A BI-OBJECTIVE OPTIMIZATION MODEL FOR A CARBON CAP JIT DISTRIBUTION NETWORK

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Specially dedicated to my beloved parents and my dear sister

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ABSTRACT

The environmental protection concerns and legislation are pushing companies to redesign and plan their activities in an environmental friendly manner. This will probably be done by constraining companies to emit less than a given amount of carbon dioxide per product that is being produced and transported. In addition, some companies may volunteer to reduce their carbon footprint. Consequently, companies will face new constraints that force them to reduce carbon emissions while still minimizing production and transportation costs. Transportation is at the heart of logistics activities and is one of the leading sources of greenhouse gas emissions. The emitted carbon dioxide through transportation activities is accounting for almost 80% of the total greenhouse gas emissions. The need to implement Just-In-Time (JIT) strategy for transporting small batch sizes seems to beagainst environmental concerns. The JIT principles favor small and frequent deliveries by many small rush transports with multiple regional warehouses. Although several attempts have been made to analyze green supply chain networks, little attention has been paid to develop JIT distribution models in carbon constrained environment. Incorporation of environmental objectives and constraints with JIT distribution will generate new problems resulting in new combinatorial optimization models. In addition, these objectives and constraints will add to the model complexities. Both areas require to be investigated. In this research, a bi-objective carbon-capped logistic model was developed for a JIT distribution that takes into account different carbon emission constraints. The objectives include minimization of total costs and carbon cap. Since the studied problem is Non-deterministic Polynomial-time Hard (NP-Hard), a non-dominated sorting genetic algorithm-II (NSGA-II) was employed to solve the problem. For validation and verification of the obtained results, non-dominated ranking genetic algorithm (NRGA) was applied. Then, Taguchi approach was employed to tune the parameters of both algorithms; their performances were then compared in terms of some multi-objective performance measures. For further improvements of NSGA-II, a modified firefly algorithm as local searcher was applied. Seven problems with different sizes of small, medium, and large were designed in order to simulate the different cases. The findings have significant implications for the understanding of how varying carbon cap could significantly affect total logistics costs and total carbon emission. More specifically, the results also demonstrated devising policies that enable companies to decide when and how to fulfill the required carbon cap could let firms fulfill these caps at significantly lower costs with lower carbon emission. In addition to these findings, the performance of the proposed solution methodology demonstrated higher efficiency particularly in terms of less CPU time usage by 6.62% and higher quality of obtained solutions by 5.14% on average for different sizes of the problem as compared to the classical NSGA-II.

