

# **UNIVERSITI PUTRA MALAYSIA**

DEVELOPMENT OF A ROBUST BI-OBJECTIVE MODEL FOR CLOSED LOOP SUPPLY CHAIN NETWORK

**GHAZALEH TAHOORI** 

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## DEVELOPMENT OF A ROBUST BI-OBJECTIVE MODEL FOR CLOSED LOOP SUPPLY CHAIN NETWORK



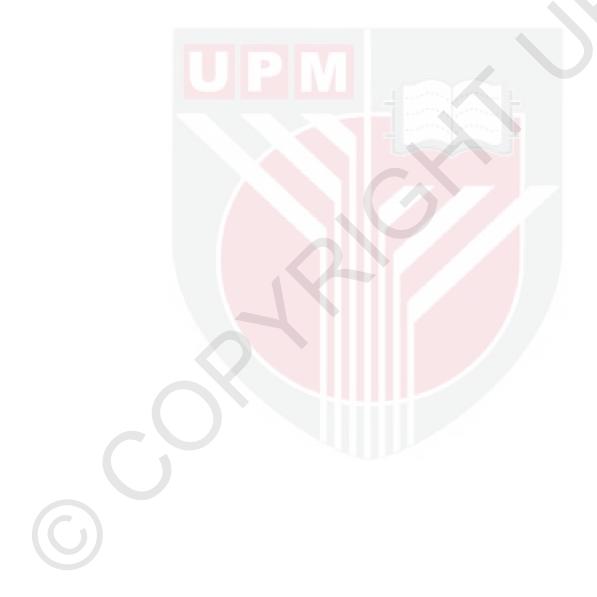
Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in fulfillment of the requirements for the Degree of Master of Science

December 2014

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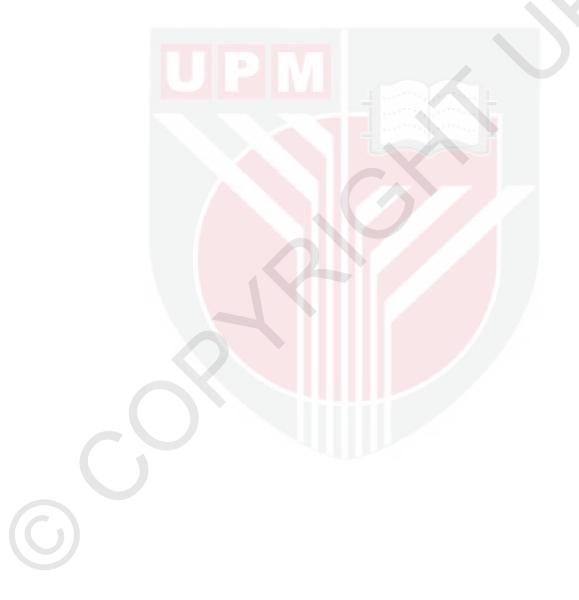
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# DEDICATION

To my beloved parents who are the meaning of life to me and gave me unconditional love and support.





Abstract of thesis to be presented to the senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

## DEVELOPMENT OF A ROBUST BI-OBJECTIVE MODEL FOR CLOSED LOOP SUPPLY CHAIN NETWORK

By

### **GHAZALEH TAHOORI**

December 2014

### Chairman: Rosnah Binti Mohd Yusuff, PhD Faculty: Engineering

Closed Loop Supply Chain (CLSC) is very influential in improving the company's reputation and business competitiveness. One of the most critical strategic decisions in CLSC planning is network design. Decision makers and supply chain planners are struggling with conflicting objectives with uncertain and ambiguous data. Furthermore, uncertainty results in infeasibility and most of the methods applied for dealing with uncertainty are unable to incorporate this infeasibility and only focus on the improvement of the obejective value. Therefore, decision makers need to apply methods which enable them to strike a balance between model feasibility and solution optimality. In order to address this issue, a bi-objective model applying robust optimization in CLSC network design is proposed in this research work. This model minimizes total cost and total environmental impact of the supply chain while defining the location of facilities and the quantities of products transported among different facilities, quantity of products to be produced, total cost and total environmental impact of different configurations. Measuring environmental impact of the supply chain is implemented using a method based on LCA (Life Cycle Assessment), i.e., ReCipe 2008. The data used regarding environmental impact scores were derived from ECO-it software. The augmented  $\varepsilon$ -constraint method is used to solve the bi-objective model. To be more precise, this study gives an insight to managers in striking a balance between economic and environmental aspects of the supply chain. The results of this research were able to define the optimum network design with minimum cost and environmental impact under uncertain demand of customers. The proposed robust model has been validated by obtaining some basic data from a case study conducted by various authors in a pulp and paper industry in Europe. However, further relevant information required for the model was obtained from various sources. The efficiency of the robust model was then verified by a comparison with the equivalent deterministic model using two



performance measures: mean value to validate the solution quality and standard deviation. Computational results of the model show that robust solution reduces mean and standard deviation of total cost and total environmental impact comparing to deterministic model.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

