UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF BI-OBJECTIVE OPTIMIZATION MODEL FOR SUPPLY CHAIN NETWORK DESIGN USING DATA ENVELOPMENT ANALYSIS

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By

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In supply chain, there are several facilities including suppliers, manufacturing, warehouses, and distributors and vendors which develop the product, procure material, and move products, produce products, finally distribute finished products between sites. Understanding different aspects of facility location in supply chain network, such as operations, decision-making policies and relating them to performance measurements have been increasingly investigated in the last decade. The number of facilities, location, and capacity of the facility affects the performance of supply chain. Therefore facility location decision in the supply chain can be performed simultaneously with data envelopment analysis (DEA) efficiency measurement. Recently data envelopment analysis method has been used to measure the performance of decision-making units (DMUs), though, sometimes there are DMUs which their behavior are like a network that a classical DEA method cannot deal with, as in the case of supply chain network. To design the optimal supply chain network several objectives, such as cost, environment, social, coverage need to be considered. Facility efficiency is recently focused by some scholars as a new objective in supply chain network. With this, network DEA has been introduced as the best model to solve this problem. In this thesis, there are two objectives which should be achieved. First objective is obtaining an optimal DEA efficiency score simultaneously with facility location pattern for two stages supply chain are studiedas a bi-objective model, and a trade-off between facility location cost with facility efficiency score alongside sensitive analysis in the supply chain are shown. Moreover, in the second objective Benders decomposition algorithm has been introduced as an effective approach for large-scale size problem. Several examples have been applied to verify and validate the effectiveness of proposed model and Benders decomposition algorithm. An example from the real case was considered to verify and validate the proposed model. One numerical example has been illustrated the effectiveness of Benders decomposition algorithm for the complicated problem.

One example with standard data from Malaysian business has shown to depict the effectiveness of proposed approach for facility location-allocation problem as a mixed integer optimization problem. Furthermore, another example from the real case has compared the effectiveness of the Benders decomposition for the proposed model with a solution has been found from the original problem and solved with the CPLEX solver. In this regard, other simulation data for the large-scale cases in the range of real case also compared. Analysis of the results expressed acceptable performance of the developed model and proposed solution for different cases in different sizes. The developed model and solution method show excellence performance in terms of CPU time for the large scale. And in the last part conclusion and future works are presented.

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

PEMBANGUNAN PENGOPTIMUMAN MODEL BI-OBJEKTIF UNTUK REKABENTUK RANGKAIAN RANTAIAN BEKALAN MENGGUNAKAN ANALISIS PENUTUP DATA

Oleh

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Dalam rantaian bekalan, terdapat beberapa komponen atau kemudahan iaitu termasuk pembekal, perkilangan, gudang, dan pengedar dan vendor yang merancang produk, memperoleh bahan dan menggerakan produk, menghasilkan produk, dan akhirnya mengedarkan produk yang telah siap. Dalam dekad yang lalu, memahami aspek lokasi kemudahan dalam hubungan rantaian bekalan, seperti operasi, dasar membuat keputusan dan mengaitkan mereka kepada ukuran prestasi telah semakin dikaji Bilangan kemudahan, lokasi, dan kapasiti kemudahan mempunyai kesan ke atas prestasi mereka. Oleh itu, keputusan lokasi kemudahan dalam rantaian bekalan boleh dilakukan dengan analisis data (DEA) pengukur kecekapan dengan serentak. Baru-baru ini, kaedah analisis data (DEA) telah digunakan untuk mengukur prestasi unit membuat keputusan (DMUs), bagaimanapun, kadang-kadang terdapat DMUs yang tingkah laku mereka adalah seperti rangkaian (network) di mana kaedah DEA klasik tidak boleh berurusan dengannya, seperti dalam kes rangkaian rantaian bekalan. Untuk merekabentuk rangkaian rantaian bekalan yang optimum, beberapa objektif seperti kos, alam sekitar, sosial, yang perlu dipertimbangkan. Kecekapan kemudahan baru-baru ini telah memberi tumpuan oleh sebahagian sarjana (para ilmuwan yang pakar dalam bidang tersebut) sebagai matlamat baru dalam rangkaian rantaian bekalan. Dengan ini, rangkaian DEA telah diperkenalkan sebagai model yang terbaik untuk menyelesaikan masalah ini. Dalam tesis ini, mendapatkan skor kecekapan DEA yang optimum pada masa yang sama dengan corak lokasi kemudahan bagi dua peringkat rantaian bekalan telah dikaji dan keseimbangan antara kos lokasi kemudahan dengan skor kecekapan kemudahan bersama analisis sensitif dalam rantaian bekalan akan ditunjukkan. Dan algoritma Bender penguraian telah diperkenalkan sebagai pendekatan yang berkesan untuk masalah berskala besar. Beberapa contoh telah digunakan untuk mengenalpasti dan mengesahkan keberkesanan model yang dicadangkan dan Bender algoritma penguraian. Contoh dari kes-kes sebenar diambil kira untuk mengenal pasti dan mengesahkan model

