HYBRID GENETIC ALGORITHM FOR INVENTORY ROUTING PROBLEM WITH CARBON EMISSION CONSIDERATION

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I dedicate this to my loved ones whom are always with me through thick and thin.

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ABSTRACT

Inventory Routing Problem (IRP) has been continuously developed and improved due to pressure from global warming issue particularly related to greenhouse gases (GHGs) emission. The burning of fossil fuel for transportations such as cars, trucks, ships, trains, and planes primarily emits GHGs. Carbon dioxide (CO2) from burning of fossil fuel to power transportation and industrial process is the largest contributor to global GHGs emission. Therefore, the focus of this study is on solving a multi-period inventory routing problem (MIRP) involving carbon emission consideration based on carbon cap and offset policy. Hybrid genetic algorithm (HGA) based on allocation first and routing second is used to compute a solution for the MIRP in this study. The objective of this study is to solve the proposed MIRP model with HGA then validate the effectiveness of the proposed HGA on data of different sizes. Upon validation, the proposed MIRP model and HGA is applied on real data and parameter sensitivity analysis is performed on the MIRP model. The HGA is found to be able to solve small size and large size instances effectively by providing near optimal solution in relatively short CPU execution time. In addition, the increase in unit carbon price results in the increase of the supply chain's total cost while the increase in carbon cap results in the decrease of supply chain's total cost. The results from the analysis gave an indication that the unit carbon price and carbon cap need to be thoroughly designed so that it will not burden the participating companies of carbon emission regulation and environment.

ABSTRAK

Masalah Penghalaan Inventori (IRP) telah berkembang dan bertambah baik disebabkan oleh tekanan daripada isu pemanasan global terutamanya berkaitan dengan pelepasan gas rumah hijau (GHG). Pengangkutan terutamanya melepaskan GHG dari pembakaran bahan api fosil untuk kereta, trak, kapal, kereta api dan pesawat. Karbon dioksida (CO2) daripada pembakaran bahan api fosil kepada pengangkutan tenaga dan proses perindustrian adalah penyumbang terbesar kepada pelepasan GHG global. Oleh itu, fokus kajian ini adalah untuk menyelesaikan masalah penghalaan inventori berbilang tempoh (MIRP) dengan pertimbangan pelepasan karbon berdasarkan polisi kapasiti karbon dan mengimbangi. Algoritma genetik hibrid (HGA) berdasarkan peruntukan pertama dan penghalaan kedua digunakan untuk mengira penyelesaian untuk MIRP dalam kajian ini. Objektif kajian ini adalah untuk menyelesaikan model MIRP yang dicadangkan dengan HGA kemudian mengesahkan keberkesanan HGA yang dicadangkan pada data yang berbeza saiz. Setelah pengesahan, model MIRP yang dicadangkan dan HGA diterapkan pada data sebenar dan analisis kepekaan parameter akan dilaksanakan pada model MIRP. HGA didapati mampu menyelesaikan data saiz kecil dan saiz besar dengan berkesan dengan menyediakan penyelesaian yang optimum dalam masa pelaksanaan CPU yang singkat. Di samping itu, peningkatan dalam harga karbon seunit mengakibatkan peningkatan jumlah kos rantaian bekalan sementara peningkatan dalam kapasiti karbon mengakibatkan penurunan jumlah kos rantaian bekalan. Keputusan dari analisis memberikan indikasi bahawa harga karbon seunit dan kapasiti karbon unit perlu direka dengan teliti agar tidak membebani syarikat yang berkait dengan regulasi perlepasan karbon dan alam sekitar.