## PEMBANGUNAN MODEL TEGUH DWI OBJEKTIF UNTUH RANGKAIAN BEKALAN TERTUTUP

#### Oleh

### **GHAZALEH TAHOORI**

#### Disember 2014

## Pengerusi: Rosnah Binti Mohd Yusuff, PhD Fakulti: Kejuruteraan

Rantaian Bekalan Gelung Tertutup (RBGT) sangat berpengaruh dalam meningkatkan reputasi dan daya saing syarikat. Salah satu keputusan strategik yang paling penting dalam RBGT ialah reka bentuk rangkaian. Pembuat keputusan dan perancang rantaian bekalan bergelut dengan objektif yang bercanggah dan data yang kabur serta tidak menentu. Tambahan pula, ketidaktentuan menyebabkan ketakbolehlaksanaan dan kebanyakan kaedah yang digunakan bagi menguruskan ketidaktentuan ini tidak ketakbolehlaksanaan menampung tetapi hanya dapat tertumpu kepada penambahbaikan nilai objektif sahaja. Oleh sebab itu, pembuat keputusan perlu menggunakan kaedah yang membolehkan mereka mendapat keseimbangan antara model kebolehlaksanaan dan pengoptimuman penyelesaian. Bagi menangani isu ini, model dwi objektif yang menggunakan pengoptimuman teguh dalam reka bentuk rangkaian RBGT dicadangkan dalam kajian ini. Model ini meminimumkan jumlah kos dan jumlah impak persekitaran rantaian bekalan serta pada masa yang sama menjelaskan lokasi kemudahan dan kuantiti produk yang dikeluarkan, jumlah kos dan jumlah impak persekitaran bagi konfigurasi yang berbeza. Pengukuran impak persekitaran bagi rantaian bekalan dilaksanakan menggunakan kaedah berasaskan-LCA, iaitu ReCipe 2008. Data yang digunakan untuk skor impak persekitaran diperoleh daripada perisian ECO-it. Kaedah imbuh  $\varepsilon$ -kekangan digunakan bagi menyelesaikan model dwi-objektif. Tuntasnya, kajian ini memberi tanggapan kepada pengurus terhadap kepentingan mewujudkan keseimbangan antara ekonomi dan aspek persekitaran dalam rantaian bekalan. Hasil kajian ini dapat menjelaskan reka bentuk jaringan yang optimum dengan kos dan impak persekitaran yang minimum dalam keadaan ketidaktentuan permintaan pelanggan.Model teguh yang dicadangkan telah disahkan dengan mendapatkan beberapa data asas daripada kajian kes yang dilakukan oleh beberapa orang penulis dalam industri palpa dan kertas di Eropah. Walau bagaimanapun, maklumat lanjut yang berkaitan diperlukan kerana model diperoleh daripada pelbagai sumber. Keberkesanan model teguh tersebut telah diverifikasikan dengan membuat perbandingan dengan model deterministic yang



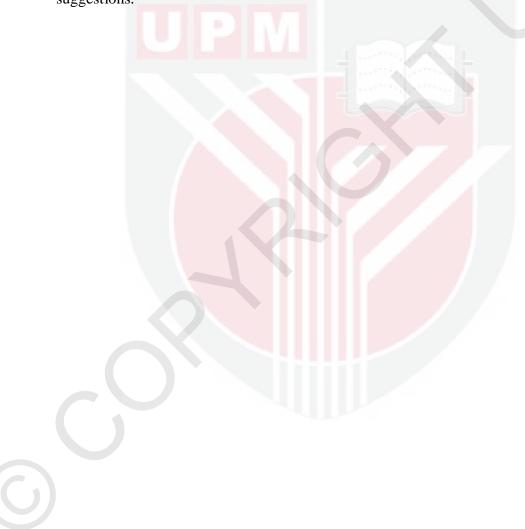
setara mengguna dua ukuran prestasi: nilai min untuk mengesah kualiti penyelesaian dan sisihan piawai. Hasil pengiraan menunjukkan penyelesaian teguh mengurangkan min dan sisihan plawai kos menyeluruh dan impak persekitaran berbanding dengan model deterministik.



