UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A HYBRID METHOD BY DATA ENVELOPMENT ANALYSIS AND ANALYTIC NETWORK PROCESS FOR PROJECT SELECTION

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By

MAJID MOJAHED

Thesis submitted to the School of Graduate Studies Universiti Putra Malaysia, in fulfillment of the requirements for the degree of Doctor of Philosophy

March 2014

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DEDICATION

This thesis is dedicated to my father, Hossein, who passed away in 1981 and to my mother whose love and encouragement are the most wonderful of the many blessings that God has given to me. Moreover I would like to dedicate it to my wife **Laleh** and my son **Kasra**, who are my unfailing source of love. Your patience, tolerance and understanding are immeasurable.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for Degree of Doctor of Philosophy

DEVELOPMENT OF A HYBRID METHOD BY DATA ENVELOPMENT ANALYSIS AND ANALYTIC NETWORK PROCESS FOR PROJECT SELECTION

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March 2014

Chair: Professor Rosnah bt. Mohd. Yusuff, PhD
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This research focuses on developing a model that can be used to rank construction projects and select the profitable one. This model will result from the integration of a decision tool called the Analytic Network Process and a data analysis model called Data Envelopment Analysis.

Due to scarce resources, contractors cannot undertake all projects simultaneously. Because of the wide variety of criteria, they are always faced with difficulties in selecting projects, so a proper scientific method is necessary to aid contractors for achieving more profit. Data Envelopment Analysis (DEA) is a very powerful benchmarking technique that determines a Decision Making Units (DMUs) as efficient or inefficient units. Moreover, it can increase the performance of inefficient units by reducing the amount of input variables and increasing the output ones. A hybrid method of decision making has been developed using Analytic Network Process method (ANP) with DEA by considering the relationship between criteria and alternatives based on network system of elements for solving in Project Selection problems. The objectives of this research are identifying and determining the weights of significant criteria in order to rank construction projects based on network system of elements and also developing prototype software as a tool.

In this study, two kinds of questionnaires have been applied. The first questionnaire was used to identify the relationship between elements and the second questionnaire specified the weight of 27 criteria. 'Political impact in area' was introduced as an important criterion for project selection. Both questionnaires were filled up by 26 contractors (whole group of contractors in Telecommunication Company of North Khorasan) who are experts in 25 selected projects for Telecommunication Company. After classifying the criteria into corresponding groups based on their characteristics,

the weight of each group was identified. The output of ANP method was modified to serve as input for DEA method. To identify project selection criteria and the number of groups, voting method was used. The inputs of Cross Efficiency Matrix were provided by inputs and outputs of DEA method and finally, this hybrid method represents the project number 3 'Building construction of call Centre in Jajarm' was selected as the profitable project and it was followed by project number 5' Building construction of call Centre in Farooj' and project number 4'Building construction of call Centre in Esfaraeen' and so on. To show how much of this prioritization is close to reality, some ordinal numbers (rank of projects) were gathered based on each contractor's viewpoint.

Based on Cohen's scales, the spearman's rank correlation of 0.586 represents strong relationship between the results of the ranked projects by hybrid method and contractor's viewpoints. The application of this hybrid method is not limited only to selecting and ranking projects. It is also applicable to any kind of decision making in the selection process. Prototype software is developed in the form of the MATLAB to help users in selecting and ranking projects. Even users without any knowledge of the applications like Super Decision and LINDO can solve these kinds of selection problems.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperiyan untuk Ijazah Doktor Falsafah

PEMBNGUNAN KAEDAH HIBRID MELALUI ANALISIS RANGKUMAN DATA DAN PROSES RANGKAIAN ANALITIK UNTUK PEMILIHAN PROJEK

Oleh

MAJID MOJAHED

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Sehubungan dengan kesukaran mendapatkan sumber-sumber, kontraktor-kontraktor tidak boleh menjalankan semua projek secara serentak. Oleh kerana terdapat pelbagai kriteria, kontraktor-kontaktor ini selalu berhadapan dengan pelbagai kesukaran dalam pemilihan projek-projek, jadi kaedah saintifik yang khas adalah diperlukan untuk membantu kontraktor-kontraktor untuk mencapai keuntungan yang lebih banyak. Kaedah-kaedah khas telah digunakan dalam pemilihan projek lapangan tetapi Analisis Hierarki Proses (AHP) hanya boleh menyusun kedudukan projek-projek dalam sistem hirarki dan kaedah-kaedah lain tidak diaplikasikan untuk membuat keputusan dengan sebab dan maklum balas.

