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Optimization Models in Green Supply Chain Management

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Dedication

Every challenging work needs effort as well as guidance of those who are very close to our heart.

My humble effort I dedicate my thesis to my sweet and loving

Father & Mother & Siblings

Whose affection, love, encouragement and prays of day and night make me able to get such success and honor.

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الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان

Optimization Models in Green Supply Chain Management

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Abbreviations

GSCM	Green Supply Chain Management
SC	Supply Chain
GDI	Green Driving Index
MINLP	Mixed Integer Non Linear Programming
MILP	Mixed Integer Linear Programming
GHG	Greenhouse Gases
CO_2	Carbon Dioxide
APP	Aggregate Production Planning
GL	Green Logistics
DC	Distribution Center
LCA	Life Cycle Assessment
GHRM	Green Human Resources Management
CSCMP	Council of Supply Chain Management Professionals
CLGSC	Close Loop Green Supply Chain
GP	Goal Programming
MOGA	Multi-Objective Genetic Algorithm
LP	Linear Programming
IP	Integer Programming
MIR	Mixed Integer Rounding
OM	Operations Management
JIT	Just In Time
ABC	Activity Based Costing
HC	Hydrocarbon
NOx	Nitrogen Oxides
Eco	Ecological
EPA	Environmental protection Agency

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Abstract

Green Supply Chain (GSC) has attained a huge attention by researchers in the last few decades, but the effect of human aspects in design and managing GSCs has been ignored. In this research, we develop a novel approach for integrating drivers' differences to examine their effect on fuel consumption and CO_2 emissions in optimizing green supply chain in the tactical and operational management levels. More specifically, a more realistic mixed integer nonlinear programming model is proposed to deal with multi-site, multi-product, and multi-period Aggregate Production Planning (APP) setting while considering different levels of drivers and different types of vehicles. The model aims to minimize the total cost and CO_2 emissions across the supply chain. In addition, it aims to derive an assignment between vehicles, drivers, and the destinations as well as an optimal selection and training of drivers. A numerical study is conducted to confirm the verification of the proposed model. The results of conducting sensitivity analysis demonstrated that, after considering green issues the total cost across the supply chain was increased. And the number of drivers for each level varies with different CO_2 emission level, so the CO_2 emission level that the company wants to achieve depends on the level of drivers' available. Also the assignments between vehicles and drivers vary with different CO_2 emission levels and different distances.

Chapter One

Introduction

Chapter One

Introduction

1.1 General Background

During the last decades, the awareness about the environmental issues has been grown, which led to increasing pressures on the firms to be more influenced in protecting the environment and human. The governments' regulations and the increasing consciousness of customers have forced the organizations to adopt green practices that help them to avoid extra taxes and to achieve sustainable competitive advantage. One of the most important areas to apply green practices is the supply chain network, adding green concepts to supply chain concept creates a new paradigm where supply chain will have a direct relation to the environment, recently known as Green Supply Chain Management (GSCM). GSCM has received a large attention in the last few decades, Srivastava (2007), defined GSCM as "integrating environmental thinking into SCM, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life".

This approach leads to integrate environmental criteria in optimizing SC at all the managerial levels; from these criteria are CO_2 emissions, wastes, suppliers' selection, green products design and Life Cycle Assessment (LCA) of the products with the aim of minimizing the environmental effect of the SC.

The GSCM is an important strategy, not just for improved environmental performance but also for improving the overall performance for corporates that adopt this strategy. In this context, Duber-Smith (2005) argued that, there are numerous benefits that could be gained by adopting GSCM such as market targeting, sustainability of resources, minimization costs/ maximization efficiency, achieving competitive advantage, compliance with government regulations and customers' pressures and reducing risk, brand reputation, and increase return on investment. Also, he suggested that, customers should be incorporated in green product design to increase market share and customer loyalty.

One of the important aspects of GSCM is Green Logistics (GL). Firstly, logistics can be defined as "the part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption, in order to meet customers' requirements" (CSCMP, 2016). Integrating green issues into logistics activates reserved a huge attention among scholars and researchers, this led to emerge of GL. Rodrigue et al. (2011) defined GL as "Supply chain practices and strategies that reduce the environmental and energy footprint of fright distribution, which focuses on material handling, waste management, packaging and transport". Whereas, transportation is one of the significance source of pollution in supply chain, and has a harmful effect on environment and human health because it is considered to be a large contributor of Greenhouse Gas (GHG) emissions and other toxic gases

(Paksoy et al., 2011; Wu and Dunn, 1995). Thus, greening transportation by optimizing the logistic network to minimize the environmental effects could play an important role in reducing CO_2 emissions across the supply chain (Barbosa-Póvoa, 2009; Grossmann, 2004).

By reviewing the literature, there are many optimization models in terms of GSCM that aim to minimize the CO_2 emission of SC network, the major of these models focused on strategic management level, which aim to optimize the facilities locations to minimize the total distances between the SC nodes so the total CO_2 emission generated from SC will be minimized (Mirzapour et al., 2013). The less number of these models focused on the tactical and operational management levels of GSCM such as Aggregate Production Planning (APP), these models aim to minimize the CO_2 emissions by optimizing selection of transportation modes and the vehicle weight Mirzapour et al. (2013).

On the other hand, many researches focused on the importance of human resources activities (i.e. recruiting, selecting, training, performance evaluation and rewards) to embrace and implement the green practices in organizations (Daily and hung, 2001; Govindarajulu and Daily, 2004). More specifically in the context of GSCM, Jabbour and de Sousa Jabbour (2015) argued that the truly sustainable supply chain management needed to integrate the Green Human Resources Management (GHRM) and Green Supply Chain Management (GSCM). Specifically, to integrate green human resources management into green logistics, we need to focus on reducing the effect of drivers on fuel consumption and CO_2 emission. Driver behavior is considered to be one of the largest factor that determines the amount of fuel consumption and CO_2 emission in commercial transportation (Liimatainen, 2011). Moreover, differences in drivers' behavior could lead to variation in fuel consumption up to 30%. (Nylund, 2006; Vangi and Virga, 2003).

1.2 Problem Statement

Environmental protection is becoming more and more important for companies due to the increasing of public awareness and increasing pressures from competitors, communities, and government regulations. Reducing the environmental pollution from upstream to downstream during purchasing raw materials, producing, distribution, selling products, and products disposals is the most important goal of GSCM. Toxic gases emission (i.e. CO_2 emission) is considered to be one of the significant sources of pollution in supply chain generated from the transportation activities. Thus, reduction of these gases will minimize the impact of supply chain on the environment. So it becomes critical to incorporate the carbon emissions when managing supply chain to reduce these emissions as much as possible. On the other hand, with increasing awareness about the effect of drivers' behavior on fuel consumption and CO_2 emission, eco-driving strategy can be adopted by companies to improve their economic and environmental performance. Integrating drivers' behavior and skills in managing and designing green supply chain make it more realistic and help to achieve a truly implementing of green initiatives in the GSC.

1.3 Significance of Research

The significance of this research derives from the importance of integrating the drivers' differences (i.e. behavior, skills) and managing the selection, training and assigning of drivers' in GSCM. This research aims to study the effect of this integration on the CO_2 emissions and fuel consumption. To the best of our knowledge, integrated drivers' differences in managing and designing GSC is equally scarce. Thus, the importance of this research is justified.

1.4 Research Questions

This thesis aims to answers the following questions:

1. How can the design of APP minimize the cost of GSC?
2. How can the design of APP reduce the CO_2 emission?
3. How can selecting and training the drivers affect the CO_2 emission and total cost of GSC?
4. How can the selection of vehicles affect the CO_2 emission and total cost of GSC?
5. How can the variation of assignment among drivers and vehicles affect the CO_2 emission and total cost of GSC?
6. How can distances between DCs and Retailers affect the selection of drivers and vehicles and assignment among them?
7. How can the differences in the allowable level of CO_2 emission affect the APP in GSC?

1.5 Research Goal

The goal of this research is to come up with a more realistic GSC model that extends the previous models in the literature by taking drivers' differences into account, and to help decision makers in the sector of retail stores to make decisions regarding APP in GSC (i.e. quantities to be shipped, inventory to be hold, workforce level, and selection of suppliers etc.).

1.6 Research Methodology

The research methodology defines the sequence of activities to be done in order to achieve the research objectives. The research will be started by problem definition and then reviewing the literatures that are closely related to problem statement (i.e. GSC optimization and drivers' differences and behavior). After that, a mathematical model will be developed as a Mixed Integer Non Linear Programming (MINLP) model. And the data required to test the developed model will be collected from the related literature in addition to hypothetical data. The Matlab 2015a software will be used to solve, test and validate the feasibility of the proposed model to give a logical solutions. After that, the sensitivity analysis will be performed to test the robustness of the results of the model in the presence of uncertainty of the input data, to increase the understanding of the relationships between input and output variables in the model and to debug the model by encountering unexpected relationships between inputs and outputs. Finally, the model should be implemented in a way confirms that the model is able to give the desired results, so that the model's applicability and solvability will be ensured.

1.7 Thesis Organization

This thesis is organized as follows: Chapter Two reviews the literature related to Green Supply Chain Management (GSCM), GSC optimization models, drivers' behavior and their effect on fuel consumption and CO_2 emissions. In this chapter, the concept of Eco-Driving is presented which helps organizations to reduce their transportation cost and environmental pollution. Chapter Three presents the mathematical description and formulation of the proposed model. The MINLP model will be presented with its assumptions, sets, parameters, objective function components, and constraints. Chapter Four presents the numerical study and the computational results. The results will include total costs of supply chain (i.e. transportation cost, purchasing cost, workers' cost, drivers' cost etc.), the workforce plan for workers (i.e. the workers needed, hired and fired), the workforce plan for drivers (i.e. the drivers needed, hired, fired and trained), the vehicles to be selected, the assignment of vehicles and drivers, and the quantities to be shipped from suppliers to DCs and from DCs to retailers. Chapter Five discusses the results of conducting sensitivity analysis. The sensitivity will be conducted on the GHG emission level, the distances between sites in SC, and the differences in cost between drivers' levels. Finally, conclusions and limitations of the proposed model will be presented in Chapter Six.

Chapter Two

Literature Review

Chapter Two

Literature Review

2.1 Overview

This chapter presents a review of the literature related to green supply chain management and green supply chain optimization in addition to the differences between drivers' performance and Eco-driving practices. The literature review provides a starting point for the research, and it is an essential part of the research process, since it helps to generate ideas for research and summarizes existing research by identifying patterns, themes and issues. The areas were chosen due to the relevance of the topic investigated.

The main topics covered are the following:

- Supply chain management
- Green supply chain management
- Green supply chain optimization
- Effect of drivers on fuel consumption and CO_2 emission
- Eco-driving
- The integration between GHRM and GSCM

2.2 Supply Chain Management (SCM)

This section is an introduction to supply chain management. We first define the concepts of supply chain and supply chain management. Then, supply chain planning is discussed.

2.2.1 Definitions of Supply Chain Management

A supply chain is "a system of suppliers, manufacturers, distributors, retailers, and customers where materials flow downstream from suppliers to customers and information flows in both directions" (Cachon, 1999). While, Chopra and Meindl (2013) defined SC as "a supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain includes not only the manufacturers and suppliers, but also transporters, warehouses, retailers, and even customers themselves."

Supply chain management aims to designing, managing and coordinating material/product, information and financial flows to fulfill customer requirements at low costs and thereby increasing supply chain profitability. Mentzer et al. (2001) defined supply chain management as "the process of managing relationships, information, and materials flow across enterprise borders to deliver enhanced customer service and economic value through synchronized management of the flow of physical goods and associated information from sourcing to consumption". According to Simchi-Levi et al. (2013), supply chain management is "a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system wide costs while satisfying service level requirements".

Moreover, the supply chain may involve a variety of stages such as suppliers, manufacturers, distributers/wholesalers, retailers, and customers. It is important to visualize information, funds, and product flows along both directions of this chain. The term may also imply that only one player is involved at each stage. In reality, a manufacturer may receive a material from several suppliers and then supplies several distributors. Therefore, most supply chains are actually networks. It may be more accurate to use the term of supply chain network to describe the structure of most supply chains (Hugos, 2011).