## ACKNOWLEDGEMENTS

I would like to take this opportunity to thank each and everyone who helped me make this accomplishment possible. I would like to thank GOD for all his blessing. I would like to convey my sincere gratitude to my parents and siblings. Their unconditional love and support gave me strength and renewed my hope to continue this journey.

I would like to express my deepest appreciation to my supervisor Professor Dr. Rosnah Mohd Yusuff who gave me continuous advice, directions and encouragement. I could not go through this journey without her support. Last, but definitely not the least I would like to express my sincere gratitude to my co supervisor Associate professor Dr. Norzima Zulkifli for her comments and suggestions.



I certify that a Thesis Examination Committee has met on 30 December 2014 to conduct the final examination of Ghazaleh Tahoori on her thesis entitled "Development of a Robust Bi-Objective Model for Closed-Loop Supply Chain Network" 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 Master of Science.

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Date: 19 March 2015

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Supervisory	Supervisory
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# LIST OF ABBREVIATIONS

CLSC	Closed Loop Supply Chain
RL	Reverse Logistic
SC	Supply Chain
APP	Aggregate Production Planning
CLM	Council of Logistics Management
CLSCM	Closed Loop Supply Chain Management
OEM	Original Equipment Manufacturer
WCED	World Commission on Environment and Development
SSCN	Sustainable Supply Chain Networks
MILP	Mixed Integer Linear Programming
LP	Linear Optimization
SDP	Semi-Definite Optimization
SOCP	Second Order Cone Optimization
OR	Operations Research
VaR	Value-at-Risk
DM	Decision Maker
NBI	Normal Boundary Intersection
NC	Normal Constraint
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
LCA	Life Cycle Assessment
SETAC	Society of Environmental Toxicology and Chemistry
UNEP	United Nations Environment Programme
ISO	International Organization for Standardization
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
AoPs	Areas of Protection
CML	Center of Environmental Science of Leiden University
NPV	Net Present Value
APME	Association of Plastics Manufacturers in Europe
MOMP	Multi-Objective Mathematical Programming
RHS	Right Hand Side
GAMS	General Algebraic Modeling Language

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### **CHAPTER ONE**

### **INTRODUCTION**

#### 1.1 Network Design in Closed Loop Supply Chain

Closed Loop Supply Chain (CLSC) is concerned with simultaneous management of the forward and reverse chain in order to create value from the return flow of materials, products or components and meanwhile reduce the environmental impacts of the system (Zarandi, et al., 2011; Krikke, et al., 2001). The primary objective of CLSC is maximizing economic benefit, adding the reverse chain and closing the loop in order to minimize the environmental impact. This will consequently improve the company's reputation and business competitiveness (Stindt and Sahamie, 2012; Neto, et al., 2010).

One of the most critical strategic decisions in supply chain planning is network design which defines the structure of the supply chain and the interconnections of the facilities. Generally, network design is concerned with determining the numbers, locations and capacities of facilities, the material flow and transportation links between them (Correia, et al., 2012; Pishvaee, et al., 2011). The real world problems in network design area are multi-period and multi-objective. Besides, using deterministic supply chain is completely unrealistic since there are various sources of uncertainty in supply chain. Generally, it is impossible to completely remove uncertainty from the supply chain therefore different techniques are applied for optimization under uncertainty. Optimization of supply chain under uncertainty is usually a complex task and requires application of efficient methods capable of incorporating perturbations of data which is an inherent characteristic of real life supply chains (Klibi, et al., 2010; Sabri and Beamon, 2000).

### **1.2 Problem Statement**

Nowadays there is a growing trend for developing multi-period and multi-objective models at strategic level of supply chain incorporating the uncertainty by applying *robust optimization*. In fact it is highly important to contemplate the uncertainty in supply chain because in real world problems a small uncertainty in the data would make the usually-considered-optimal solutions completely meaningless.