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ABSTRAK

Penekanan terhadap perlindungan dan perundangan alam sekitar telah mendesak syarikat-syarikat untuk merangka semula dan merancang aktiviti mereka supaya lebih mesra alam. Hal ini berkemungkinan boleh dicapai melalui kekangan kepada syarikat-syarikat untuk mengeluarkan karbon dioksida yang lebih rendah daripada yang diperuntukkan bagi setiap produk yang dihasilkan dan yang diangkut. Tambahan lagi, sesetengah syarikat juga boleh mengurangkan kesan karbon secara sukarela. Akibatnya, syarikat-syarikat akan menghadapi cabaran baru yang memaksa mereka untuk mengurangkan pelepasan karbon di samping meminimakan kos pembuatan dan pengangkutan. Pengangkutan merupakan aktiviti logistik yang utama dan juga punca utama kepada pelepasan gas rumah hijau. Pelepasan karbon dioksida melalui aktiviti pengangkutan menyumbang kepada 80% bagi keseluruhan pelepasan gas rumah hijau. Keperluan untuk melaksanakan strategi Tepat-pada-Masa (Just-In-Time) (JIT) untuk mengangkut kelompok bersaiz kecil bertentangan dengan isu alam sekitar. Prinsip JIT menjalankan penghantaran kecil dan kerap oleh banyak kenderaan kecil yang pantas daripada beberapa gudang di sesebuah kawasan. Walaupun beberapa usaha telah dilakukan untuk menganalisis saluran rantaian bekalan hijau, tumpuan tidak diberikan kepada pembangunan model pengedaran JIT dalam situasi kekangan karbon. Gabungan antara objektif alam sekitar dan kekangan terhadap pengedaran JIT akan membentuk masalah baru yang menghasilkan model gabungan yang dioptimumkan. Objektif-objektif dan kekangan-kekangan ini akan menambah kepada kompleksiti model ini. Kedua-dua bidang ini memerlukan kajian yang mendalam. Dalam kajian ini, model logistik karbon-terhad dwi-objektif telah dibangunkan untuk pengedaran JIT yang mengambil kira kekangan pelepasan karbon yang berbeza. Objektif-objektifnya termasuklah meminimumkan kos keseluruhan dan had karbon. Memandangkan masalah yang dikaji adalah NP-sukar (NP-hard), algoritma-II genetik isihan non-dominasi (NSGA-II) telah digunakan untuk menyelesaikan masalah ini. Bagi validasi dan verifikasi keputusan yang didapati, algoritma genetik aturan non-dominasi telah digunakan (NRGA). Kemudian, pendekatan Taguchi digunakan untuk memperincikan parameter-parameter bagi kedua-dua algoritma; prestasi mereka kemudiannya dibandingkan dari sudut beberapa ukuran pencapaian multi objektif. Bagi memperbaiki lagi NSGA-II, algoritma kunang-kunang yang diubahsuai telah diaplikasikan sebagai pencarian setempat. Tujuh masalah dengan saiz kecil, sederhana dan besar yang berbeza telah direka untuk mensimulasikan kes-kes berlainan. Hasil kajian mempunyai implikasi yang signifikan terhadap pemahaman bahawa pengubahsuaian had karbon memberi kesan terhadap keseluruhan kos pengangkutan dan pelepasan karbon. Lebih spesifik lagi, hasil kajian juga menunjukkan polisi boleh ubah yang membolehkan syarikat-syarikat menentukan bila dan bagaimana untuk menepati had karbon yang ditetapkan dengan kos yang lebih rendah dan pengurangan pelepasan karbon. Tambahan kepada penemuan-penemuan ini, prestasi bagi kaedah penyelesaian yang dicadangkan menunjukkan efisiensi yang tinggi terutamanya dari segi penggunaan CPU yang rendah iaitu sebanyak 6.62% dan kualiti lebih tinggi sebanyak 5.14% secara purata untuk pelbagai saiz masalah berbanding NSGA-II klasikal.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CO_2	-	Carbon Dioxide
DC	-	Distribution Center
DOE	-	Design of Experiments
DOF	-	Degrees of Freedom
EA	-	Evolutionary Algorithm
EOQ	-	Economic Order Quantity
FA	-	Firefly Algorithm
GA	-	Genetic Algorithm
GD	-	Generational Distance
GHG	-	Greenhouse Gases
GSCM	-	Green Supply Chain Management
JIT	-	Just-In-Time
MILP	-	Mixed-Integer Linear Programming
MIP	-	Mixed-Integer Programming
MOEA	-	Multi-Objective Evolutionary Algorithm
MOGA	-	Multi-Objective Genetic Algorithm
MOLP	-	Multi-Objective Linear Programming
MOO	-	Multi-Objective Optimization
NP-Hard		Non-deterministic Polynomial-time Hard
NPS	-	Number of Pareto Solutions
NRGA	-	Non-Dominated Ranked Genetic Algorithm
NSGA-II	-	Non-Dominated Sorting Genetic Algorithm-II
OR	-	Operations Research
PSO	-	Particle Swarm Optimization
SC	-	Supply Chain
SCM	-	Supply Chain Management
Sp	-	Spacing

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1. 1 Background of the Study

Global warming impacts are becoming more visible in our daily life. Companies, international organizations and governments have recognized the need of reducing greenhouse gases (GHG) emissions globally. Many countries are implementing various mechanisms to reduce GHG emissions including incentives or mandatory targets. Carbon taxes, carbon markets (emission trading) and different legislations and regulations on carbon emissions (such as Kyoto protocol) are examples of these trends (Labatt and White, 2011). Upon this direction, some companies may volunteer to reduce their carbon footprint. Voluntary programs like Chicago Climate Exchange in United State and Montreal Climate Exchange in Canada are some instances of this trend (Peace and Juliani, 2009; Johnson and Heinen, 2004).

Supply chain (SC) activities such as industrial processes, transportation and many logistics activities are one of the leading sources of carbon dioxide (CO_2) emissions and environmental pollutions (Arıkan *et al.*, 2014). With regard to the environment, transportation is the most visible aspect of supply chain (Dekker *et al.*, 2012). Transportation at the heart of logistics activities belongs to the leading sources of GHG emissions and environmental pollution. The ever growing level of freight and passenger transportation activities led to road freight transportation accounting for the largest share of the freight-related emissions (Piecyk and McKinnon, 2010) and emitted CO_2 through burning of fossil fuels accounts for almost 80% of total GHG emissions (Li *et al.*, 2013). Therefore, these issues have raised concerns to reduce CO_2 emissions amount through supply chain networks planning. Indeed, adding *environmental thinking* concept into traditional supply chain management (SCM), leads to study of green issues on SCM related processes. A large body of research on SCM literature has been devoted to environmental concerns over the evolving concept of "Green Supply Chain Management" (GSCM).