2.2.2 Hierarchical Supply Chain Planning (HSCP)

Although there is no a systematic way for defining the scope of supply chain planning problem (Min and Zhou, 2002). Supply chain management planning decisions can be classified into three main categories: competitive strategic, tactical plans, and operational routines (Chopra and Meindl, 2013). As illustrated in Figure 2.1, strategic planning activities focus on a horizon of approximately 2 or more years into the future, whereas tactical and operational activities focus on plans and schedules for 12–24 months, and 1–18 months in advance, respectively (Liang et al., 2016).

The competitive strategic analysis includes location-allocation decisions, demand planning, distribution channel planning, strategic alliances, new product development, outsourcing, supplier selection, information technology (IT) selection, pricing, and network structuring. Although most supply chain problems are strategic by nature, there are also some tactical problems. This include inventory control, production/distribution coordination, order/fright consolidation, material handling, equipment selection, and layout design. Finally the operation routines include vehicles routing/scheduling, workforce scheduling, record keeping, and packaging. Because supply chain problems may involve hierarchical, multi echelon planning that overlap different decision levels (Min and Zhou, 2002), the feedback loops from the operation level to the tactical level, and from the tactical to the strategic level represent one of the most important characteristics of the supply chain planning (Liang et al., 2016).

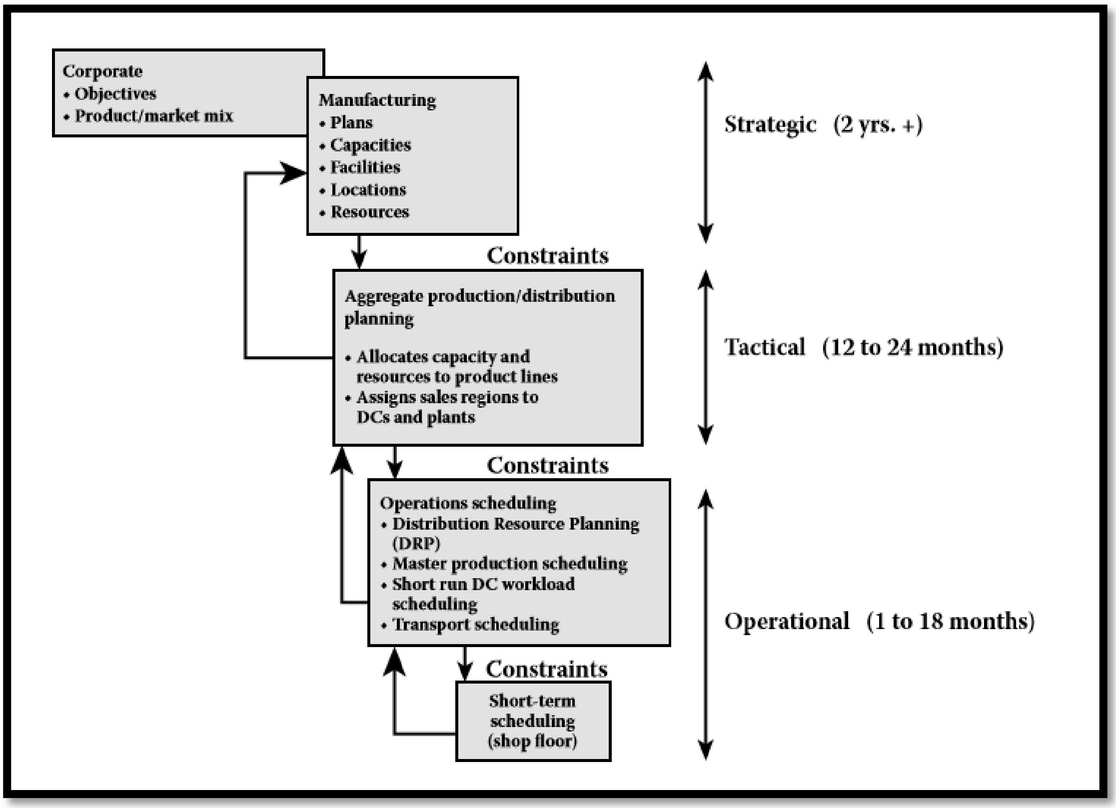

Figure 2.1: Hierarchical supply chain planning framework, (Liang et al., 2016).

2.3 Green Supply Chain Management (GSCM)

Green supply chain management received a considerable attention from scholars, researchers and managers in recent years, as a result of increased awareness about the negative impact of supply chain on environment and humans. So it becomes a key challenge to incorporate environmental aspect in supply chain management (Venkat and Wakeland, 2006).

Designing and managing supply chain involve many activities that could have negative impact on the environment such as raw materials acquisition, manufacturing processes, logistics and waste (Fahimnia et al., 2013; Wisner et al., 2015). The environmental impact of supply chain could be greenhouse gas (GHG) emission, hazardous materials, toxic chemical and other pollutants, in addition to resources depletion issues (Sanders, 2011). Greenhouse Gas (GHG) emissions and global warming have brought our planet to many disturbing impacts such as climate change, droughts, floods etc. In addition, human health is facing serious dangers and risks due to the different kinds of pollutions. “In order to halt the buildup of greenhouse gases in the earth’s atmosphere, global emissions would have to stop growing at all in this decade and be reduced by an astonishing 60% from today’s levels by 2050” (Lash and Willington, 2007). This is why researchers, scientists and many other people involved in industry have begun to include environmental considerations in their studies and in experience in diverse aspects. Many companies have realized the importance of environmental issues to the extent that they define their core values based on these issues. However, “Adopting the environment as a core value, for an individual or an institution means more than just declaring it as a value, it means changing the behavior.” (Grant and Campbell, 1994).

Organizations will have to expect questions about how green their manufacturing processes and supply chain (Lee, 2008). Many variables force the organizations to adopt green practices such as: customers' willingness to purchase products that satisfy the environmental requests; and the government regulations that may occur as technical and financial support or as tax-cut and infrastructure development for environmentally friendly industrial complexes (Lee, 2008). Some of the examples on the governments' legislation to protect the environment from the impact of supply chain, the European Commission's mandatory schemes and incentive programs, the Australian government legislated a carbon tax in 2011 to contribute to the global reduction of carbon dioxide emissions (Bradshaw et al., 2013). Another example is China imposing restrictions on the import and manufacture of products containing cadmium or mercury (Wisner et al., 2015).

Some companies have succeeded in finding environmental solutions and remaining profitable as well. They strengthen their management systems by implementing solutions for reducing costs and strong considerations of environmental impact of their activities. This is going to be the dominant business strategy as Wal-Mart CEO Lee Scott addresses: "It will save money for our customers, make us more efficient business, and help position us to compete effectively in a carbon-constrained world." (Lash and Willington, 2007).

2.3.1 Definitions of Green Supply Chain Management (GSCM)

Various definitions of GSCM exist in the literature. This section will summarize some of these definitions. Firstly, Gilbert (2001) defined GSCM as "greening the supply chain is the process of incorporating environmental criteria or concerns into organizational purchasing decisions and long-term relationships with suppliers. Indeed, there are three approaches to GSC: environment, strategy, and logistics”. According to Zsidisin and Siferd (2001), the green supply chain management is “the set of supply chain management policies held, actions taken and relationships formed in response to concerns related to the natural environment with regard to the design, acquisition, production, distribution, use, re-use and disposal of the firm’s goods and services”. While Srivastava (2007), in the comprehensive review of the green practices, defined GSCM as “integrating environmental thinking into SCM, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life”. Within this context, Rettab and Ben Brik (2008) defined the green supply chain as “a managerial approach that seeks to minimize a product or service’s environmental and social impacts or footprint”. Also, Zhu et al. (2008a) defined GSCM as “ranges from green purchasing to integrated life-cycle management supply chains flowing from supplier, through to manufacturer, customer, and closing the loop with reverse logistics”. Finally, Dawei et al. (2015) defined green supply chain as “Green supply chain is an innovative supply chain which complies with social development trends. It integrates economic performance, environmental performance and resource efficiency into the entire spectrum of supply chain activities involving raw materials and component purchasing, manufacturing, packaging, distribution, retailing, and the subsequent recycling of the products. It is a comprehensive strategic alliance consisting of suppliers, manufacturers, distributors, retailers, consumers and, lately, recyclers and governments. Great efforts are being made to reduce costs and increase economic benefits while improving environmental performance and minimizing resource consumption. Green supply chain management is also known as environmental supply chain management or sustainable supply chain management, which is a modern management mode inspired by sustainable development ideas based on supply chain management techniques. It serves all the partners through planning, organizing, directing, controlling and coordinating material, information, capital and knowledge flows in green supply chains. Its objective is to achieve optimal allocation of resources, increase economic benefits and improve environmental consistency in the whole product life cycle so as to promote the coordinated development of environmental, social and economic performance".

Hervani et al. (2005) discussed the processes that are involved in GSCM. These processes are illustrated in Figure 2.2.

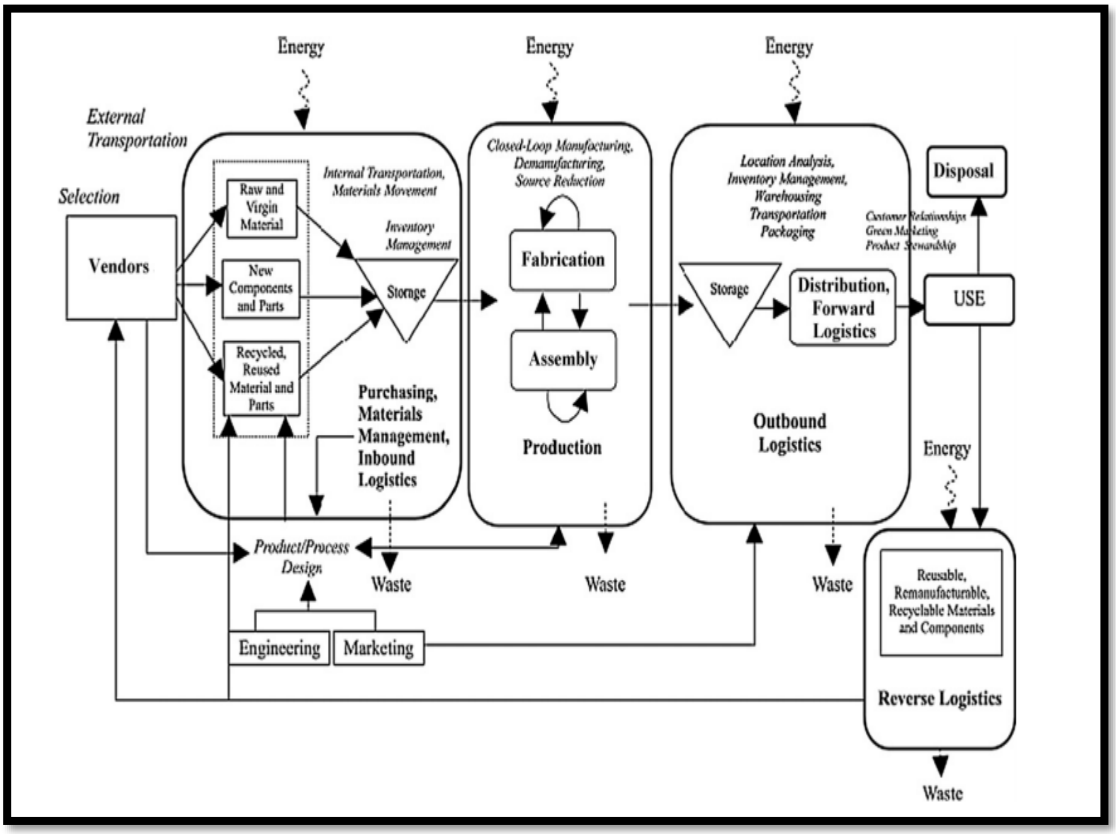

Figure 2.2: Process involved in green supply chain management (Hervani et al. 2005).