yang dicadangkan. Satu contoh berangka telah menggambarkan keberkesanan algoritma Benders penguraian untuk masalah yang rumit. Satu contoh bersama dengan data standard daripada perniagaan Malaysia telah menunjukkan keberkesanan pendekatan yang dicadangkan untuk masalah lokasi kemudahan pembahagian sebagai masalah pengoptimuman campuran integer. Dan akhir sekali, contoh lain dari kes sebenar telah membandingkan keberkesanan penguraian Benders untuk model yang dicadangkan dengan penyelesaian yang dijumpai dari masalah asal dan diselesaikan dengan penyelesai CPLEX. Dalam hal ini, data simulasi lain bagi kes-kes berskala besar dalam lingkungan kes sebenar juga dibandingkan. Analisis keputusan menggambarkan prestasi model yang dibangunkan boleh diterima dan mencadangkan penyelesaian bagi kes-kes lain yang berbeza saiznya.

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I certify that a Thesis Examination Committee has met on 10 July 2017 to conduct the final examination of Iman Rahimi on his thesis entitled "Development of Bi-Objective Optimization Model for Supply Chain Network Design using Data Envelopment Analysis" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

MP	Master Problem
MIP	Mixed Integer Programming
BDA	Benders Decomposition Algorithm
DEA	Data Envelopment Analysis
SCM	Supply Chain Management
MOO	Multi Objective Optimization
DSP	Dual Sub Problem
LP	Linear Programming
MINLP	Mixed Integer Non-Linear Programming
CLSC	Closed-Loop Supply Chain
NP	Non-Deterministic Polynomial
GAMS	General Algebraic Modelling System
CPLP	Capacity facility location problem
UPLP	Uncapacity facility location problem
UFSD	Incapacitated fixed simultaneous DEA/UPLP
CASD	Capacitated adjustable simultaneous DEA/CPLP
PTRM	Pittiglio , Rabin, Todd & McGrath
CCR	Charnes, Cooper & Rhodes
BCC	Banker, Charnes and Cooper
MOP	Multi objective programming

CHAPTER 1

INTRODUCTION

1.1 Background

Understanding different aspects of facility location in supply chain network, such as operations, decision-making policies and relating them to performance measurements have been increasingly investigated in the last decade. The number of facilities, location, and capacity of the facility affects their performance. For evaluating the performance of the supply chain management (SCM), a significant task is how to choose performance measure since the action of management and solutions which caused to enhancement, are resulting from the measurement. These measures could vary based on fields. Reviewing literature depicts which early performance measures mostly consider cost, and since the metrics of cost were interested, decision-makers used to apply it more (Ellram et al., 2002). However, there was some limitations such as inflexibility and lack of integration with strategic decisions causing to scholars to study more to find measures which contain quantitative and qualitative measures in the SCM.