There are two primary aims in GSCM initiatives (Srivastava, 2007): green product design and green operations. In this research, the focus is on green operations of SCM from the logistics perspectives. One of the primary goals in green logistics is to assess the environmental influence of various production and distribution approaches to reduce the carbon emission through logistics and distribution activities (Absi *et al.*, 2013). With respect to carbon reduction through logistics chains, the modeling efforts can be classified into two main categories: (i) No focus on the carbon regulatory schemes. (ii) Specific focus on the carbon regulatory schemes. Although the academic literatures in both these categories have grown over the years, however; some of the early best practices of modern logistics trends such as just- in-time (JIT) logistics has been rarely investigated (Seuring, 2013; Dekker *et al.*, 2012).

The concept of JIT and supply chain in early studies was concerned with improving operational efficiency and waste minimization (Faurote, 1928; Bornholt, 1913). However, the purpose of waste minimization was for economic, not environmental reasons. Waste means greater economic loss (Lai and Cheng, 2009). Distributing of products using JIT logistics calls for very small batches of products to be distributed on an as-needed basis by many small rush transports with less than truckload shipments and multiple regional warehouses. This strategy leads to increase available capital and reduce storage costs. On the other hand, small volume shipments yield more frequent deliveries, that lead to end up with higher environmental pollution and could have significantly affect CO_2 emitted by a firm through distribution of products (Porter and Van der Linde, 1995).

There is also evidence from empirical studies about the influence of JIT distribution on environmental and economic sustainability (Govindan *et al.*, 2014;

Arvidsson *et al.*, 2013; McKinnon and Piecyk, 2009); however, the synthesis of green issues and JIT distribution remains a major challenge in available literatures. Therefore, in this research, green concept is added into classical JIT distribution and it is defined as "distribution of the right amount of products, at the right time to the right place with right amount of environmental impact".

Since 1990s, green issues have been gradually more considered in design and planning of supply chain problems by researchers (Srivastava, 2007). Mathematical models in the area of GSCM pursue not only cost aspects, but also emissions reduction of GHG. In addition, OR helps to find the balance between costs and environmental aspects. Very often, major reduction in emissions can be achieved with only a marginal increase in costs (Dekker *et al.*, 2012; Sarkis *et al.*, 2011).

Multi-objective optimization has been widely employed to study carbon emission across supply chain networks. In most of multi-objective optimization studies, the objective is to determine those solutions in which environmental damage can be decreased only if costs are increased. These solutions are termed eco-efficient. The idea of finding the best eco-efficient alternatives is based on Pareto-optimality (Dekker *et al.*, 2012). Huppes and Ishikawa (2005), with an emphasis on the necessity of eco-efficiency, presented a framework for quantifying eco-efficiency analysis at macro and micro level. There may be several reasons, why the application of eco-efficient models into SC networks is necessary (Huppes and Ishikawa, 2005), however; one major drawback of this approach is that it does not have the capability to control and impose carbon emission restrictions through SC networks planning. In United States, for instance, emitted CO_2 from trucks increased from 42% of total transportation CO_2 emissions in 1995 to 49% in 2006 and show no signs of decreasing (Ülkü, 2012).

Clearly applying trade-off and finding the balance between environmental and economic issues does not make sense in such situations, since identifying the optimum solution based on costs does not necessarily mean an optimum alternative for carbon emission. In addition some companies may be enforced to control the amount of their CO_2 emissions or may do not exceed from a specific level. All these issues lead to impose carbon constraint into mathematical models rather than finding eco-efficient solutions. Despite of the many efforts that have been made to find the balance between eco-efficient solutions in mathematical models, little attention has been paid to carbon emission constraints in current logistics practice.

Distribution decisions are jointly linked problems and need to be managed in an integrated way concurrently (Park *et al.*, 2007). Developing integrated inventory planning decisions along with logistics models result in complex models that might be difficult to find their optimal solutions. The complexities associated with this type of decision making can be more augmented by the complex maze of network, the SC geographical area and various parties involvement with conflicting objectives (Pitty *et al.*, 2008; Pandey *et al.*, 2007). In addition, decision making in complex SC includes conflicting objectives and different constraints which imposed by the suppliers, manufacturers and distributors. Furthermore, majority of the complex SC planning problems are categorized under NP-hard problem classification (Fahimnia *et al.*, 2013). Due to this reason, heuristic or metaheuristic techniques are required to solve these problems (Zhang *et al.*, 2015; Griffis *et al.*, 2012).