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LIST OF ABBREVIATIONS

ACO	-	Ant colony optimization
AGA	-	Adaptive genetic algorithm
CH4	-	Methane
CO2	-	Carbon dioxide
DP	-	Dynamic programming
DSW	-	Double sweep algorithm
EU	-	European Union
F-gases	-	Fluorinated gases
GA	-	Genetic algorithm
GDP	-	Gross domestic product
GHGs	-	Greenhouse gases
HGA	-	Hybrid genetic algorithm
HTS	-	Hybrid tabu search
IC-SA	-	Imperialist competitive-simulated annealing
IRP	-	Inventory routing problem
LCSM	-	Low carbon supply chain management
m-CTP	-	multi-vehicle covering tour problem
MILP	-	Mixed-integer linear programming
MIP	-	Mixed integer programming
MIRP	-	Multi-period inventory routing problem
mm-CTP	-	multi-vehicle multi-covering tour problem
N2O	-	Nitrous oxide
PSO	-	Particle swarm optimization
RTIs	-	Returnable transport items
SA	-	Simulated annealing
SCP	-	Sustainable consumption and production

SI	-	Swarm intelligence
SIRP	-	Stochastic inventory routing problem
SW	-	Sweep algorithm
UN	-	United Nation
US	-	United States
VMI	-	Vendor managed inventory
VND	-	Variable neighbourhood descent
VNS	-	Variable neighbourhood search
VRP	-	Vehicle routing problem

LIST OF SYMBOLS

A	-	A set of all nodes
S	-	A set of suppliers
DP	-	Depot
AP	-	Assembly plant
H	-	Time horizon
d_{it}	-	Demand for product type i in period $t(t \in H)$
F	-	Fixed vehicle cost per trip
C	-	The weight capacity of each vehicle
h_i	-	Unit inventory holding cost at assembly plant for product i
c_{ij}	-	Distance between node i and node j
f	-	Unit fuel price ($\frac{\$}{l}$)
ρ_0	-	The fuel consumption rate ($\frac{l}{km}$) for empty-loaded vehicle
ρ^*	-	The fuel consumption rate ($\frac{l}{km}$) for fully-loaded vehicle
ε	-	Emissions generated per unit of fuel consumption ($kg\,\frac{CO_2}{l}$)
cc_t	-	Carbon cap in period t
p	-	The price per unit carbon emission bought
x_{ijt}	-	arc (i, j)
ω_{ijt}	-	The total product weight carried by a vehicle through arc (i, j) in period t
q_{it}	-	The product quantity picked up at supplier i in period t
I_{it}	-	The inventory level of product i at the assembly plant at the end of period t
fc_{ijt}	-	Fuel consumption from node i to node j in period t
e_t^+	-	Amount of carbon emission credits purchased in period t

CHAPTER 1

INTRODUCTION

1.1 Preface

Inventory Routing Problem (IRP) incorporates both vehicle routing problems and inventory management problems in a supply chain network. The main objective of the traditional IRP is to minimize simultaneously the inventory cost and transportation cost of a supply chain. From the optimal solution of the IRP, decisions can be made on the delivery schedule, quantity of goods to be delivered to the customers and the delivery routing (Campbell *et al*., 1997).

Along with the increasing environmental concern related to global warming, various initiatives had been taken to achieve a green and sustainable economy. One of the many initiatives is to develop a low carbon supply chain system by focusing on the transportation network. Researchers had made an extension on the existing IRP model by considering the minimization of carbon emission in the model to optimize simultaneously the inventory cost, transportation cost and cost related to carbon emission of a supply chain.

This research studies the extended IRP with multiple period which considers the minimization of inventory cost, transportation cost and carbon emission cost in a supply chain network. The supply chain network in this study consists of multiple suppliers, one depot and one assembly plant. This chapter discusses about the background of the problem, statement of the problem, objectives of the research, scope of the research and significance of the research.

1.2 Background of the Problem

IRP is a fundamental decision-making approach in supply chain management and has been researched and improved upon extensively, most notably since the seminar paper published by Bell *et al*. (1983) where customers inventory level must be met under stochastics demand. In the past, classical IRP often revolves around maximizing profits and minimizing costs with some additional requirements such as travelling time or distance (Li *et al*., 2014; Madadi *et al*., 2010).