Beamon (1999) recognized three types of measures that included input, output, and flexibility. Extending measures above resulting in providing a novel framework which could evaluate supply chain and measure performance of SCM in three levels, including the strategic, tactical, and operational. PTRM was generated as the first universal performance measures by (Kaplan, 2005). This method was the first widespread method which provides a general class SCM measurement. In PRTM, the important keys for the quality of the supply chain are considered as delivery performance, responsiveness and flexibility, the cost of logistics, etc. The idea of PRTM was developed, and the supply chain's managers recommended the supply chain operations reference (SCOR) model (Stewart, 1995) that resulting in a cross-industry framework which was used to evaluate the performance of SCM. Three levels are considered for SCOR that is regarding the plan, source, and framework which used in SCOR contain a wide range including the performance of delivery, order fulfillment, flexibility in production. Many researchers have worked on performance measurement. However, there are still some gaps in a particular area. One of these gaps is the need for strong measurement criteria and existing inadequate methods to combine available performance measurement. Most of existing approaches could not be able to consider the relative importance of measures that differ among the companies. Moreover, lack of an aggregate measure of overall supply chain performance which could be applied for comparing performance with other firms. Despite the numerous benefits of SCOR, (Huan et al., 2004) depicted which using of SCOR seems to be rather rigid and requires more enhancement. Because of the fact structure of SCM are becoming more increasing, the SCOR model requires to be more dynamic and must be able in providing an adequate platform to measure these complex aspects. While SCOR offers deterministic performance metrics which are controllable by decision makers, it should be more dynamic to provide synchronize different elements. Furthermore, from reviewing the works of other scholars, it could be decided which past researchers had failed to mention the collaborative relationship in the fields which involve cooperative decision making (DM).

A non-parametric approach in the evaluation of firms is Data Envelopment Analysis (DEA) that considers quantitative as well as qualitative measures, providing managers with reasonable judgment on the efficiency of the resource usage. It uses the concept of the efficient frontier which was suggested by(Farrell, 1957). DEA can also compute efficiency for multiple inputs and outputs by dividing the weighted sum of outputs by a weighted sum of inputs. All the efficiencies would lay between 0 and 1, in which 1 represents the most efficient decision making units (DMUs) and 0 shows the inefficient DMU. Facility location in the supply chain can be performed with DEA efficiency measurement simultaneously. Considering facility location supply network design as well as measuring efficiency is more worthy and practical than working with a single objective.

1.2 Problem statement

The given information offered in the background, either gravity or network optimization models may be used to design the network. Based on research by (Melo et al., 2009) the most of the research papers featured a cost minimization objective. Also, this objective is typically addressed as a single objective through the sum of several cost components which depend on the set of decisions which are modeled. Therefore, the aim of the most of the papers worked is to identify the network configuration with the minimum total cost as a first problem.

Supply chain could be classified in the range of size and complexity which is formed from a simple supply chain which shows independent decision-making units to a complex company which includes interactions. Hence, there is need to design an appropriate performance measurement for supply chain which can consider the network structure of the chain and its interactions, this problem is known as the second problem for the thesis.

Classic DEA model, such as BCC &CCR, is not able to consider internal structures. Fairly they treat each decision-making units as a “black box” which consider only initial resources which are consumed to produce final outputs (Chen and Yan, 2011).This viewpoint is suitable for a simple production structure. However as supply chain possesses complex structure, such a method neglects the internal linking activities and necessarily supposes which all the divisions in the supply chain network are under one single decision maker and each internal process is completely efficient. Such method cannot correctly measure the performance of supply chain. Furthermore, for an inefficient supply chain, the classic DEA approaches like CCR and BCC cannot provide underlying information to the management. For measuring the efficiency of the inherent complex structure effectively, this issue can be assumed as the third problem in this thesis. Many scholars have attempted to abandon the "black box "viewpoint and consider internal structure in the DEA model. Models above are called "Network DEA" in the DEA literature.