1. 2 Problem Statement

Statement of the problem can best be treated under three main issues: green supply chain modeling, JIT logistics modeling and solution approach. First, in mathematical modeling of green supply chain networks, many efforts have been made to find the balance between carbon emission and total cost (finding eco-efficient solutions). However, one of the major drawbacks of this trend is it does not have the capability to control carbon emission through planning of supply chain networks. Another criticism of much of the literature is that identifying the optimum answer based on costs does not necessarily mean an optimum alternative for carbon emission. A more effective modeling would include carbon emission constraints. Although the interest in green logistics has grown in the last decades, current logistics practice still rarely complies with environmental constraints and little attention has been paid to carbon emission constraints in modeling of supply chain networks.

Secondly from JIT perspective, although, there have been few empirical investigations on negative environmental influences using JIT logistics but these investigations rely too heavily on empirical analysis. A systematic understanding of how JIT distribution effects on carbon emission is still lacking.

Lately, given the fact that supply chain problems generally present substantial real life complexity, the existing solving approaches in literature have been mostly restricted to small sizes of the problems on the subject. Such approaches, however, have failed to address large-scale supply chain problems. There is certainly a need to further extend the effectiveness of the current optimization approaches for tackling large-scale optimization problems.

Therefore, there is a need for further study to develop a mathematical model as well as an efficient solution approach in a logistics network, taking into account the products are distributed using JIT logistics while carbon emission can be optimally controlled in the whole logistics network.

1. 3 Research Questions

The questions that this study attempts to answer are:

i. What are the constraints and objective functions for developing a multi-objective mathematical model to optimize JIT logistics that consider green criteria beside the traditional optimization criteria?

ii. How solving methodology can be more efficient for tackling large-scale cases?

1. 4 Objective of the Study

In this research, the focus is on the realization of the following objectives:

i. To develop a bi-objective model for a JIT distribution network considering CO_2 emission objective and constraints.

ii. To propose an algorithm to solve the bi-objective mathematical model.

1. 5 Scope of the Study

As a supply chain network may involve various echelons and parties, in this study the main focus is on distributing multiple products through a three echelons supply chain network consists of multiple manufacturers, multiple distribution centers and multiple retailers. The scopes of the research are stated as follow:

i. This research only focuses on deterministic mathematical models since it is more relevant to the investigated issues and to avoid confounding complexity.

ii. For verification and validation of the performed model, seven different problems with different sizes of small, medium and large are considered where the value of parameters in mathematical model were extracted from reference cases in literature. A full discussion of determining these problems is presented in Section 5.3 of Chapter 5.

iii. This research focuses on metaheuristics algorithms as solving approach since the developed model is NP-Hard problems.

1. 6 Significance of the Study

This study adds a new perspective to body of current GSCM literature and offers some important insights for managers and environmental policy makers. Furthermore, the applied solution approach can be a basis to tackle large-scale supply chain problems.

Many companies and industries tend to centralize their facilities which require JIT delivery and this practice has been proven quite successful mainly caused by the substantial cost savings achieved by centralizing stocks and facilities and from employing reliable and fast transportation for both outbound and inbound to the distribution centers transportation. This study proposes a more effective planning approach with respect to environmental restrictions and it helps logistics managers to plan their activities in more environmentally friendly manner while still being responsive and profitable. The findings should make an important contribution to the field of GSCM and green logistics. Finally, this research can provide a unified method to further develop environmental friendly JIT based logistics networks.

1. 7 Definition of Terms

The following terms are frequently used in the context of this thesis:

a) Carbon Cap

The term Carbon Cap refers to maximum allowable carbon emission quota (equivalent) and it sets a limit on carbon emission for companies. Companies may be penalized if they exceed their carbon emission allowances (Absi *et al.*, 2013).

b) Non-deterministic Polynomial-time Hard (NP-Hard)

NP-Hard is a class of problems in theory of problems complexity. NP-Hard problem informally means "at least as hard as the hardest problems in NP" (Talbi, 2009). In this thesis, a full discussion of problems complexity is presented on Section 2.9 of Chapter 2.

c) Pareto Front

Pareto Front, Pareto Set, Pareto Optimality and Pareto Frontier are the synonym terms that refer to a set of optimal solutions obtained by a multi-objective optimization approach (Coello *et al.*, 2007). For more details, please refer to Section 2.7.1 of Chapter 2.

d) Eco-efficient Solutions

A Pareto Front resulting from a multi-objective optimization with two objectives cost and any GHG emissions is termed as Eco-efficient solutions (Huppes and Ishikawa, 2005).