Data Envelopment Analysis (DEA) ialah teknik yang sangat berkesan yang menentukan kecekapan atau ketidakcekapan unit Decision Making Units (DMUs). Lebih-lebih lagi ia boleh meningkatkan prestasi unit-unit ketidakcekapan dengan mengurangkan jumlah input pembolehubah dan meningkatkan output. Menggunakan kaedah ANP dengan keadah DEA boleh memberikan penilaian yang lebih realistik melalui penentuan berat elemen-elemen dengan mempertimbangkan persekitaran jaringan perhubungan antara mereka.

Dalam kajian ini,dua jenis soal selidik telah digunakan. Soal selidik yang pertama digunakan untuk mengenal pasti hubungan antara elemen-elemen dan soal selidik kedua khusus untuk berat 27 kriteria tersebut. ‘Kesan politik dalam kawasan’ telah diperkenalkan sebagai kriteria yang penting untuk pemilihan projek. Kedua- dua soal selidik telah diisi oleh 26 orang kontraktor yang mahir dalam 25 projek yang terpilih untuk Syarikat Telekomunikasi. Selepas mengklasifikasikan kriteria tersebut kepada kumpulan yang berkaitan berdasarkan kepada ciri-ciri masing-masing, berat setiap kumpulan telah dikenalpasti. Output kepada kaedah ANP telah diperbaiki untuk menjadi

input untuk kaedah DEA. Untuk mengenal pasti kriteria pemilihan projek dan bilangan kumpulan, kaedah mengundi telah digunakan. Input untuk Cross Efficiency Matrix telah disediakan oleh input dan output kaedah DEA dan akhirnya kaedah hybrid ini mewakili projek nombor 3 'Pembinaan bangunan Pusat Panggilan dengan Jajarm' telah dipilih sebagai projek yang menguntungkan dan ia diikuti oleh projek nombor di Farooj ' Pembinaan bangunan Pusat Panggilan' dan projek nombor 4' Pembinaan bangunan Pusat Panggilan dengan Esfaraeen' dan seterusnya. Untuk membuktikan berapa banyak keutamaan ini hampir kepada realiti, beberapa nombor ordinal (kedudukan projek) telah dikumpulkan berdasarkan kepada setiap pandangan kontraktor.

Korelasi kedudukan Spearman ialah 0.586 dan berdasarkan skala Cohens, dari pandangan kontraktor ini merupakan hubungan yang stabil di antara keputusan kedudukan projek yang telah disenaraikan oleh kaedah hibrid. Penggunaan kaedah hybrid ini bukan sahaja berkaitan dengan lokasi khas, memilih dan menyusun kedudukan projek, malahan juga digunakan untuk apa-apa jenis membuat keputusan dalam proses pemilihan. Perisian prototaip dibangunkan dalam bentuk MATLAB untuk membantu pengguna dalam memilih dan menyusun projek. Pengguna yang tidak didedahkan dengan sebarang pengetahuan tentang Perisian seperti Super Keputusan dan lindo juga boleh menyelesaikan pelbagai masalah pemilihan ini.

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I am also very thankful to have such a great family. My brothers are the greatest source of joy in my life with colorful personalities. Without their support it would not have been possible. No words could ever convey the depth of my gratitude and love to each of them.

I certify that a Thesis Examination Committee has met on 20 March 2014 to conduct the final examination of Majid Mojahed on his thesis entitled "Development of a Hybrid Method by Data Envelopment Analysis and Analytic Network Process for Project Selection" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] IS March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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I hereby confirm that:

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
AW	Annual Worth
B/C	Benefit
C	Benefit-Cost analysis
CCR	Cost
CF	Cash Flow
D	Disbenefit
DEA	Data Envelopment Analysis
DM	Decision Maker
DMU	Decision Making Unit
ELECTRE	Elimination Et Choice Translating Reality
ERR	External Rate of Return
F	Future worth
FW	Future Worth
I	Interest rate
IRR	Internal Rate of Return
LP	Linear Programming
MARR	Minimum Attractive Rate of Return
MCDM	Multi Criteria Decision Making
n	Number of interest period
NPV	Net Present Value
P	Present worth
PP	Payback Period
PW	Present Worth
PW_b	Present Worth-benefit
PW_c	Present Worth-cost
ROR	Rate of Return
R&D	Research and Development
TOPSIS	Technique for Order-Preference by Similarity to Ideal Solution
U_{rj}	The amounts of r_{th} variable (output) in j_{th} DMU
U_r	Output weight
V_i	Input weight
V_{ij}	The amounts of i_{th} variable (input) in j_{th} DMU
WPM	Weighted Product Method
WSM	Weighted Sum Method
X_{ip}	The weight of i_{th} variable (input) in p_{th} DMU
Y_{pr}	The weight of r_{th} variable (output) in p_{th} DMU
$\bar{z}_j$	The amount of average in J_{th} DMU
Z_p	Relative efficiency score of DMU_p

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This chapter introduces the background and basic ideas of this study. It starts by discussing the background of the study. It further discusses the problem statement as well as the objectives of the study. Then it goes through knowledge contribution of the research and scope and limitation and ends with organization of the thesis.

1.2 Background of the Study

Contractors are always faced with difficulties in selecting construction projects that offer return on investment. Because of lack of resources, they cannot start all projects simultaneously. Instead, they should choose the most doable projects, which not only maximize positive results but also minimize any negative results. This increases the need for relying on a set of collection criteria for ranking a number of projects (Cheng & Li, 2005). Those projects with most promising scores are given the highest priorities for undertaking. Badri et al. (2001), after directing a simple analysis, found that there are thirteen kinds of methods that are raised for IS project selection decision, including scoring, ranking, mathematical programming, fuzzy logic, and analytic hierarchy process (AHP). A review of recent published papers has identified another list of methods that have been developed to address project selection problems in the construction field (Cheng & Li, 2005). At the same time, the total number of criteria which a human is able to analyze is seven plus or minus two (Doyle & Green, 1994; Saaty, 2003). In addition, in some papers about project selection, authors show that without finding relationship between criteria, selection of the best project could not be found exactly (Jiang & Klein, 1999; Lee & Kim, 2000). Therefore, the main question is how to select and rank projects to achieve more profit. In order to maximize profit, a proper scientific method is necessary to aid contractors for ranking projects.

Data Envelopment Analysis (DEA) is a very powerful benchmarking technique that determines a Decision Making Units (DMUs) as efficient or inefficient units. Moreover, it can increase the performance of inefficient units by reducing the amount of input variables and increasing the output ones. This can be possible through creating a virtual unit and using reference sets for any inefficient unit (Dai & Kuosmanen, 2014). It is a mathematical method which develops an efficient frontier to provide an estimate of relative efficiency for each decision making unit (DMU) in the problem set (Çelebi & Bayraktar, 2008). The DMU's efficiency is shown as the ratio of the weighted sum of its outputs to the weighted sum of its inputs. In other words, to determine weights of DMU individually and optimally, an optimization problem should be solved (Womer et al., 2006). Finally, the DMUs will be placed into efficient and inefficient categories: the efficient, when the DMU lies on the frontier or surface and the inefficient will be otherwise. The frontier is a line that will connect all efficient DMU's. Therefore, the efficient DMU's cannot improve one of its input values without worsening the others.

Other DMUs cannot produce the identical outputs by consuming less inputs or consuming the identical inputs by producing more outputs (De Boer et al., 2001). Preparing efficiency scores and also finding reference units for inefficient DMUs is another job of DEA method. In the form of Input Oriented and Output Oriented, a DMU can be efficient by decreasing its inputs and increasing its outputs respectively (Joro, 1998). It is one of useful management and decision tool that was first developed by Charnes et al. (1978).

The principles of DEA date back to (Farrell, 1957). The recent series of discussions on this topic started in a seminal paper by (Charnes et al., 1978) as a means for comparing the efficiency of DMUs. Fractional linear measure of efficiency was changed into a Linear programming format (LP) in order to solve these kinds of problems easily (Adler et al., 2002). The traditional DEA models are not very appropriate for ranking DMUs because they simply classify the units into two groups: efficient and inefficient (Nazarko & Šaparauskas, 2014; Adler et al., 2002). The amount of alternatives efficiencies start from zero to one so the DMUs with the amount of one are called efficient and the others are called inefficient. Cross Efficiency Matrix method proposed by (Sexton et al., 1986), is a DEA extension tool that can be utilized to identify good overall performers and rank DMUs. Its main idea is to use DEA in a peer evaluation instead of a self-evaluation, but there are at least two advantages for cross-evaluation method (Wu et al., 2009). First, it provides a unique ordering among the DMUs. Second, it eliminates unrealistic weight schemes without requiring the elicitation of weight restrictions from application area experts. Therefore, the cross evaluation method is widely used for ranking the performance of DMUs (Wu et al., 2008).