Modeling of the supply chain network with above mentioned has drawn attention from researchers usually as a single objective, while the design in the real cases typically involves generally involve compromises and balance between conflicting objectives. One of the most important questions in this regard is how it can be found the solutions that balance between cost and efficiency concern both together, this is known as the fourth problem.

Besides, the larger and more complex the supply chain is, the more challenging it becomes to be measured effectively. Moreover, facility location problem is a kind of NP-hard problem (Nagy and Salhi, 2007), so it can be supposed statement above as the fifth problem.

Furthermore, since in supply chain network design, there are a variety of the variables, parameters, and limitations that should be considered in modeling simultaneously they belong to multi-objective optimization. The first approach involves transforming the multi-objectives problem into a single-objective problem that aggregates all the objectives through a procedure called weighted sum in which every objective is to multiply by weight, and the optimal value is obtained summing the weighted objectives. Also, empirical evidence suggests that this approach performs poorly in the case of multi-objective optimization (Moncayo-Mart ńez and Zertuche, 2011). Multi- objective optimization, time-consuming, large size problem, and practical cases, all mentioned as following problems which are faced in this thesis.

To solve the mentioned above problem, it needs an approach which has a proven analytically optimal solution and is based on algebra concept, and decision makers can adapt the optimality gap when they need and could achieve to the optimal solution in a reasonable time.

Therefore, the above-mentioned problems indicate the research about developing transportation and logistics network for supply chain network design that finds Pareto optimal solution to find a trade-off between DEA efficiency and the total cost including shipping cost and fix cost simultaneously and moreover developing a solution approach for the proposed model which could solve large-scale size problem is necessary.

Generally speaking the problem statement of the thesis could be specify as below:

- There is a need for developing a bi-objective model for supply chain network design using DEA efficiency
- There is a need for optimizing aforementioned model and find pareto optimal solutions
- There is a need to verify and validate the proposed model and solution method with a real case study.

1.3 Aims & Research Objectives

The aim of this research are:

1) To develop a bi-objective model that optimizes the cost of supply chain network design as well as maximizes the efficiency of this network regarding to data envelopment analysis concept.
2) To optimize developed model based on Benders decomposition algorithm (BDA) and find the Pareto set of solutions.
3) Verification by numerical test cases, and data from literature and run the sensitivity analysis.
4) Validation with an actual real case study and compare results from Benders decomposition with the results found from original problem by CPLEX.

1.4 Scope of research

Due to the availability of resources, the scope of this research is focused on formulating a mathematical model that can be applied for supply chain network design. The mathematical model is used in this research to optimize bi-objective model that can optimize total cost, and DEA efficiency in supply chain network for facilities that possess two stages include plants, warehouses, and retailers. The bi-objective model considers strategic decisions related to facility location that belongs to responsibilities of top level management. Moreover, this model used to evaluate the relative performance of a set of manufacturers in the supply chain that it includes the processes of designing the distribution centers, and plants and allocation products to retailers as a bi-objective model for firm level of supply chain and division level of the supply chain. The research can be used by manufacturers in industries such as electric power companies, solar energy industries, car manufacturers, which want to establish big business or the businesses that are interested in developing their forward logistics. Moreover, the proposed model is developed for two stages supply chains which use intermediate and external inputs for the second stages. The final stage of the supply chain which has been suggested in the thesis is retailers. Furthermore, the supply chain's case in the model only includes forward logistic.

1.5 Organization of the thesis

The dissertation is arranged as follows: chapter two presents a general review of supply chain network design and optimization, tools used in supply chain evaluation, data envelopment analysis, data envelopment analysis and facility location models, and the trade-off between data envelopment analysis and facility location –allocation models. Chapter three addresses the core of research and concern determining limitation, parameters, and variables. Moreover, explaining the weighted sum method, Benders decomposition algorithm will be discussed in this chapter. Chapter four includes thesis results and illustrates the application in a real case, also findings of numerical examples and comparing results also will be involved. Moreover, finally, chapter five presents research findings and discusses a recommendation for future study.

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