2.3.2 Importance of Green Supply Chain Management

Many studies examine the importance of green supply chain for companies to improve their environmental and economic performance, compliance to governments' regulations, and help organization to achieve and sustain competitive advantages.

Porter and van der Linde (1995) explained the fundamentals of greening as a competitive initiative, since investment in greening could be profitable through resource conserving, waste eliminating and productivity improving. While, Kopicki et al. (1993) and Van Hoek (1999) suggested three approaches in GSCM, reactive, proactive, and value seeking. In the reactive approach, companies commit to minimal resources to environmental management, by labeling product that are recyclable and use “pipe line initiatives” to reduce the environmental impact of production. In the proactive approach, commitment to new environmental initiative such as, recycling of products and designing green products. In the value seeking approach, companies integrate environmental activates into their strategies such as green purchasing and ISO 14001 implementation.

The perspective of greening then change from the greening as a burden to greening as a source of competitive advantage (Van Hoek, 1999). In a study linking GSCM elements and performance measurement, Beamon (1999) advocated for the traditional performance measurements systems structure of supply chain must include mechanisms for product recovery. GSCM has emerged as an important new archetype for companies to achieve profit and market share objectives by lowering their environmental risks and impacts and while raising their ecological efficiency (Van Hock, 1999) as mentioned by (Zhu et al., 2005). While, Sinding (2000) emphasized that, the GSCM is a necessary outcome of the evolution in environmental management from “housekeeping” to product-related approaches (such as LCA), when a company really wants to gain an environmental and competitive advantage. Within this context, Kaiser et al. (2001) argued that, to address the environmental issues proactively, it should consider all stages of product life cycle during material selection and adopt purchasing mechanism to promote the use of environmentally preferable products in the health care industry.

Zhu and Sarkis (2004) presented their empirical findings on the relationships between GSCM practices and environmental and economic performance, quality management, and Just-In-Time (JIT) or Lean manufacturing among early adopters of green supply chain management practices in Chinese manufacturing enterprises. They found that, the GSCM practices have Win-Win relationships with environmental and economic performance, while quality management has a positive moderator, so the organizations that seriously consider the implementation of GSCM practices could benefit greatly with introduction of Quality Management practices. Finally, the JIT programs with internal environmental management practices may cause further degradation of environmental performance, and care should be taken when implementing GSCM programs in manufacturing organizations with JIT philosophies in place. Theyel (2006) examined the importance of collaboration between suppliers and customers as information exchange to meet the environmental requirements. While, Testa and Iraldo (2010) assessed the determinants and motivations for the implementation of green supply chain management, and find that the company is able to involve its business partners in the development of co-operative environmental plans, the more it is able to achieve the expected results and improve its performance. Wu and Pagell (2011) used theory building through case studies to answer how do organizations balance short-term profitability and long-term environmental sustainability when making supply chain decisions under conditions of uncertainty. Zhu et al. (2012) focused on the importance of coordinating internal and external GSCM practices to seek performance improvements. Yang et al. (2013) studied the influence of internal green practices and external green collaboration on the green performance and the firm's competitiveness for container shipping industry. They found that, the internal green practices and external green collaboration have positively influence firm performance and competitiveness.

Then, the environmental and financial performance can be achieved by implementing GSCM concepts in many sectors. Chiou et al. (2011) demonstrated that many industrial sectors have improved their performance through the implementation of GSCM concepts by greening the supplier, which leads to green product innovation, green process innovation, and green managerial innovation, as a results of this companies can acquire competitive advantage.

2.3.3 Green Supply Chain Management Practices

Green supply chain management covers many practices and activates such as green design, green sourcing/procurement, green operations or green manufacturing, green distribution, logistics/marketing and reverse logistics (Srivastava, 2007). Within this context, Ninlawan et al. (2010) studied the activities involved in implementing green supply chain in electronics industry. They argued that, these activities include all the process across the supply chain from green purchasing (i.e. supplier selection, raw material selection etc.), into green manufacturing (i.e. green design, waste minimization, reducing energy consumption etc.), to green logistics, recycling and managing waste of the products, as shown in Figure 2.3.

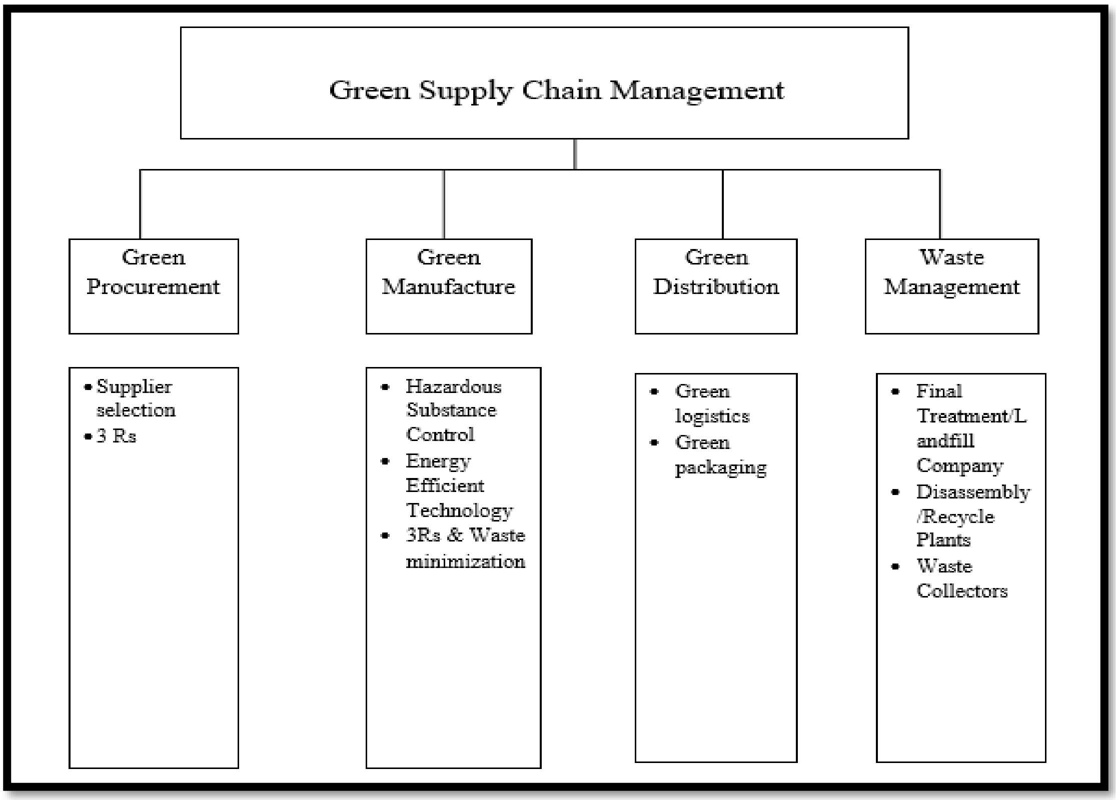

Figure 2.3: Activities in Green Supply Chain (Ninlawan et al., 2010).

2.3.3.1 Green Design

The green design or eco-design is concerned with the development of products that are more durable and energy-efficient; products that avoid the use of toxic materials and can be easily disassembled for recycling (Gottberg et al., 2006). These activities provide opportunities to minimize waste and improve the efficiency of resource use through modifications in product size, serviceable life and recyclability (Gottberg et al., 2006). On the other hand, the green design may be presented a certain potential limitations or disadvantages, which includes the following: the easily recyclable materials may have substantial environmental impact during other life-cycle stages; the obsolescence of the products in fashion-driven markets; the compatibility with existing infrastructure and systems; the increased complexity; and the increased risk of failure (Gottberg et al., 2006). The green design of product could be used to analyze the product impact on environment during its life-cycle (Life Cycle Assessment of the product). This approach is referred to as a cradle-to-grave approach, which is a quantitative process for evaluating the total environmental impact of a product over its life cycle (Mann et al, 1996).

2.3.3.2 Green Purchasing

Green purchasing is related to the increasingly heightened environmental awareness, the decisions will impact through the purchase of materials that are either recyclable or reusable or have already been recycled (Zhu et al., 2008b; Sarkis, 2003). The importance of green purchasing for enterprises as it pertains to the marketing of their products and the key elements of green purchasing, which include: (1) the organizational framework, (2) a model for supplier selection, (3) key factors and criteria affecting supplier selection and (4) the establishment of beneficial buyer-supplier relationships (Zhu and Geng, 2001). In this context, Min and Galle (2001) showed the effects of green purchasing on suppliers selection, waste management, packaging, and regulatory compliance.

2.3.3.3 Green Manufacturing

Manufacturing processes consume a lot of energy, chemicals and toxic material that discharge a large amount of pollutants. Without effective management, it can cause great damage to the environment. In a recent years, green manufacturing has attracted a lot of attention, due to increasing awareness of environment protection. Green manufacturing is a modern manufacturing mode, it gives a comprehensive consideration of the environment influence and resources efficiency, by minimizing the environmental impact and maximizing the resources utilization (Li et al., 2016). Melnyk and Smith (1996), as mentioned by Kannan et al. (2014), defined green manufacturing as “a system that integrates product and process design issues with issues of manufacturing planning and control in such a manner to identify, quantify, assess, and manage the flow of environmental waste with the goal of reducing and ultimately minimizing environmental impact while trying to maximize resource efficiency”.

One of the main strategies of green manufacturing is the three R’s (Remanufacture, Reduce, Reuse/Recycle), which includes policies such as reducing hazardous waste volume, minimizing coolant consumption while machining, and calculating a proper energy mix to ensure a sustainable energy source (Dornfeld et al.,2013). Green manufacturing aims to reduce the ecological burden by using appropriate materials and technologies, and operations are intended to reduce, recycle, production planning and scheduling, inventory management, remanufacturing, reuse, and product and material recovery (Srivastava, 2007).

2.3.3.4 Waste Management

Human activities have always generated waste, poor management of these wastes can lead to contamination of water, soil and atmosphere and to a major impact on public health (Giusti, 2009).

Waste management makes it possible to know how well the processes are designed for the prevention of waste. The management of waste passes through several sources: reduction, pollution prevention and disposal, which in turn include collection, transportation, incineration, composting, recycling and disposal (Srivastava, 2007). Consequently, there will be a number of system and process requirements that may change among the stages, depending on the organization, industry and product type (Sarkis, 2003).

In general, all products have a life cycle cover a sequence of interrelated activities from the acquisition of raw material until their end-of-life management (Jofre and Morioka, 2005). There are five basic end of life strategies that are classified according to their potential economic and environmental efficiency to reuse, servicing, remanufacturing, recycling, and disposal. Re-use represents the recovery and trade of used products or their components as originally designed. Servicing is a strategy aimed at extending the usage stage of a product by repair or maintenance. Remanufacturing considers the process of removing specific parts of the waste product for further re-use in new artifacts. Recycling (with or without disassembly) includes the treatment, recovery, and reprocessing of materials contained in used products or components in order to replace virgin materials in the production of new goods. Finally, disposal entails the processes incineration (with or without energy recovery) or landfill (Billatos, 1997; Rose et al., 1999). The aim of all of these strategies is to maximize profitability and efficiency (Jofre and Morioka, 2005).

2.3.3.5 Reverse Logistics

Reverse logistics focuses primarily on the return of recyclable or reusable products and materials to the forward SC. The reverse logistics process has identified a number of stages: collection, separation, densification, transitional processing, delivery, and integration (Sarkis, 2003). Within this context, Chouinard et al. (2005) dealt with problems related to the integration of reverse logistics activities within a supply chain information system. They defined reverse logistics as" the recovery and processing of unused products and to the redistribution of reusable materials". In fact, the integration of reverse logistics within the regular supply chain aims to improve the efficiency of the entire logistic network to meet the pressures exerted by the environment (government agencies, competitors, customers, actors of the supply chain). While, Srivastava and Srivastava (2006) presented a framework to manage product returns for reverse logistics by focusing on estimation of returns for selecting categories of products in the Indian context. They developed a model that utilizes product ownership data, average life cycle of products, post sales, forecasted demand and likely impact of environmental policy measures for estimating return flows.