Over the years, IRP had been continuously developed and improved to meet various demands from current issues for instance, the global warming issue particularly related to greenhouse gases (GHGs) emission. GHGs contributes to global warming by trapping heat from leaving the atmosphere and make the planet warmer. The burning of fossil fuel for transportations such as cars, trucks, ships, trains, and planes primarily emits GHGs. Over 90 percent of the fuel used for transportation is petroleum based, which includes gasoline and diesel (IPCC, 2007).

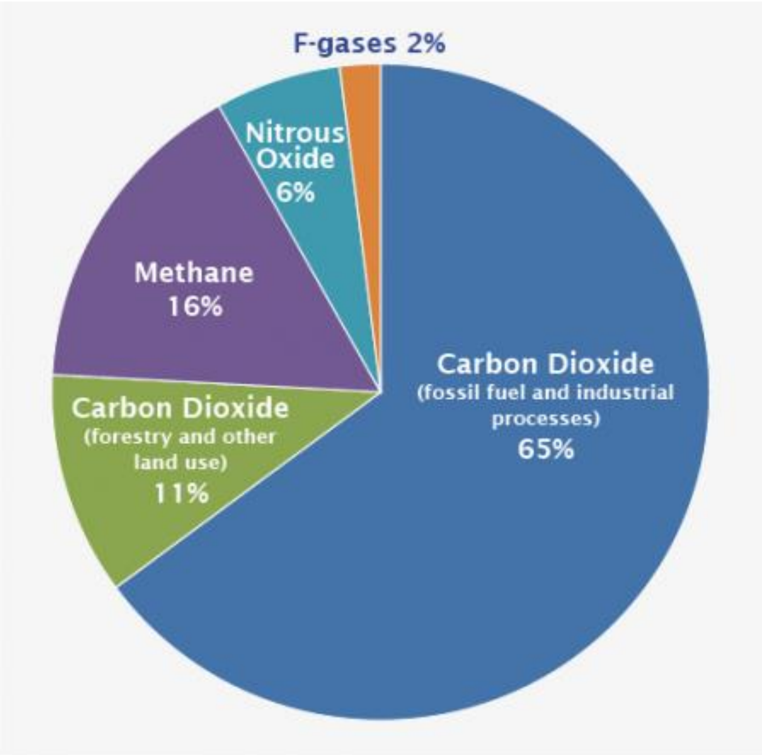

Figure 1.1 Global GHGs emission (IPCC, 2014)

Globally, the key GHGs emitted by human activities are carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and fluorinated gases (F-gases). Figure 1.1 shows the contribution of each gas to the global GHGs emission. It is obvious that CO2 from fossil fuel and industrial process is the largest contributor to global GHGs emission at a total of 65 percent. Therefore, it is crucial to tackle on reducing the amount of CO2 gases in the atmosphere to prevent global warming from getting worse.