The applications of DEA method are in many different areas. Efficiency Evaluations of Nursing Homes (Sexton et al., 1986), Selection of a Flexible Manufacturing System (Shang & Sueyoshi, 1995), Justification of Advanced Manufacturing Technology (Talluri & Paul Yoon, 2000), Preference Voting and Ranking (Green et al., 1996) and some other ranking with Cross Efficiency (Jahanshahloo et al., 2011; Wu et al., 2009; F. Yang et al., 2012; Zerafat Angiz et al., 2012). Currently, among a variety of project selection techniques, one of the most effective is Multi Criteria Decision Making in which contractors or decision makers set a list of criteria which are important and evaluate the potential projects against these criteria.

The Multi Criteria Decision Making (MCDM) prepares an effective frame for comparison based on the assessment of multiple conflict criteria and it is called one of the fastest growing areas of operational research. It has been shown as the most popular branch of decision making (García et al., 2014; Triantaphyllou, 2000). In the literature review, there are some methods in MCDM approach that are available with different ways to categorize them (Feizizadeh et al., 2014). Deterministic, Stochastic and Fuzzy Methods are some of them. Another way of categorizing MCDM is based on the number of decision makers involved in the decision process. To become more familiar with MCDM approach, the Taxonomy of this method has been shown in Figure 1-1, as it was presented by (Chen et al., 1992)(Hwang, 1987).

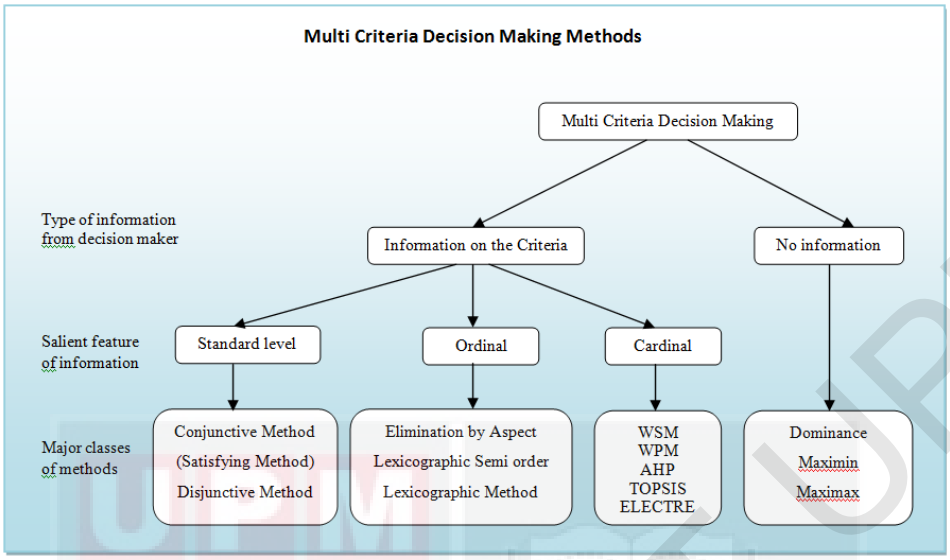

Figure 1-1: Structure of MCDM approach

In Figure 1-1, there are five methods that could be applied in this research in order to solve some defects in traditional DEA. Each method has its own advantages. (These methods have some advantages over each other that should be compared). The best method is a method which can solve more defects using DEA method. In this figure, the Weighted Sum Model (WSM), the Weighted Product Model (WPM), Analytic Hierarchy Process (AHP), Technique for Order-Preference by Similarity to Ideal Solution (TOPSIS) and Elimination Et Choice Translating Reality (ELECTRE) were considered as methods of the MCDM approach. After comparing these methods in order to select the efficient one for helping DEA, researchers found a new method. Analytic Network Process (ANP) was developed from the AHP by Saaty (1996) which creates a better understanding of the complex relationships among the elements in decision making and at the same time it will improve the reliability of decision making (Habtamu et al., 2013; Jharkharia & Shankar, 2007). It was introduced by Saaty and he found later that many complex decision making problems can be solved by an effective tool such as ANP.