2.3.3.6 Green Logistics

Distribution and transportation operations form the important operational characteristics in Logistics. These operations are more complicated when the entire SC is considered. With the rapid increase of long-distance trade, SCs are increasingly covering larger distances, consuming significantly more fossil-fuel energy for transportation and emitting much more carbon dioxide than they did a few decades ago (Venkat and Wakeland, 2006).

However, with increasing awareness about the effect of logistics activities (i.e. transportation) on the global warming, air pollutions and energy usage have been grown, which led to emerge of GL. There are several activities in the field of GL such as redressing the distribution system, route optimization, measuring the pollution levels, using alternative fuels and improving the packaging design (Sharma, 2000). Furthermore, Martinsen and Huge-Brodin (2010) summarized the GL innovations that can be adopted by companies into nine categorizes as follows:

- ❖ Vehicle technologies: the development in engine and exhaust systems, aerodynamic profiling, reduction in vehicle tare weight and improved tire performance can have an effect on environmental performance.
- ❖ Alternative fuels: switching to a fuel with low carbon intensity such as bio-fuel has implications for the environmental impact.
- ❖ Mode choice and intermodal transports: carbon intensity of different modes (road, rail, sea and air) varies and the proportion among them also varies. Thus, it affects environmental impact. Intermodal transports refer to a combination of different transport modes.
- ❖ Behavioral aspects: eco-driving and defensive training are well known measures to apply in order to lower environmental impact from transports.
- ❖ Logistics system design: this factor affects the distances that cargoes are transported. It is used to minimize the total distance travelled by a

vehicle to deliver a certain amount of cargoes. Centralized versus decentralized distribution structures is one parameter that can be of importance for the environmental impact from logistics system.

- Transport management: occupancy or fill rate and distances of empty running vehicles are important aspects for environmental performance. Route planning and orders aggregations or freight consolidation are aspect of relevance.
- Choice of partners: how to select the partners and how to manage the relationships are two factors of interest when the aim is to lower the environmental impact of supply chains.

2.4 Green Supply Chain Optimization

In this section, we will review the optimization models in Green Supply Chain in strategic and tactical management levels (i.e. Network design) and in tactical and operational management levels (i.e. Aggregate Production Planning (APP)).

2.4.1 Green supply chain network optimization

The supply chain networks design is a strategic and tactical levels problem aims to determine suppliers, facility location and transfer system combinations or chains. “Supply chain network optimization refers to models supporting strategic and tactical planning across the geographically dispersed network of facilities operated by the company and those facilities operated by the company's vendors and customers” (Shapiro, 2004) as mentioned by (Tognetti et al., 2015).

Traditionally, the field of supply chain design has focused on economic objectives, such as cost minimization and profit maximization, or on performance-based objectives, including customer service level or supply chain responsiveness (Liu and Papageorgiou, 2013; You and Grossmann, 2008). However, the advent of sustainability concerns have added several new dimensions that are increasingly crucial in supply chain design and to achieve truly sustainable solutions, a supply chain should be designed with economic, environmental, and social sustainability criteria (Grossmann, 2004; Simões et al., 2014; Yue et al., 2014).

Many mathematical modeling was developed to address the problem of network design in GSC. In this context, Bloemhof-Ruwaard et al., (1996) used linear programming network flow to find optimal configurations and reallocation of paper production, and the model used to analyze the scenarios with different recycling strategies. This model consists of a mix of different pulping technologies, a geographical distribution of pulp and paper production, and a level of recycling consistent with the lowest environmental impacts. While, Hugo and Pistikopoulos, (2005) developed a mathematical programming-based methodology that integrated LCA criteria into the design and planning decisions of supply chain networks. Multiple environmental concerns were considered along with financial criteria in formulating the planning task as an optimization problem. Strategic decisions involving the selection, allocation and capacity expansion of technologies along with the assignment of appropriate transportation modes that would satisfy market demand were addressed using MIP. Neto et al. (2008)

introduced an integrated methodology of multi-objective programming that balancing the environmental performance and process in design logistic networks of European pulp and paper sector. While, Ramudhin et al. (2008) tied greenhouse gases to carbon trading based on carbon market sensitive green supply chain network design. They developed mixed integer programing model (MIP) that focuses on the impact of transportation, subcontracting, and production activities in terms of carbon footprint on the design of a green supply chain network. The model integrates carbon prices and exploits the opportunities offered by carbon market in the design of green supply chain network. Tsai and Hung (2009) used fuzzy goal programming approach to integrate activity-based costing (ABC) and performance evaluation in a value chain structure for optimum selection of suppliers and flow allocation in GSC, and the final objectives were determined using Analytical Hierarchy Process (AHP) method that contains the criteria of mission, circumstance, product stage, and precision degree. In the same context, Diabat and Simchi-Levi (2009) introduced an optimization model that integrates green supply chain network design problem with carbon emission constraint using MIP. In their model, the throughput capacity of the manufacturing site, storage capacity of the distribution centers and their locations are considered as decision variables in order to ensure that the total carbon emission does not exceed an emission cap while minimizing the total supply chain cost. However, they found that as carbon emission allowance decreases, supply chain total costs increase. Abdallah et al. (2010) presented a different MIP in which the green procurement concept where the decision on which supplier to choose affects the overall carbon footprint of the supply chain is integrated in green supply chain network design problem to minimize traditional supply chain cost in addition to minimize the carbon emission cost.

Another related study is conducted by Paksoy et al. (2010), who considered the green impact on a close-looped supply chain. A traditional network design problem that minimizes the total transportation and purchasing costs and tried to prevent more carbon emissions and encourage the customers to use recyclable products was developed. They have presented different transportation choices according to carbon emissions by using multi-objective linear programming model. Sundarakani et al. (2010) developed an analytical model that uses the long-range Lagrangian and the Eulerian transport methods. The aim of this model is to minimize the CO_2 emission from both stationary and non-stationary across the supply chain processes, by examining various heat transfer devices. This model helps to understand the heat flux and carbon wastage at each node of the supply chain and allows to calculate the total heat and carbon emission transferred from one stage of the supply chain to another. While, Wang et al., (2011) were interested in the environmental investment decision in the design of green supply chain network and provided a multi-objective MIP model. The model linked the decision of the environmental investment in the planning phase while its environment influence in the operation phase. After conducting a sensitivity analysis, the results showed that the total cost and CO_2 emission would be lower in supply chain networks with larger capacities. Pishvaee and Razmi,

(2012) proposed a multi-objective fuzzy optimization model for designing both forward and reverse green supply chain under inherent uncertainty of input data. The model aims to minimize the multiple environmental impact by using LCA method, and to minimize the traditional cost to make balance between them. To solve the problem, they developed an interactive fuzzy solution approach. While, Elhedhli and Merrick (2012) developed a MIP model alongside Lagrangian relaxation method, so that the relation between carbon emission and vehicle weight is modeled to reduce the amount of vehicle kilometers travelled and thereafter the combined costs of carbon emission, fixed cost to set up facility, transportation and production costs can be minimized. The results indicated that considering carbon emission cost can change the optimal configuration of the network. Tognetti et al. (2015) developed a multi-objective optimizations model for strategic production networks planning that presents the interplay between emissions and the costs of the supply chain contingent upon the production volume allocation and the energy mix. The implementation of a practical case study in the German automotive industry, shown that by optimizing the energy mix, the CO_2 emissions of the supply chain can be reduced by 30% at almost zero variable cost increase. Talaei et al. (2015) proposed a novel bi-objective facility location-allocation MILP model for CLGSC network design problem that consisting of manufacturing/remanufacturing and collection/inspection centers as well as disposal center and markets with uncertainties of the variable costs and the demand rate. The aim of this model is to reduce the network total costs and the rate of CO_2 emission throughout the supply chain network. The model has been developed using a robust fuzzy programming approach to investigate the effects of uncertainties of the variable costs, as well as the demand rate, on the network design. The ε-constraint approach has been used to solve the bi-objective programming model. A numerical study of Copiers Industry is used to show the applicability of the proposed optimization model. Results have revealed that the model is capable of controlling the network uncertainties as a result of which a robustness price will be imposed on the system.

In context of relationship with suppliers and customers, Yeh and Chuang (2011) developed an optimum mathematical planning model for green partner selection, which involved four objectives such as minimization of the total cost, minimization of the total time, maximization of the average product quality and maximization of the green appraisal scores. They used Multi-Objective Genetic Algorithms (MOGA) to find the set of Pareto-optimal solutions. Kannan et al. (2013) proposed an integrated approach of fuzzy multi attribute utility theory and multi-objective programming, for rating and selecting the best green suppliers according to economic and environmental criteria and then allocating the optimum order quantities among them. The objective of the mathematical model is simultaneously to maximize the total value of purchasing and to minimize the total cost of purchasing. To handle the subjectivity of decision makers' preferences, fuzzy logic has been applied. The obtained results help organizations to establish a systematic approach for tackling green supplier selection and order allocation problems in a realistic situation. Within this context, Coskun et al. (2016) proposed a Goal Programming (GP) model to measure the relations between green supply chain network design and customer behavior, to improve the practical efficiency of green supply chain networks, by considering three customers segments according to their attitudes for green products in the markets (i.e. green, inconsistent, and red customers), the results have shown that the green supply chain network could be re-designed cooperating with suppliers according to the expected greenness level of suppliers and customers .

2.4.2 Aggregate production planning (APP) in GSC Optimization

One of the important subjects that could be addressed in tactical and operational level of GSCM is Aggregate Production Planning (APP). Chopra and Meindl (2013) defined aggregate planning as “a process by which a company determines planned levels of capacity, production, subcontracting, inventory, stockouts, and even pricing over a specified time horizon”. While, Mirzapour et al. (2013) addressed APP as” an operational activity that draws up an aggregate plan for the production process, in advance of 3-18 months, to give an idea to management as to what quantity of materials and other resources are to be produced and when, so that the total cost of operations of the supply chain is kept minimum over that period”. Also, Baykasoglu (2001) defined APP as “medium-term capacity planning over 3–18 months planning horizon, which determines the optimum production, workforce and inventory levels for each period of planning horizon for a given set of production resources and constraints”.

By reviewing the literature relate to APP, there are numerous models that have been developed with various degrees of complexity. In this context, Hanssman and Hess (1960) developed a model on the LP approach using a linear cost function of the decision variables. This model focused on minimizing the total cost of regular payroll and over time, the cost of hiring and firing, and the cost of holding inventory and shortages that incurred during a given planning horizon. Haehling (1970) developed a multi-product, and multi-stage production system model in which optimal disaggregate decisions can be made under capacity constraints. Masud and Hwang (1980) proposed three Multi Criteria Decision Making Methods (MCDMs), its GP, sequential multi-objective and the step method. The three methods are used to solve APP problems with minimizing cost, changes in workforce levels, inventories, and backorders. In this context, Paiva and Morabita (2009) developed a MIP model to support decisions in the APP of sugar and ethanol milling companies. This model is based on the industrial process selection and the production lot-sizing model. Sillekens et al. (2011) proposed a MIP model for an APP problem of flow shop production lines in automotive industry with special consideration of workforce consideration flexibility. So their model, in contract to traditional approaches, considered discrete capacity adaptions which originated from technical characteristics of assembly lines, work regulations and shift planning. Ramezanian et al (2012) developed a MILP model for general two-phase APP systems, with consideration multi-period, multi-product and multi-machine systems with setup decisions. The model was solved using genetic algorithm and Tabu search methods. Mirzapour et al. (2011a) proposed a robust multi-objective MINLP model for multi-site, multi-period, multi-product APP problem under uncertainty in supply chain. The developed model considered two conflicting objectives simultaneously, its cost parameters and demand fluctuations under uncertainty.