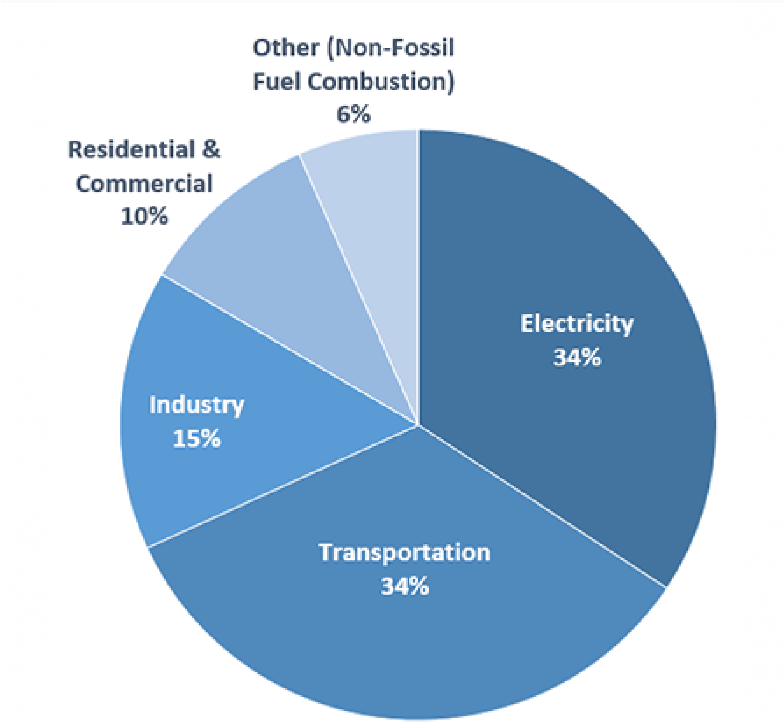

Figure 1.2 US CO2 emission by source (EPA, 2018)

Other than that, from Figure 1.2, in United States (US), transportation and electricity are the largest share of CO2 at 34 percent. Which means that, focusing on reducing CO2 emission in the transportation sector might result in great benefits to the environment. The issue of reducing CO2 emission in transportation sector gave motivation to researchers to study on the management of transportation in supply chain activities which leads to the improvement on the classical IRP model by considering carbon emission in the model.

Nationally, to play a role in halting global warming, in 2009, an announcement made by Malaysia's former Prime Minister Datuk Seri Najib Razak at the 15th Conference of the Parties to the United Nations Framework Convention on Climate Change that by 2020, Malaysia will reduce the level of GHGs emission of its Gross Domestic Product (GDP) by up to 40 percent compared to the levels in 2005. The Tenth Malaysia Plan from 2011 to 2015 focuses on the Renewable Energy Act, Feed-in Tariff mechanism, household recycling, forest reserve while in the transportation sector, the government gazetted EURO 4M standards in 2013 to control emissions from motor vehicles along with higher use of energy efficient vehicles and bio-fuels. On the Eleventh Malaysia Plan, Sustainable Consumption and Production (SCP) approach is established. Under SCP, the government creates market for green products and services, purchases environmentally friendly products and services to spur demand for green industries and encourages low carbon mobility through utilisation of energy efficient vehicles and public transportation (Economic Planning Unit, 2015).

However, these are not the only methods that can be implemented to play a role in preserving the environment, the government may encourage companies in Malaysia to practice a sustainable supply chain to curb carbon emissions. For instance, foreign companies such as IKEA, HP, IBM and GE, made effort to implement environmental friendly initiatives not only by designing greener products but also considers carbon emission in their supply chain networks (Wang *et al*., 2011).

Moreover, the United Nations (UN), the European Union (EU), and several countries have imposed regulations to control CO2 emissions in supply chain network. The four-existing carbon emission regulation policies are the carbon cap, carbon cap and offset, carbon cap and trade, and carbon taxing (Konur and Schaefer, 2014). Under the carbon cap policy, companies manage their operations so that the level of carbon emissions permitted, known as a carbon cap, is not violated. Meanwhile, for the carbon cap and offset policy, a company is allocated a limited amount of carbon cap, but the company can get extra emission credits by paying for them. The carbon cap and trade policy mean that a company can buy (or sell) emission credits if its emission level is higher (or lower) than the cap. Lastly, under the carbon taxing policy, a company must pay for its carbon emissions as taxes (Cheng *et al*., 2016). In addition to the existing methods to halt global warming in the Tenth and Eleventh Malaysia Plan, controlling carbon emission in supply chain is considerably an important initiative to achieving the voluntary target set by the 6th Prime Minister of Malaysia.

There have been several transportation studies focusing on minimizing fuel consumption and carbon emissions by using fuel cost to measure varying transportation cost in IRP. Treitl *et al*. (2014) proposed and applied Inventory Routing Model to a case study of the petrochemical industry. The focus was on analysing how will the routing decisions in transport processes will affect the economy and environment in a supply chain. Niakan and Rahimi (2015) presented a new IRP model specialized in healthcare sector for medicinal drug distribution to healthcare facilities. Cheng *et al*. (2016) studied four different carbon emission regulations, namely the carbon cap, carbon cap and offset, carbon cap and trade, and carbon taxing on the IRP for inbound distribution. Lin and Sarker (2017) developed a new inventory model considering carbon tax policy and investigated the effect of different carbon tax systems on the model. Kang *et al*. (2018) studied the effect of carbon credit price and a carbon cap on the cost of an inventory-allocation network.

