1580	0.1651	0.1616	0.1634	0.1620	0.1838	0.1495	0.163
I3	0.2815	0.2898	0.2723	0.2852	0.2724	0.2723	0.2723	0.2909	0.2772	0.2609	0.2552	0.2167	0.2889	0.272
I4	0.0619	0.0544	0.0543	0.0622	0.0571	0.0697	0.0543	0.0690	0.0576	0.0607	0.0749	0.0679	0.0604	0.062
I5	0.1351	0.1269	0.1293	0.1239	0.1263	0.1380	0.1293	0.1469	0.1150	0.1373	0.1352	0.1395	0.1302	0.132
I6	0.0844	0.0820	0.0747	0.1098	0.0782	0.0786	0.0747	0.0931	0.0918	0.0891	0.0866	0.0873	0.0801	0.085