With the increase of the environmental conscious and the globally trends to reduce the effect of the supply chain and others industrials activities on the human and environment, it becomes difficult to ignore the gap of environmental aspects in the APP. In the context of green supply chain, by reviewing the literature, the first attempt to integrate green concepts to APP, was by Mirzapour et al. (2011b), by proposing a multi-period, multi-product and multi-site APP in a GSCM by considering quantity discounts, interrelationship between lead times and transportation cost, as well as lead time and GHG emission, and backorders. While, Jamshidi et al. (2012) proposed a multi-objective optimization model that considered the cost elements of supply chain such as transportation, holding, and backorder cost as well as the environmental aspects such as the amount of NO2, CO and the volatile organic particles produced by facilities and transportation in the supply chain. In this model, the facilities and transportation options have capacity constraints. To solve the model, they utilized a new hybrid genetic taguchi algorithm (GATA). Moreover, Mirzapour et al. (2013) developed a more sophisticated model by proposing a stochastic programming approach to solve a multi-period, multi-product, and multi-site aggregate production planning in a green supply chain under the assumption of demand uncertainty. This model considered flexible lead times, nonlinear purchase, shortage cost functions and a GHG emission.

In the context of tactical planning, Fahimnia et al. (2015) developed a multidimensional MINLP model for GSCM at tactical planning level. The model aims to tradeoff between cost and environmental aspects including carbon emissions, energy consumption and waste generation to investigate the relationship between Lean practices (i.e. waste and lead time reduction) and green outcomes. The Nested Integrated Cross-Entropy (NICE) method has been developed to solve the proposed mixed-integer nonlinear mathematical model. The applicability and the validity of the model are investigated in an actual case problem, the results have shown that, not all lean interventions at the tactical supply chain planning level result in green benefits, and a flexible supply chain is the greenest and most efficient alternative when compared to strictly lean and centralized situations. Moreover, the model has shown how the organization can take advantage of SC flexibility and agility through integrated lean and centralized situations for more efficient environmental performance.

In the operational green supply chain planning level, Memari et al. (2015) developed a novel multi-objective mathematical model in a green supply chain network consisting of manufacturers, DCs and dealers in an automotive manufacture case study. The aim of this model is to minimize the total costs of production, distribution, holding and shortage cost at dealers as well as minimizing environmental impact particularly the CO_2 emission of supply chain network. This model can be used as a decision support system in order determine the green economic production quantity (GEPQ) using Just-In-Time (JIT) logistics. To solve the model, they used MOGA in order to minimize the conflicting objectives simultaneously. The performance of the proposed model is evaluated by calculating the gap between the best results of the obtained Pareto fronts from MOGA and Goal Attainment Programing (GAP) solver in Matlab.

2.5 Drivers' Differences

2.5.1 The effect of drivers differences on fuel consumption

There are many factors affect fuel consumption and CO_2 emission such as driving behavior (i.e. gear changing), choice of travelling modes and route choice etc. The holistic analysis of the factors that affect fuel consumption and CO_2 emission are shown in Figure 2.4.

Within this context, Ericsson (2001) investigated the effect of independent driving patterns factors on emissions and fuel consumption. He used 16 independent driving patterns factors, by using different types of cars driven by about 45 randomly chosen drivers. The results have shown that, by applying regression analysis on the relation between driving pattern factor and fuel-use and emissions, nine of driving pattern factors had an important effect on fuel consumption and on emissions of HC, NO_x, and CO_2. Four of the driving patterns factors describe different aspects of acceleration and power demand, three factors describe aspects of gear-changing behavior and two factors describe the effect of certain speed intervals/levels. The relation between these nine driving patterns factors and fuel consumption and emission as follow; factor for acceleration with strong power demand (+), the stop factor (+), the speed oscillation factor (+), the factor of acceleration with moderate power demand (+), the extreme acceleration factor (+), the factor of speed 50-70 km/h (-), the factor of late gear changing from 2^{nd} to 3^{rd} gear (+), the factor for engine speed >3500 rpm (+) and the factor for moderate engine speeds in 2^{nd} and 3^{rd} gear (-). This study shows that, these independent driving patterns factors (i.e. acceleration and power demand, gear changing behavior, and speed levels) are important explanatory variables for emission and fuel consumption. He argued that, the needed to focus on changing environments, drivers and vehicles in a way that does not promote heavy acceleration, power demand and high engine speeds will be a challenges for further research and development of traffic planning and management, vehicle technology and driver education. Driver behavior is one of the greatest factor determining the fuel consumption and CO_2 emission of a heavy-duty vehicle and differences in fuel consumption can be up to 30% depending on the driver (Nylund, 2006; Vangi and Virga, 2003). Different drivers can obtain a different fuel consumption (and CO_2 emission) for the same car (Van der Voort et al., 2001). Within the context, Sivak and Schoettle (2012), showed that the differences in drivers' driving patterns can lead to variation in fuel consumption and CO_2 emission by more than 30%. Also, Edmunds (2005) performed an argument that the moderate (normal) driving yielded 31% better mileage than aggressive driving, on average.

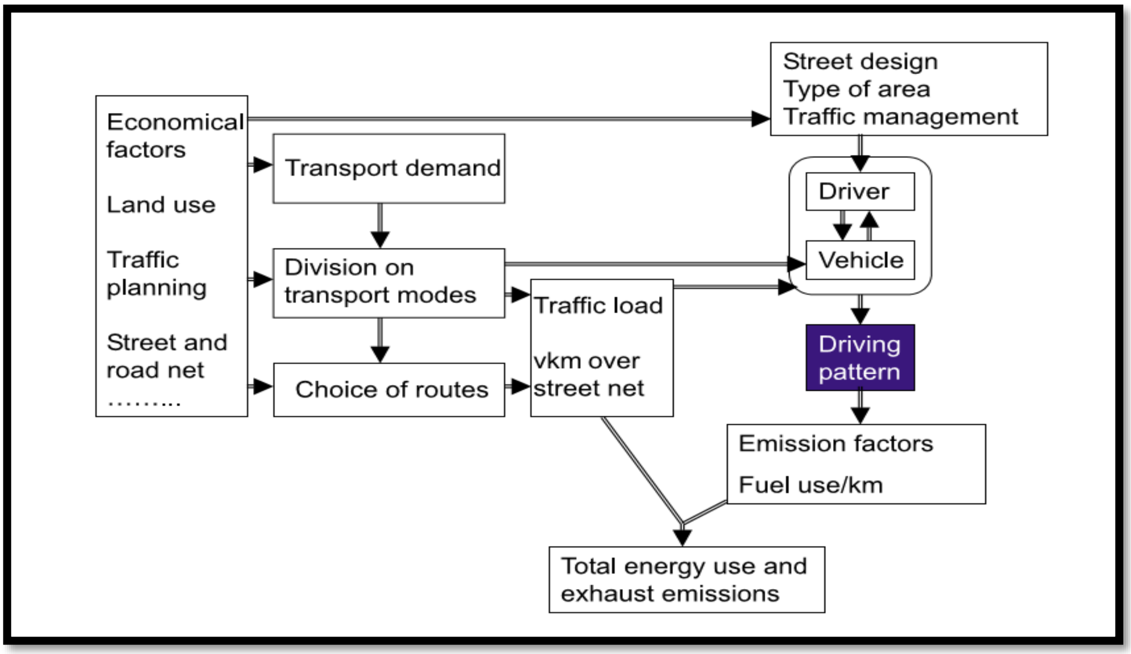

Figure 2.4: Model describing factors that affect the amount of vehicular energy use and exhaust emission (Ericsson, 2001).

There are many factors under the control of driver, if the driver avoids them, 45% reduction in fuel consumption and CO_2 emission can be achieved such as aggressive driving, excessive high speed, out of tune engine, neglect of tire maintenance, air conditioning use, excessive idling, additional weight and improper engine oils (Sivak and Schoettle, 2012). Alessandrini et al. (2009) quantified the effect of some of parameters such as throttle standard deviations and accelerator pedal on fuel consumption and CO_2 emissions. They argued that, the differences between drivers have a calm driving style and aggressive one can result in differences in terms of fuel consumption (and therefore CO_2 emissions) up to 40%. Carrese et al. (2013) studied the relationship between drivers' behavior and fuel consumption and CO_2 emission. They argued that, the differences in drivers' behavior can lead differences in fuel consumption and CO_2 emission up to 27%. While, Tang et al. (2015) developed an extended car-following to study the influences of driver's bounded rationally on his/ her micro driving behavior, and on fuel consumption and gases emissions. The results have shown that considering the driver's bounded rationally will reduce his/her speed during the staring process and improve the stability of the traffic flow during the evolution of the small perturbation, and reduce fuel consumption and CO_2 emission.

2.5.2 Eco-Driving

The road transportation is a major consumer of fossil fuel as well as a major contributor to CO_2 emission and then the environmental pollution. With increase awareness about saving natural resources and protect the environment as known as a sustainability. The need to reduce fuel consumption and CO_2 emission has been rapidly grown (Van der Voort et al., 2001).

There are many methods for reducing fuel consumption and CO_2 emission, and these can be classified according to the horizon into long term and short term methods. On the long term, the new technologies such as alternative fuels, improving the rolling, air resistance, engine and transmission efficiency of the vehicles, the potential savings by using this method is 49% on average or by law and policy (i.e. setting goals and standards, and by imposing taxes). On a short term, the factors that affect fuel consumption include infrastructure changes (i.e. car pools lanes), traffic management (because the congestion are closely related to fuel consumption and CO_2 emission) with 5% fuel savings, and driver behavior, the changing in driver behavior has a potential saving up to 15% (DeCicco and Ross, 1996). Unwanted driving behaviors such as harsh acceleration, harsh breaking and sudden steering are major for increased fuel consumption, air pollution (i.e. GHG) and maintenance cost. Introduce driver to change his/her driving is an effective way to reduce fuel consumption and CO_2 emission in the short term (Van der Voort et al., 2001). This lead to develop a new driving style called Eco-Driving. Eco-driving is driving that is economical, ecological, and safe, with the goal of reducing fuel consumption and greenhouse gas emissions (Martin et al., 2012). Eco-driving practices have been found to be effective in reducing energy consumption and CO_2 emission, with potential reduction reach to 20% (Barkenbus, 2010; Stillwater and Kurani, 2013).

With growing popularity of eco-driving courses as a powerful tool that can improve drivers' behavior in context of economic and ecologic performance, numerous researches focus on the importance of Eco-driving behavior and training as a strategic tool to reduce the fuel consumption and CO_2 emission. Barkenbus (2010) defined the characteristics of Eco-Driving such that accelerating moderately, anticipating traffic flow and signals, avoiding sudden starts and stops, driving within speed limit, and eliminating excessive idling, etc. While, Sivak and Schoettle (2012) presented eco-driving in a broadest way, Eco-Driving includes those strategic decisions (vehicles selection and maintenance), tactical decisions (route selection and vehicle load) and operational decisions (driver behavior) that improve vehicle fuel economy and CO_2 emission. In the strategic level, there are many factors affect fuel consumption and CO_2 emission such as; selection of vehicle class, vehicle model, vehicle configuration; and vehicle maintenance (i.e. Tires' pressure and engine oil), according to EPA (2011a), "fixing a car that is noticeably out of tune or has failed an emission test can improve its gas mileage by an average of 4%, through the results vary based on the kind of repair and how well it is done". Also, "fixing a faulty oxygen sensor can improve mileage by as much as 40%" (EPA, 2011b). At tactical level, the driver in this level is responsible for selecting the best routes based on road type, grade and congestion. First, different road types result in difference in fuel consumption and CO_2 emission, because the average speeds, profiles of acceleration and deceleration depend on the road type. A recent Canadian study (Natural Resources Canada, 2009) found that a highways with average speed of 80 km/h is better than other roads with about 9%. The second responsibility of the driver is selecting the most flat route among the available alternatives. Boriboonsomsin and Barth (2009) found that the fuel consumption has nonlinear relationship with the road grade in a particular scenario with the same origin and destination but two alternative routes, a longer but flat route yielded 15-20% better fuel economy and CO_2 emission than a shorter hilly route. Third, the ability of driver to avoid the more congested routes can save fuel consumption and reduce CO_2 emission by 10-20%. TRB (2000) classified the road according to the level of services (i.e. congestion) into six categories: A (free flow), B (reasonably free flow), C (stable flow), D (approaching unstable flow), E (unstable flow) and F (forced or breakdown flow). Facanha (2009) used these categories and indicated that depending on the vehicle type and road type the reduction in fuel consumption and CO_2 emission from service level A to service level F can range from 10-20%. Finally, the driver must avoid extra weight in his vehicle, according to EPA (2011c), extra cargo in a vehicle can increase fuel consumption and CO_2 emission by 2% and more with a smaller vehicles.