IRP is known to be NP-hard as it is an integration between inventory control and vehicle routing problem (VRP) (Federgruen and Simchi-Levi, 1995). A metaheuristic algorithm is essential to produce a near optimal solution in a reasonable amount of time. Recent researches show that genetic algorithm (GA) is an effective and time-saving method to solve NP-hard problems. For instance, Park *et al*. (2016) proposed a GA to solve a vendor managed inventory (VMI) problem, the study concluded that GA produces solutions that are similar to the solutions obtained from the optimization model while requiring shorter computational time. In addition, Santosa *et al*. (2016) compared hybrid tabu search (HTS) method with hybrid genetic algorithm (HGA) on a multi-product IRP in shipping industry. The results showed that HGA provides better results for several different conditions which involved changes in parameter. Yang and Sun (2015) applied a modified GA to a problem involving the electric vehicles battery swap station location and inventory problem which determines the location and battery inventory of battery swap stations. The GA algorithm is effective in solving large-scale network.

Therefore, the focus of this study is on solving a multi-period inventory routing problem (MIRP) involving carbon emission consideration based on carbon cap and offset policy. HGA based on allocation first and routing second is used to compute a solution for the MIRP in this study. The HGA is a combined algorithm of GA and double sweep algorithm (DSW) with the former is used for allocation decisions, while the latter is used for routing decisions. The supply chain involved in this study is an inbound product collection network with one depot, a set of geographically dispersed suppliers and one assembly plant with deterministic and time-varying demands. The transportation cost, fuel consumption cost and inventory holding cost are fixed. Fuel consumption is used to generate the value of carbon emissions. The expected solution will display the best supplier allocation choice and product collection route which results in minimal system's total cost.

1.3 Statement of the Problem

Global warming is among the greatest issue throughout the years and CO_2 emission is one of the known contributors to global warming. To tackle this issue, several carbon emissions regulation policies such as the carbon cap and offset policy, had been imposed on various sectors contributing to carbon emission. Having to abide to these policies, as it would result in certain form of penalty if violated, companies need to make critical decision in their supply chain network to maximize their profit and minimize costs while curbing carbon emission. However, a policy that is not well designed will be a burden to some companies. Therefore, by studying the impact of carbon cap and offset policy on MIRP in a supply chain network, companies will be able to make the best choice in the inventory and routing decisions while policy makers will be able to come up with a reasonable policy that will help participating companies to provide better service to customers while sustaining the environment.

1.4 Objectives of the Study

The objectives of this study are:

a) To solve the proposed MIRP model involving carbon emission consideration with HGA.
b) To validate the effectiveness of the proposed HGA on data of different sizes.
c) To apply the proposed MIRP model and HGA on real data.
d) To perform parameter sensitivity analysis on the MIRP model.

1.5 Scope of the Study

This study focuses on an inbound product collection network consisting of one depot, several suppliers which provide different products and one assembly plant with deterministic and time-varying demand. Data sets of different sizes ranging from small, medium to large and a real data is used in this study.

1.6 Significance of the Study

This study aids decision making process by providing a near optimal option on the product collection schedule, quantity of products to be collected from the suppliers and the product collection route while abiding to the carbon emission regulation. From the sensitivity analysis, policy makers can device the best carbon emission policy which can be implemented on every sector while companies are able to make better decisions based on the effect of these regulations on their transport services.

1.7 Overview of the Study

This chapter gives a detailed description on why researching carbon emission regulation on IRP model is essential. The literature reviews of related studies are discussed in Chapter 2, and Chapter 3 consists of thorough description on the mathematical model and algorithm used in this study. Chapter 4 is a complete illustration on the problem solving and sensitivity analysis. Chapter 5 concludes the study with some recommendations.

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