Generally three major methods are applied to deal with the uncertainty in supply chain: *Fuzzy methods, stochastic programming* and *robust optimization*. Many research works in supply chain have applied stochastic programming in order to deal

with uncertainty. However, *stochastic programming* is unable to incorporate the infeasibility in optimization and focuses more on improving the objective performance. Models applying *fuzzy method* were generally used when the mathematical model of the process under study is not available. *Robust optimization* is capable of striking a balance between model feasibility and solution optimality on one hand, and keeping the solution and performance immune against the uncertainty of vague parameters on the other hand.

A wave of new research works applying robust optimization in supply chain is increasing during very recent years. However, most of these research works are focused on tactical and operational levels of supply chain (Wang and Huang, 2013; Mirzapour Al-E-Hashem, et al., 2011; Leung, et al., 2007; Wu, 2006) and the application of *robust optimization* at strategic level is still scarce and limited to single objective models (Ramezani, et al., 2013b; Alumur, et al., 2012a; Pishvaee, et al., 2011; Pan and Nagi, 2010). Consequently, lack of a bi-objective robust model incorporating both environmental and economic aspects of sustainable supply chain is observed in strategic supply chain planning. Therefore, the necessity of proposing a model incorporating all multi-period, multi-objective and uncertain features which enables the contemplation of vagueness and uncertain environment is evident. Considering the comprehensiveness and flexibility of robust optimization and scarce number of robust models integrating both environmental and economic aspects of sustainability in supply chain network design, developing such model to deal with uncertainty would be significantly beneficial to overcome the real world challenges in strategic level of supply chain.

## 1.3 Objectives of the Study

This research study is an effort to develop a Mixed Integer Linear Programming (MILP) bi-objective multi-period model in CLSC network design applying *robust optimization* in order to define the optimal facility location and optimal flows among nodes while minimizing both total cost and total environmental impact of the network. To be more precise, the major objectives of this research work are:

1- Develop a robust CLSC network incorporating the economic and environmental aspects.

2- Validate the proposed robust model in a case study for the pulp and paper industry.

This research is one of the scarce applications of bi-objective robust optimization in CLSC network design.

### 1.4 Significance of Study

Most of the models previously presented by researchers in supply chain area applying robust optimization are either single objective or developed at operational or tactical level. Therefore, the main contribution of this study is that the model proposed in this research work is one of the first bi-objective robust models in strategic level of CLSC incorporating economic and environmental aspects of supply chain.

### **1.5** Scope and limitation

Some of the assumptions and limitations of the proposed model are as follows:

First of all the validation of the proposed model is limited to a case study of paper industry in Europe. However, this model could be applied in other industries as well specially in process industries such as steel industry or chemical industry.

One of the limitations of this study is the difficulty of accessing data for environmental impacts assessment of the supply chain concerning different material and processes. The required data is available in different international or national, general or industrial based databases. If there is no data regarding a specific process or activity in the supply chain, some assumptions should be made in the life cycle assessment process by model developers or decision makers in order to incorporate the insufficiency of information.

Since the supply chain network design is targeted in this research study which is a strategic decision, regarding some of the environmental impact information the average data is used, however this is not possible for tactical or operational level decision making such as Aggregate Production Planning (APP) or Scheduling.

### **1.6** Organization of the Thesis

This thesis is aimed to practice the application of bi-objective robust optimization in CLSC network design. This work is done through chapters one to five of this research study.

The first chapter of this thesis provides an introduction of the current research work, problem statement, research objectives and significance of study, scope and limitations, and the organization of the thesis.

The second chapter is reviewing the available literature regarding CLSC, the evolution of supply chain, different issues in supply chain, optimization under uncertainty, robust optimization, its background and applications, and different multi-objective optimization approaches. Furthermore, Life Cycle Assessment (LCA), LCA structure and components, software and databases, and the role of LCA in Green Supply Chain (GSC) are discussed as well. At the end a brief discussion of major issues in pulp and paper industry is presented.

The third chapter describes the detailed outline of the methodology of the current research. Also comprehensive explanation of robust optimization and augmented  $\varepsilon$ -constraint method (as the multi objective methodology) are presented in this chapter.

Chapter four presents the mathematical modeling, model assumptions, objective functions and constraints of the proposed model. This chapter also reports the results of the model after implementing the case study. Moreover, analysis of data and efficiency of the proposed model is illustrated by graphs and figures.

Chapter five presents the conclusions of the model in order to fulfill the objectives of this research study and address recommendations for future researches and possible development areas in the field of study.

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