On the other hand, at the operational level, the driver behavior significantly affects fuel consumption in many issues. First, the driver should be aware about the long idle time and its relation with increasing fuel consumption and CO_2 emission, according to (EPA, 2011c), idling uses a quarter to half gallon per hour that depending on engine size and accessories in use. And the driver should turn off the engine if the expected idling time more than a minute (Emandus, 2005). According to (EPA, 2011c), “it is only takes a few seconds worth fuel to restart your engine”. Emandus (2005), in a specific test found that turning the engine off during idle period can save fuel consumption and reduced CO_2 emission by 19% during each of 10 idle periods each period lasting a 2 minutes. Second, Optimal fuel consumption is on the speed of about 61 mph, increase the speed to 90 mph can increase the fuel consumption and CO_2 emission by 33%, and decrease the speed to 30 mph can increase the fuel consumption and CO_2 emission by 31% (LeBlanc et al., 2010). Third, if the driver uses cruise control in highway fuel consumption can be improved by about 7% (Emandus, 2005). Also, air conditioner can increase fuel consumption and CO_2 emission by 5-25% (EPA, 2011d). Finally, the degree of aggressive driving of the driver can increase fuel consumption and CO_2 emission by 20-30% more than the moderate driving (LeBlanc et al., 2010; Emandus, 2005). These decisions and their effect on fuel consumption and CO_2 emission are shown in Table 2.1.

Table 2.1: The effect of driver on fuel consumption and CO_2 emission at different levels (Sivak and Schoettle, 2012).

Level	Factor	Effect
Strategic	Vehicle class	38%
	Vehicle model	800% all cars; 355% cars excluding fully electric; 227% cars excluding fully electric and hybrids; 100% all pickups
	Vehicle configuration	18% cars, 28% pickups
	Out-of-tune engine	4–40%
	Tires with 25% higher rolling resistance	3–5%
	Tires underinflated by 5 psi	1.5%
	Improper engine oil	1–2%
Tactical	Route selection: road type	Variable
	Route selection: grade profile	15–20%
	Route selection: congestion	20–40%
	Carrying extra 100 lb	$\leq$ 2%
Operational	Idling	Variable
	Driving at very high speeds	30%
	Not using cruise control	7% (while at highway speeds)
	Using air conditioner	5–25%
	Aggressive driving	20–30%

Within this context, Kurani et al. (2015) identified six categories for Eco-Driving behavior by reviewing the popular and academic sources of Eco-Driving. The six categories and their characteristics are shown in Table 2.2.

Table 2.2: Categories of Eco-Driving behavior and some of their psychologically attributes (Kurani et al., 2015).

Category	Factors	General functions (beyond MPG and CO_2)	Context: When the behavior occurs	Frequency of Opportunities	Cost ($; beyond minimum for fuel/kWh)
Driving	Accelerating, Cruising, Decelerating, Waiting, Parking	Operate the vehicle	En route	Very high	None
Cabin Comfort	HVAC, AUX electronics	Provide comfort, communications, entertainment	En route	Very high	None
Trip Planning	Road type; Road grade; Congestion; Right turns; Trip-chaining; Timing	Get from point A to point B	Pre-trip and en route	High	None (Very low if toll)
Load Management	Cargo weight; Aerodynamics	Be prepared	Pre-trip	High	None
Fueling	Fuel selection; Evaporation during and after fueling; Charging frequency, level, and source	Fuel vehicle	Pre-trip(s)	High	None-low
Maintenance	Oil change and type; Tire inflation; Tire selection; Engine tuning	Maintain vehicle	Regular intervals based on vehicle use	Low-moderate	Low-high

Barkenbus (2010) argued that, the characteristics of Eco-driving involve such thing as accelerating moderately (with shift ups between 2000 and 2500 revolutions for those with manual transmissions); anticipating traffic flow and signals, thereby avoiding sudden starts and stops; maintaining an even driving pace (using cruise control on the highway where appropriate); driving at or safely below the speed limit; eliminating excessive idling; maintaining optimum tire pressure and the regular changing of air filters, with advantages are reduce CO_2 emission, cost of driving, and producing tangible and well know safely benefits (with fewer accidents and traffic fatalities).

Within this context, numerous previous studies emphasized that the Eco-driving behavior of the driver can reduce fuel consumption and CO_2 emission up to 10%, and with motivating drivers by providing incentive system, the eco-driving behavior can reduce fuel consumption and CO_2 emission up to 25% (Barkenbus, 2010; Vagg et al, 2013). Also, Alam and McNabola (2014) in a comprehensive review of driving behavior, showed that the improvement in fuel economy can reach to 45% by adopting eco-driving strategies. Training, monitoring, and feedback are ways of guiding drivers towards more fuel efficient driving patterns. Liimatainen (2011) developed a methodology for fairly measuring drivers' performance that helps organizations to apply incentive system that motivates drivers to achieve its energy efficiency targets.

2.6 Green Human Resources Management (GHRM) in Supply Chain Management (SCM)

Green Human Resources Management (GHRM) and Green Supply Chain Management (GSCM) are popular subjects in the areas of Human Resources Management (HRM) and Operations Management (OM), respectively. Human resources practices are critical for implementation and maintenance of environmental management systems (Jabbour and Santos, 2008; Daily et al., 2011). Human aspects are fundamental to adoption of advanced environmental practices (Sarkis et al., 2010; Graves et al., 2013). Environmental training stands out as one of the primary methods through which human resources support environmental management (Daily et al., 2012; Jabbour et al., 2013).

Within this context, Daily and Hung (2001) stated that each of the phases of an environmental management system required the specific support of a human resources practice, with emphasis on recruitment and selection, training, performance evaluation, and rewards for employees. In the context of GSCM, Jabbour and de Sousa Jabbour (2015) constructed a framework that integrated GHRM and GSCM. They argued that, the GHRM practices such as recruitment and selection, training, performance evaluation, empowerment, and rewards are important to implementing GSCM. Also, the truly implementation of GSCM cannot be archived without integration of these paradigms.

With increasing awareness about the effect of drivers' on fuel consumption and CO_2 emission and the differences between them depending on their driving patterns, experience in route selection, maintenance issues, awareness about environmental issues, motivation to adopt a green initiatives and to improve their performance, and the training they own. This leads to increase importance of human resource practices in selection drivers, testing, training and motivating them, assigning them to the appropriate vehicles and destinations, monitoring them, evaluating their performance, and rewarding them based on the fairly incentive system. In such way that, implementing GSCM for reducing CO_2 emission across the supply chain could be truly achieved.

2.8 Summary

This chapter introduced the readers to sufficient knowledge about the supply chain and their planning scope, green supply chain management, their practices and the importance of GSCM to improve the firms' environmental and economic performance. This chapter presents many optimization models in green supply chain management that aim to minimize the environmental effect of supply chain (i.e.CO_2 emission) as well as minimizing the total cost. And then, the significance of driver behavior as a factor that influences fuel consumption and CO_2 emission and the importance of Eco-driving as a tool that helps organization to manage their drivers' behavior to improve their environmental and economic performance in their supply chains networks have been presented. Finally, the importance of GHRM in implementing and adopting GSCM and focusing on the drivers as an important human source should be taken into account in managing and designing GSCM to minimize the CO_2 emission and fuel consumption.

Chapter Three

Model Formulation

Chapter Three

Model Formulation

3.1 Overview

This chapter presents the mathematical formulation of the proposed model. The proposed model was developed as a Mixed Integer Non Linear Programming (MINLP) Model and then converted to a linear one. At first, this chapter presents to the reader the basic concepts of MINLP/MILP model. And then, the model description will be introduced, that includes the model's assumptions, sets, parameters, decision variables, objective function components and constraints.

3.2 Mixed Integer Non Linear Programming (MINLP)

Linear Programming (LP) is the problem of optimizing (minimizing or maximizing) a linear function subject to a linear constraints. A wide variety of practical problems, from nutrition, transportation, production planning, finance, and many more areas can be modeled as linear programming. All decision variables in the LP have been continuous, in the sense that decision variables are allowed to be fractional. At some scenarios, the fractional solutions are not realistic. Which led to develop another optimization problem, such as the following:

Objective Function:

$$\textbf{Maximize or Minimize} \sum_{j=1}^{n} C_j x_j$$

Subject to:

$$\sum_{j=1}^{n} a_{ij}x_j = b_i \ \ (i = 1,2,\dots,m),$$

$$x_j \geq 0 \ \ (j = 1,2,\dots,n),$$

$$x_j \ integer \ \ \ (for\ some\ or\ all\ j = 1,2,\dots,n)$$

This is called Integer Programming (IP) problem. It is said to be a Mixed Integer Linear Program (MILP) when some, but not all, variables are restricted to be integer (discrete variables), and is called pure integer program when all decision variables must be integers, and in the two previous cases the objective function and all the constraints must be linear.

Many optimal decision problems in scientific, engineering, and public sector applications involve both discrete decisions and nonlinear system dynamics that affect the quality of the final design or plan. Mixed-integer nonlinear programming (MINLP) problems combine the combinatorial difficulty of optimizing over discrete variable sets with the challenges of handling nonlinear functions. MINLP is one of the most general modeling paradigms in optimization and includes both nonlinear programming (NLP) and mixed-integer linear programming (MILP) as sub-problems. Mixed Integer Nonlinear Programming (MINLP) refers to mathematical programming with continuous and discrete variables and nonlinearities in the objective function and constraints. The use of MINLP is a natural approach of formulating problems where it is necessary to simultaneously optimize the system structure (discrete) and parameters (continuous). MINLP has been used in various applications, including the process industry and the financial, engineering, management science and operations research sectors. It includes problems in process flow sheets, portfolio selection, batch processing in chemical engineering (consisting of mixing, reaction, and centrifuge separation), and optimal design of gas or water transmission networks. Other areas of interest include the automobile, aircraft, and Vary Large Scale Integration (VLSI) manufacturing areas (Bussieck and Pruessner, 2003).

3.2.1 Importance of MILP in solving GSCM problems

One of the most important applications where they are used MILP are the GSC optimization problems. The GSC optimization models have many variables that should take integer values such as number of workers, number of vehicles, number of products and inventory levels etc. Also, there are many variables that take a binary (0-1) value such as open or closed facility, assignment problem etc. Solving GSC optimization problems using MILP gives more realistic results than LP. In this context, there are many researches used MILP to optimize SCM or GSCM. In this research, the proposed model is formulated as MINLP but converted to a MILP by using an auxiliary binary variables.