1. 8 Structure of the Thesis

The overall structure of this thesis takes the form of seven chapters, including introduction, literature review, research methodology, mathematical model development, solution approach, results and discussions and conclusion. The remainder of the thesis is structured as follows: the literature on related researches in green supply chain optimization, JIT logistics and optimization techniques are presented in Chapter 2. The research design and methodology are then described in Chapter 3. In Chapter 4, the problem and the proposed mathematical model development is explained. Chapter 5 presents the solution approach. The results and discussions are described in Chapter 6 and the thesis ends with concluding remarks and some areas for future research, in Chapter 7. Figure 1.1 depicts the structure of this thesis.

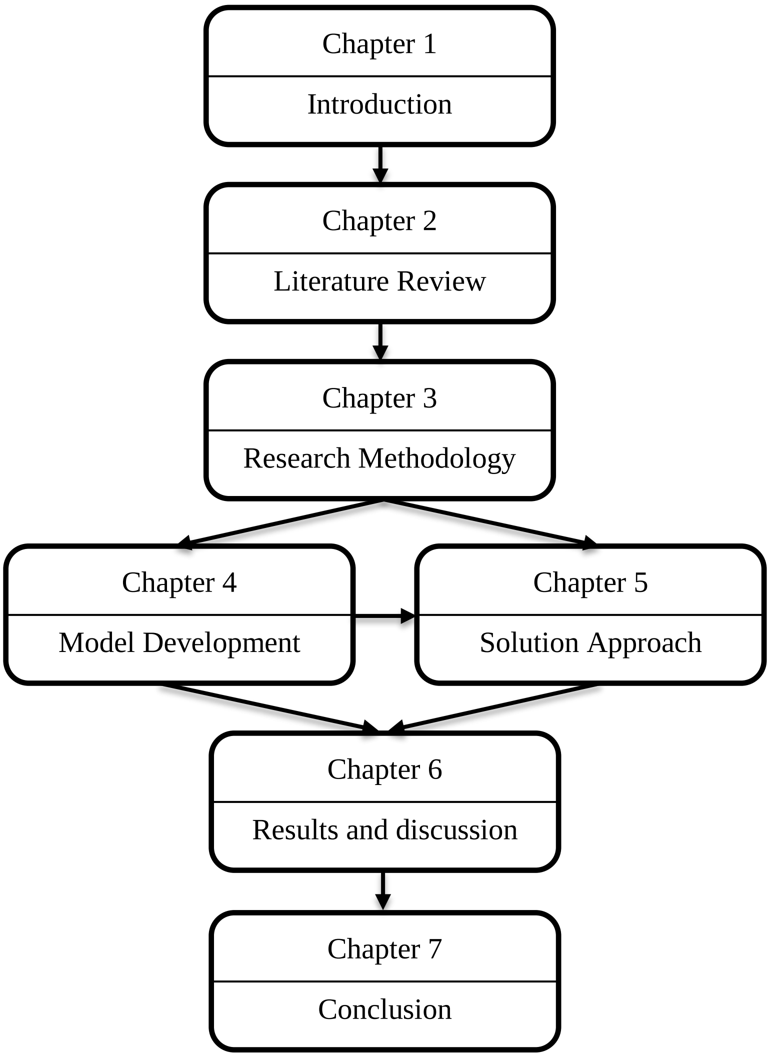

Figure 1.1 Structure of the thesis

1. 9 Summary

This chapter started with a background of the study. This was followed by describing the problem statement, research questions and objectives of the research. Subsequently, the scopes of the study were discussed. The significance of the research was also highlighted. In addition, the frequently used terms in this thesis were defined and finally, the outline of the remaining chapters in the thesis was presented.

7. 4 Recommendations for Future Research

Further works need to be done to establish integrated models in which production and operational decisions are also concurrently addressed. Although this study focuses on green issues, it is however possible to take the social and sustainable perspective for further development of the proposed model. This would be a fruitful area for further work. The present study can also be extended to address the following issues:

i. Considering perishable products would be an interesting direction for further development of the proposed model since the products expiry dates influence products holding duration time in warehouse and order time.

ii. Considering the different transportation mode (e.g. air, rail or ship) with different carbon emission.

iii. Delivery to end customers by third party logistics for on-line purchase (e-commerce).

iv. Applying response surface methodology (RSM) to tune the parameters.

v. To investigate the effectiveness of discrete-event simulation in modeling approaches.

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