All decision problems that were solved with AHP could be done by ANP. In addition, ANP is capable of solving more complex problems such as interaction and feedback among different elements in decision problems (Saaty & Vargas, 2006). In other words, ANP provides a solution for problems which cannot be structured hierarchically. Therefore, a diagram (that is) called a network will solve many complex problems (Saaty, 1986). To start the MCDM approach, some criteria and alternatives are required. Criteria or factors can be positive or negative. For applying the methods of this approach identifying essential criteria is needed. However, alternatives must be ranked or selected by this approach. In the next paragraph, for better understanding, the project has been described as a kind of alternative and also a contractor will be the decision maker.

1.3 Problem Statement

Construction projects deal with many unique features, including long period, complicated processes and financial intensity (Cheng & Li, 2005; Zou et al., 2007). Contractors cannot consider all projects concurrently and often confront difficulties in selecting the construction projects, because of limited resources. The most viable projects have to be selected to maximize positive outcomes (e.g., profits, reputation, etc.) and minimize any negative results (e.g., technical deficiency, environmental harm, etc.). This raises the need for relying on a set of selection criteria for prioritizing a number of projects (Ebrahimnejad et al., 2012). Therefore, the problem of selecting and ranking projects is a multi-criteria selection problem which calls for advanced multi-objective problem solving techniques.

To deal with such a problem, a scientific method is needed, which can rank projects by considering relationship between elements in a network system (Lee & Kim, 2000). The usual practice in this respect is to select a number of inter-related criteria and apply a MCDM technique (e.g. AHP, ANP, DEA, etc) to find the weights of the criteria which enables ranking of Decision Making Units (DMUs). But such a straightforward approach is not efficient in all problem settings and especially in project selection problems where the number of criteria is high and there is interrelationship between pairs of criteria which should be taken into consideration when ranking the projects. In other words, not all the criteria are independent. Analytic Hierarchy Process (AHP) is a scientific method that can only rank projects in the Hierarchy system. Some of MCDM methods are not able to mix qualitative and quantitative factors and also are not applied for decision making with dependence and feedback. Furthermore, DEA cannot be an appropriate decision making method when there are a variety of project selection criteria and relationship amongst those criteria.

Thus, there are two issues which should be addressed in multi criteria project selection problem. First, the number of criteria is considerably high which restricts the application of the developed methods. Therefore, the first issue is to scale down the criteria domain. Second, pure expert based methods that rely only on the expert judgments are somehow inapplicable in real situations since individual psychological, even ethnic factors could bias expert opinion and consequently the results of the project selection study.

To address these two aforementioned issues, this study proposes an integrated ANP-DEA method for project selection. Adopting this integrated method in real-world project selection applications offer some advantages which will be discussed in the following. Data Envelopment Analysis (DEA) is a very powerful technique that not only determines Decision Making Units (DMUs) as efficient or inefficient units but also it can offer targets and benchmarks for improvement of the inefficient DMUs either by reducing the amount of inputs or increasing the outputs.

In judgment procedure sometimes important factors could be ignored in the analysis, which happens when giving a zero to the corresponding variable or when the weight found is in contradiction with a priori knowledge. This limitation has been overcome in

DEA by weight restriction and established bounds within which the weights can vary, preserving some flexibility or some uncertainty about the real value of the weights (Angulo-meza et al., 2002). Peer-evaluation instead of a self-evaluation which is calculated by the other methods is another advantage of DEA method. A peer-evaluation means that each DMU is evaluated according to the optimal weighting scheme of other DMUs. This besides increasing discrimination, provides an interesting meaning, considering a negotiation meeting among experts in order to select criteria or alternatives in a decision making process (Daraio & Simar, 2007). However, though DEA is extensively adopted in the problem of evaluating a group of alternatives, it has some limitation:

i. The DEA method cannot determine if there are any relationships between variables and DMUs (Cooper et al., 2006).

ii. The number of DMUs should be at least 2 or 3 times larger than the total number of input and output variables (Ramanathan, 2003; Berg, 2010).