3.3 Model Description

The proposed multi-site, multi-product and multi-period APP problem in a green supply chain network can be described as follows: the network consists of a set of suppliers of various capacities, a set of distribution centers (DCs) of various storage capacities, a set of retailers with different demands and different storage capacities (assuming that the storing of products in retailers is possible), as all suppliers, DCs and retailers spread geographically; the distance from suppliers to DCs and from DCs to retailers can differ, (as shown in Figure 3.1). Also, there are a set of products types, a set of vehicle types, each vehicle type has an amount of fuel consumption and CO_2 emissions per unit distance, and finally there are a set of drivers, who are classified into three levels according to their green driving indices (GDI), each level of GDI for drivers has different effects based on the fuel consumption and CO_2 emissions. Green Driving Index (GDI) is an index used to measure the driver's readiness according to environmental issues, and there are some factors that might be used in evaluating the driver's readiness such as awareness about green issues, experience about transportation networks. Sivak and Schoettle (2012) showed that, the decisions that drivers take such as strategic decision (i.e. maintenance issue), tactical decision (i.e. route selection) and operational decision (i.e. driving behavior), affect vehicles fuel consumption (and therefore CO_2emission). Also, driving patterns (i.e. sportive, aggressive, or Eco-driving patterns) adopted by drivers affecting on the degree to which extent the driver has a green driving index (GDI). Alessandrini et al. (2009), argued that the driver's driving style can lead to different in fuel consumption and CO_2 emission up to 40% in comparison between a calm driver and an aggressive one. In this thesis, we assume that the three levels of drivers are different according to their driving patterns (styles), the driver of level one has an aggressive driving pattern, the driver of level two has a calm or moderate driving pattern and the driver of level three has an Eco-driving patterns. Furthermore, the motives s/he has owned either materialistic or non-materialistic can influence on the driver's style and to which extent the driver adopt eco-driving behavior. Lai (2015) emphasized that providing incentive system to motivate drivers to adopt Eco-driving, will lead to improve their economic and environmental performance, and therefore improve their $GDIs$. So, high $GDIs$ can be reinforced and achieved by applying training courses and reward incentive system, to encourage drivers to keep their $GDIs$ high and adopting Eco-driving style. As mentioned in the previous studies, the suitable driver training and using monetary reward system can reduce fuel consumption and CO_2emission by 10% on average (Young et al, 2011; Zarkadoula et al, 2007). So the environmental and economic performance will be improved across the entire supply chain network. The proposed model is to minimize the total costs and CO_2 emission in the entire supply chain and fulfill the various demands at the retailers, so the problem is to determine: (1) which products to ship from suppliers to DCs and from DCs to retailers in each period, (2) the quantity of products should be stored at each DC and each retailer in each period, (3) the number of vehicles from each vehicle types should be used to transport products from each distribution center to each retailer in each period, (4) the optimal assignment among vehicles and drivers by taking into account the vehicle types and the green driving index (GDI) of the drivers, so each driver's assign to one and only one vehicle and vice versa, and then assigned these pairs of vehicles and drivers to each shipments of products from DCs to retailers according to distances between DCs and retailers, so the model should select the optimum assignments in each period, (5) the number of drivers would be hired, fired or trained in each period. In such a way that the total costs are minimized and total CO_2 emission does not exceed the predetermined CO_2 emission level.

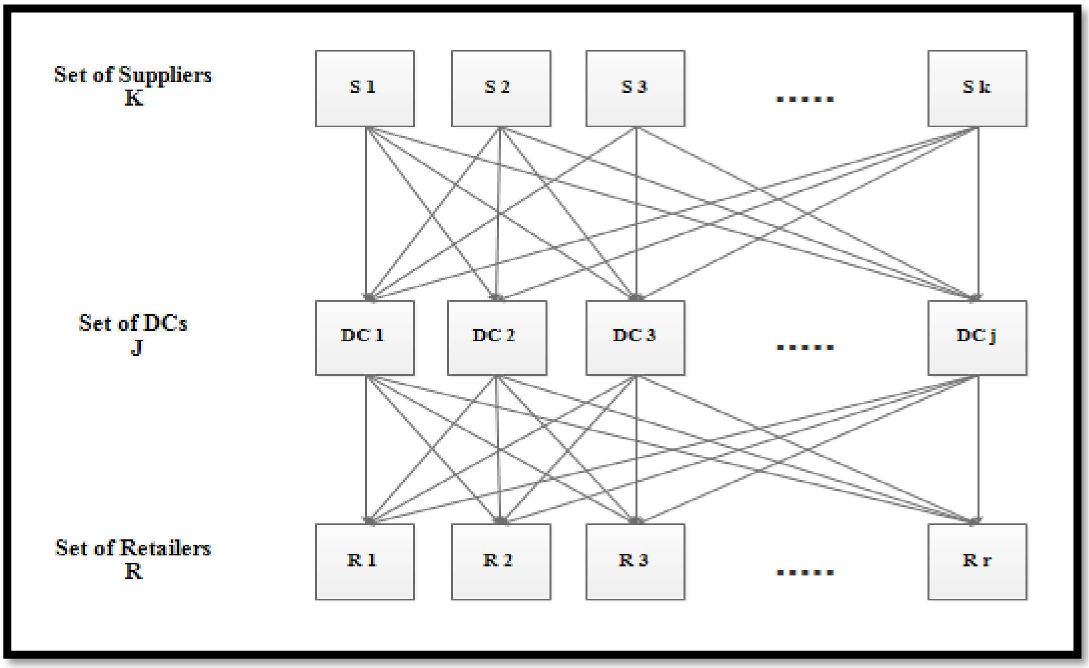

Figure 3.1: A configuration of the supply chain network.

3.3.1 Assumptions:

The model assumes the following:

1. The retailers' demands are supposed to be known for each period during the planning horizon.
2. The number and location of DCs and retailers are known.
3. The distribution centers and retailers have limited storage capacities.
4. Each supplier could provide several types of products with limited capacity, and the suppliers are responsible for delivering the products

to each distribution center, so the purchasing cost includes the product cost, transportation cost and ordering cost.

5. The lead time to ship products from DCs to retailers is assumed to be zero, so it is ignored.
6. The vehicles are being rented from a third party, and the fixed costs associated with the rental of vehicles paid each period, and vary depending on the type of vehicles.
7. There are three types of vehicles that vary in their cost (i.e. rental and variable costs), capacity, and the amount of CO_2 that will be emitted.
8. There are three levels of drivers who are classified depending on their driving patterns. Driver level 1 has an aggressive driving pattern, driver level 2 has a moderate/calm driving pattern, and driver level 3 has an eco-driving pattern. As the level of driver increases, his/her efficiency in reducing fuel consumption and CO_2 emission will increase. In such a way that, the difference between each level in term of fuel consumption and CO_2 emission is 20% (Barkenbus, 2010; Stillwater and Kurani, 2013).

3.3.2 Sets

Set	Description	Index
$\boldsymbol{K}$	Set of suppliers, with various capacities, various cost, various lead time.	k; 1 … $\boldsymbol{K}$
$\boldsymbol{J}$	Set of DCs, with various throughput capacity, various fixed and variable cost	j; 1 … $\boldsymbol{J}$
$\boldsymbol{R}$	Set of retailers, with various storage capacity and various demand.	r; 1 … $\boldsymbol{R}$
$\boldsymbol{L}$	Set of products, with various volume and purchasing cost.	l; 1 … $\boldsymbol{L}$
$\boldsymbol{G}$	Set of vehicles, with various capacities, various rental cost, various fuel consumption per km and various CO_2 emission per km.	g; 1… $\boldsymbol{G}$
$\boldsymbol{O}$	An auxiliary set that use to help in assignments between vehicles and drivers, indicates to number of available vehicles type g.	o; 1 … $\boldsymbol{O}$. Where $\boldsymbol{O}$ is a big positive number.
$\boldsymbol{M}$	Set of GDI levels of drivers.	m; 1 … $\boldsymbol{M}$.
$\boldsymbol{N}$	An auxiliary set that use to help in assignments between vehicles and drivers, indicates to number of available drivers' level m, at DC j in period t.	n; 1… $\boldsymbol{N}$. Where $\boldsymbol{N}$ is a big positive number.
$\boldsymbol{T}$	Set of periods.	t; 1…..$\boldsymbol{T}$.

3.3.3 Parameters

Parameter	Description
$\boldsymbol{D}_{rlt}$	Demand of retailer r for product type l in period t.
$\boldsymbol{CV}_g$	Variable cost (fuel and maintenance cost per unit distance, cost per km) of vehicle type g.
$\boldsymbol{CF}_g$	Fixed costs associated with the rental of one vehicle type g in each period.
$\boldsymbol{a}_{jl}$	Inventory unit holding cost for product l at DC j.
$\boldsymbol{a}_{rl}$	Inventory unit holding cost for product l at retailer r.
$\boldsymbol{LCD}_j$	Labor cost (salary of one worker) at DC j in each period.

$\boldsymbol{LCR_r}$	Labor cost (salary of one worker) at retailer r in each period.
$\boldsymbol{FCD_j}$	Labor firing cost at DC j.
$\boldsymbol{HCD_j}$	Labor hiring cost at DC j.
$\boldsymbol{FCR_r}$	Labor firing cost at retailer r.
$\boldsymbol{HCR_r}$	Labor hiring cost at retailer r.
$\boldsymbol{C_{kl}}$	Purchase cost of product type l provided by supplier k (include ordering cost, product price and transportation cost), from door to door.
$\boldsymbol{DC_{mjt}}$	Labor cost of m-level drivers (salary for one driver's has m-level) at DC j in period t.
$\boldsymbol{TC_{mm'jt}}$	Training cost for m-level driver trained to level m' at DC j in period t.
$\boldsymbol{FC_{mjt}}$	Firing cost for m-level driver at DC j in period t.
$\boldsymbol{HC_{mjt}}$	Hiring cost for m-level driver at DC j in period t.
$\boldsymbol{TP_{mm'j}}$	1 if training from skill level m to skill level m' is possible at DC j, 0 otherwise.
$\boldsymbol{w_j}$	Product storage capacity of DC j in m^3.
$\boldsymbol{R_r}$	Product storage capacity of retailer r in m^3.
$\boldsymbol{CS_{klt}}$	Max. No. of product type l that could be provided by supplier k in period t.
$\boldsymbol{V_g}$	The capacity of vehicle type g (in $m^3/vehicle$).
$\boldsymbol{v_l}$	Volume of product l (in $m^3/unit$).
$\boldsymbol{m_l}$	Manpower needs to handle one unit of product type l at DCs and retailers.
$\boldsymbol{d_{jr}}$	Distance, in km, between DC j and retailer r.
$\boldsymbol{LT_{kjl}}$	Lead time required for transporting product type l from supplier k to DC j.
$\boldsymbol{GDI_m}$	The green driving index for m-level driver in period t.
$\boldsymbol{GHG_g}$	CO_2 Emissions for vehicle type g per unit distance.
$\boldsymbol{GHL_t}$	Allowed CO_2 emissions level in period t.

3.3.4 Decision variables

Decision Variable	Description
$\boldsymbol{X_{jrlgt}}$	Total number of units of product type l distributed to retailer r from DC j by vehicle type g in each period t.
$\boldsymbol{Y_{kjlt}}$	Total number of units of product type l to be shipped from supplier k to DC j in each period t.
$\boldsymbol{ID_{jlt}}$	Inventory level of product type l at DC j at the end of period t.
$\boldsymbol{IR_{rlt}}$	Inventory level of product type l at retailer r at the end of period t.
$\boldsymbol{XD_{ongmjrt}}$	1 if vehicle type g assigned to m-level driver to transport products from DC j to retailer r in period t; 0 otherwise.
$\boldsymbol{XG_{jrgt}}$	Number of vehicle type g needed for shipping products from DC j to retailer r in period t.
$\boldsymbol{ND}_{mjt}$	Number of m- levels drivers at DC j in period t.
$\boldsymbol{TD_{mm'jt}}$	Number of m-level drivers at DC j trained to level m' in period t.
$\boldsymbol{FD}_{mjt}$	Number of m-level drivers at DC j fired in period t.
$\boldsymbol{HD}_{mjt}$	Number of m-level drivers at DC j hired in period t.
$\boldsymbol{LD}_{jt}$	Number of workers needed for DC j in period t.
$\boldsymbol{LR}_{rt}$	Number of workers needed for retailer r in period t.
$\boldsymbol{FLD}_{jt}$	Number of workers fired at DC j in period t.
$\boldsymbol{HLD}_{jt}$	Number of workers hired at DC j in period t.
$\boldsymbol{FLR}_{rt}$	Number of workers fired at retailer r in period t.
$\boldsymbol{HLR}_{rt}$	Number of workers hired at retailer r in period t.