To overcome these limitations the proposed integrated ANP-DEA uses ANP prior to DEA for determining the weight of criteria by considering relationship between them in a network system and scale down the number of criteria by classifying selected criteria into a relatively small number of groups. Moreover, DEA treats each group as an input or output. Therefore, the number of input-output will decrease considerably by ANP and this reduces the need for extensive number of DMUs. Using ANP integrated with DEA makes the assessment more realistic. These two methods could be applied in the field of project selection even with a wide variety of criteria. They are used in an integrated manner when the output of ANP as auxiliary method is served as input or output for DEA as the main method.

Application of DEA model needs determination of some special features of the model (Cooper et al., 2007). These features are:

- Input-output determination: a desirable input in DEA is the variable its decrease is of interest. Inversely, a desirable output in DEA is the variable its increase is of interest. This simple set of definitions can be served as a simple rule to determine the DEA inputs and outputs (Seiford and Zhu, 2002).

- Model type: in project selection problem one can decide between two types of DEA models namely basic models and full ranking models. Basic models divide between efficient and inefficient projects where more than one project may be selected as efficient projects. While full ranking models discriminate between all the projects where a full ranking of projects will be possible (Zhou et al., 2008).

- Model orientation: DEA model can be input-oriented or output-oriented. The orientation of DEA model is something that related to the degree of control that the modeler has on the variables. If the modeler can keep control on the input variables, make decrease or increase in them, then the model will be input-

oriented. On the other hand, where the modeler can keep control on the output variables and make decrease or increase in outputs, then the model will be output-oriented (Cooper et al., 2007).

- Return to scale: return to scale is an economic concept which describes the type of functional relationship between inputs and outputs. There are two types of RTS namely constant RTS (CRS) and variable RTS (VRS) including increasing RTS and decreasing RTS. Not in every application of DEA this economic concept is relevant. However, one always could draw a linear or non-linear functional relation between inputs and outputs. In the project selection problem we can set a simple rule to determine return to scale. If the functional relationship between inputs and outputs is linear, then the DEA model should be CRS. Otherwise, if a non-linear functional relationship is preferred, then the DEA model should be VRS (Cooper et al., 2007).

1.4 Research Objectives

Overall Aim

To develop a hybrid DEA-ANP method in solving project selection problems.

Specific Objectives

i) To identify and determine the weights of significant criteria for project selection.

ii) To rank projects in network system using Analytic Network Process and Data Envelopment Analysis.

iii) To develop a prototype software for project selection problems.

1.5 Knowledge Contribution

It is essential to state that not only can this study be applied to selecting and ranking project, but also it can be applicable to any kind of decision-making procedure in the selection process in order to develop a hybrid method of decision-making considering the relationship between the criteria and the alternatives based on network system of elements and prototype software to be used as a tool utilizing Super Decision and LINDO applications in Project Selection issues.

1.6 Scope and Limitations

In DEA, the DMUs that have been applied must be homogenous units. This means the objectives of DMUs must be similar. In addition to this, the characteristics of their inputs and outputs should be identical, but they can be different in intensity or magnitude. For example, efficiencies of DEA will not be suitable when we compare construction projects and IT projects because of differences between their inputs and outputs. In order to eliminate this, the study compares construction projects. The number

of DMUs to be compared depends upon the number of criteria in DEA study. In general, as the total number of criteria (sum of inputs and outputs) are increased, the number of DMUs must be increased too. So the relation between the number of DMUs and the total number of criteria in the DEA will be followed by some rules of thumb. Therefore, the limitation of DEA is that the sample size of DMUs should be at least two or three times larger than the number of inputs and outputs in total (Avkiran, 2001; Ramanathan, 2003). Therefore, in the hybrid method, the criteria will be analyzed based on the Input-Output Efficiency Method to classify inputs and outputs. In this case, fewer projects can be compared with the same number of criteria.

1.7 Organization of the Thesis

There are five chapters in this thesis and each chapter can generally be summarized as follows:

Chapter one includes a background of the research with a problem statement, research objectives, knowledge contribution, the scope of the study etc. Chapter two is a literature review that includes literature on Multi Criteria Decision Making, Data Envelopment Analysis, project selection and also some previous studies about them. This chapter will provide the theoretical background for the study. Chapter three explains the general methodology on how the questionnaires were designed, distributed and gets results step by step. Chapter four is a description of the present situation of construction project selection in contractors' sights including analysis and interpretation of the results obtained from the survey questionnaire and previous document from case study. Lastly the results will be extracted; appropriate recommendations will be made and also presented in chapter five.

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