3.3.5 Objective Function

To reduce the total costs and CO_2 emission across the entire supply chain network, the main cost components are considered in the objective function of the model. They are as follows:

- Total Labor costs:

$$\sum_{j,t} LCD_j \times LD_{jt} + \sum_{r,t} LCR_r \times LR_{rt} + \sum_{j,t} FCD_j \times FLD_{jt} + \sum_{j,t} HCD_j \times HLD_{jt} + \sum_{r,t} FCR_r \times FLR_{rt} + \sum_{r,t} HCR_r \times HLR_{rt} + \sum_{j,m,t} DC_{mjt} \times ND_{mjt} + \sum_{j,m,t} FC_{mjt} \times FD_{mjt} + \sum_{m,j,t} HC_{mjt} \times HD_{mjt} + \sum_{m,m',j,t} TC_{mm'jt} \times TD_{mm'jt} \quad (1)$$

Description of equation (1): *summation of labor cost (salary of one worker) at DC j × number of workers needed for DC j in period t + Summation of labor cost (salary of one worker) at retailer r in each period × number of workers needed for retailer r in period t+ Summation of labor firing cost at DC j × number of workers fired at DC j in period t+ summation of labor hiring cost at DC j × number of workers hired at DC j in period t+ summation of labor firing cost at retailer r × number of workers fired at retailer r in period t+ Summation of labor hiring cost at retailer r × number of workers hired at retailer r in period t+ summation of labor cost of m-level drivers (salary for one driver's has m-level) at DC j in period t × number of m- levels drivers at DC j in period t+summation of firing cost for m-level driver at DC j in period t × number of m-level drivers at DC j fired in period t+ summation of hiring cost for m-level driver at DC j in period t × number of m-level drivers at DC j hired in period t+summation of training cost for m-level driver trained to level m' at DC j in period t × number of m-level drivers at DC j trained to level m' in period t.*

- Total Inventory cost:

$$\sum_{j,l,t} a_{jl} \times ID_{jlt} + \sum_{r,l,t} a_{rl} \times IR_{rlt} \qquad (2)$$

Description of equation (2): *summation of inventory unit holding cost for product l at DC j × inventory level of product type l at DC j at the end of period t+summation of inventory unit holding cost for product l at retailer r × inventory level of product type l at retailer r at the end of period t.*

- Total Transportation cost that includes fixed and variable costs, the fixed cost depends on the number of vehicles needed of each type in each period, and the variable cost depends on the types of vehicles used and the drivers assigned to these vehicles as well as on the distances between distribution centers and retailers. The drivers have an inverse effect on the fuel consumption (variable cost) depending on their GDI. As the GDI of the driver increases the fuel consumption as well as the variable cost decreases:

$$\sum_{j,r,g,t} CF_g \times XG_{jrgt} + \sum_{j,r,g,o,m,n,t} CV_g \times d_{jr} \times \frac{1}{GDI_m} \times XD_{jrgomnt} \qquad (3)$$

Explanation of equation (3): *summation of fixed costs associated with the rental of one vehicle type g in each period × number of vehicle type g needed for shipping products from DC j to retailer r in period t +summation of variable cost (fuel and maintenance cost per unit distance, cost per km) of vehicle type g × distance, in km, between DC j and retailer r ×(1/ green driving index for m-level* *driver)* $\times$ *binary variable (1 if vehicle type g assigned to m-level driver to transport products from DC j to retailer r in period t; 0 otherwise).*

- Purchasing costs:

$$\sum_{k,j,l,t} C_{kl} \times Y_{kjlt} \tag{4}$$

Description of equation (4): *Purchase cost of product type l provided by supplier k* $\times$ *Total number of units of product type l to be shipped from supplier k to DC j in each period t.*

3.3.6 Total Objective Function

$$\textbf{Minimize } Z = \sum_{j,t} LCD_j \times LD_{jt} + \sum_{r,t} LCR_r \times LR_{rt} + \sum_{j,t} FCD_j \times FLD_{jt} + \sum_{j,t} HCD_j \times HLD_{jt} + \sum_{r,t} FCR_r \times FLR_{rt} + \sum_{r,t} HCR_r \times HLR_{rt} + \sum_{j,m,t} DC_{mjt} \times D_{mjt} + \sum_{j,m,t} FC_{mjt} \times FD_{mjt} + \sum_{m,j,t} HC_{mjt} \times HD_{mjt} \sum_{m,m',j,t} TC_{mm'jt} \times TD_{mm'jt} + \sum_{j,l,t} a_{jl} \times I_{jlt} + \sum_{r,l,t} a_{rl} \times I_{rlt} + \sum_{j,r,g,t} CF_g \times XG_{jrgt} + \sum_{j,r,g,m,t} CV_g \times d_{jr} \times \frac{1}{GDI_{mt}} \times XD_{jrgmt} + \sum_{k,j,l,t} C_{kl} \times Y_{kjlt} \tag{5}$$

3.3.7 Constraints

- Inventory balance equation for DC j in the end of period t:

$$ID_{jl(t-1)} + \sum_k Y_{kjl(t+LT_{kj})} - \sum_{r,g} X_{jrlgt} = ID_{jlt} \quad \forall\, j, l, t \tag{6}$$

Description of equation (6): *inventory level of product type l at DC j at the end of period $(t-1)$ + summation of total number of* *units of product type l to be shipped from supplier k to DC j in each period t with considering lead time that required for transporting product type l from supplier k to DC j – summation of total number of units of product type l distributed to retailer r from DC j by vehicle type g in each period t= inventory level of product type l at DC j at the end of period; for each distribution center, product, and period.*

- Inventory balance equation for retailer r in the end of period t:

$$IR_{rl(t-1)} + \sum_{j,g} X_{jrlgt} - D_{rlt} = IR_{rlt} \qquad \forall\, r, l, \tag{7}$$

Description of equation (7): *inventory level of product type l at retailer r at the end of period $(t-1)$+ summation of total number of units of product type l distributed to retailer r from DC j by vehicle type g in each period t − demand of retailer r for product type l in period t= inventory level of product type l at retailer r at the end of period t; for each retailer, product, and period.*

- Workforce balance equation for DC j in period t:

$$LD_{j(t-1)} + HLD_{jt} - FLD_{jt} = LD_{jt} \qquad \forall j, t \tag{8}$$

Description of equation (8): *the number of workers at DC j in period $(t-1)$+ number of workers hired at DC j in period t − number of workers fired at DC j in period t = number of workers needed at DC j in period t; for each distribution center and period.*

- Workforce balance equation for Retailor r in period t:

$$LR_{r(t-1)} + HLR_{rt} - FLR_{rt} = LR_{rt} \qquad \forall r, t \tag{9}$$

Description of equation (9): *the number of workers at retailer* r *in period* $(t-1)$+ *number of workers hired at retailer* r *in period* $t-$ *number of workers fired at retailer* r *in period* t= *number of workers needed at retailer* r *in period* t*; for each retailer and period.*

- Manpower capacity at DC j in period t:

$$\sum_{k,l} m_l \times Y_{kjlt} + \sum_{r,g,l} m_l \times X_{jrlgt} \leq LD_{jt} \quad \forall\, j,t \tag{10}$$

Description of equation (10): *summation of manpower needs to handle one unit of product type* l *at DC* j × *total number of units of product type* l *to be shipped from supplier* k *to DC* j *in each period* t+ *summation of manpower needs to handle one unit of product type* l *at DC* j × *total number of units of product type* l *distributed to retailer* r *from DC* j *by vehicle type* g *in each period* t ≤ *number of workers needed at DC* j *in period* t *; for each distribution center and period.*

- Manpower capacity at retailer r in period t

$$\sum_{j,g,l,t} m_l \times X_{jrlgt} \leq LR_{rt} \quad \forall\, r,t \tag{11}$$

Description of equation (11): *summation of manpower needs to handle one unit of product type* l *at retailer* r × *total number of units of product type* l *distributed to retailer* r *from DC* j *by vehicle type* g *in each period* t ≤ *number of workers needed for retailer* r *in period* t*; for each retailer and each period.*

- Satisfy demand of product type l at retailer r in period t:

$$\sum_{j,g} X_{jrlgt} \geq D_{rlt} \quad \forall\, r,l,t \tag{12}$$

Description of equation (12): *summation of product type l distributed to retailer r from DC j by vehicle type g in each period ≥ demand of retailer r for product type l in period t; for each retailer, product, and period.*

- Number of vehicle g used for transportation between DC j and retailer r in period t:

$$(XG_{jrgt} - 1) \times V_g \leq \sum_l v_l \times X_{jrlgt} \leq XG_{jrgt} \times V_g \quad \forall j, r, g, t \tag{13}$$

Description of equation (13): *((Number of vehicle type g needed for shipping products from DC j to retailer r in period t) −1) × capacity of vehicle type g ≤ summation of Volume of product l × total number of units of product type l distributed to retailer r from DC j by vehicle type g in each period t ≤ Number of vehicle type g needed for shipping products from DC j to retailer r in period t × capacity of vehicle type g; for each vehicle type, retailer, distribution center and period.*

- Ensure that, the total number of drivers who are available from all levels is greater than or equal the number of vehicles needed from all types at DC j in each period t:

$$\sum_m ND_{mjt} \geq \sum_{r,g} XG_{jrgt} \quad \forall j, t \tag{14}$$

Description of equation (14): *summation of number of m- levels drivers at DC j in period t ≥ summation of number of vehicle type g needed for shipping products from DC j to retailer r in period t; for each distribution center and period.*

- Ensure that, the total assignment of vehicle type g to drivers equal to the number of vehicles type g that selected to transport products from DC j to retailer k:

$$\sum_{o,m,n} XD_{jrgomnt} = XG_{jrgt} \quad \forall\, j, r, g, t \tag{15}$$

Description of equation (15): *summation of assignment binary variables (1 if vehicle type g assigned to m-level driver to transport products from DC j to retailer r in period t; 0 otherwise) = number of vehicle type g needed for shipping products from DC j to retailer r in period t; for each distribution center and each period; for each distribution center, retailer, vehicle, and period.*

- Ensure that the total number of m-level drivers who are assigned to the vehicles not exceed the total number of m-level drivers are available in each period t:

$$\sum_{n,g,o,r} XD_{jrgomnt} \leq ND_{mjt} \quad \forall m, j, t \tag{16}$$

Description of equation (16): *summation of assignment binary variables (1 if vehicle type g assigned to m-level driver to transport products from DC j to retailer r in period t; 0 otherwise) $\leq$ number of m- levels drivers at DC j in period t; for each distribution center, drivers level, and period.*

- The number of m-level drivers available at DC j in period t

$$ND_{mjt} = ND_{mj(t-1)} + HD_{mjt} - FD_{mjt} + \sum_{m'} TD_{m'mjt} - \sum_{m'} TD_{mm'jt} \quad \forall\, j, m, t \tag{17}$$

Description of equation (17): *number of* m*- levels drivers at DC* j *in period* t *= number of* m*- levels drivers at DC* j *in period* $(t-1)$ *+ number of* m*-level drivers at DC* j *hired in period* $t-$ *number of* m*-level drivers at DC* j *fired in period* t*+ number of* m'*-level drivers at DC* j *trained to level* m *in period* $t-$ *number of* m*-level drivers at DC* j *trained to level* m' *in period* t*; for each distribution center, driver level, and period.*

- The total number of laying off or training of drivers' level m in current period cannot exceed the number of drivers' level m who are available in the previous period:

$$FD_{mjt} + \sum_{m'} TD_{mm'jt} \leq ND_{mj(t-1)} \ \forall \ m, j, t \tag{18}$$

Description of equation (18): *number of* m*-level drivers at DC* j *fired in period* t*+summation of number of* m*-level drivers at DC* j *trained to level* m' *in period* t $\leq$ *number of* m*- levels drivers at DC* j *in period* $(t-1)$*; for each drivers level, distribution center, period.*

- This constraint ensures that upgrading drivers from skill level m' to level m is possible, if and only if this training session is available:

$$TD_{m'mjt} \leq M \times TP_{m'mj} \ \forall \ m, m', j, t \tag{19}$$

, where M is an arbitrary big positive number.

Description of equation (19): *number of* m*-level drivers at DC* j *trained to level* m' *in period* t $\leq$ *arbitrary big positive number* $\times$ *binary number (1 if training from skill level* m *to skill level* m*' is possible at DC* j*, 0 otherwise); for each driver level m', driver level m, distribution center, and period.*

- This constraint guarantees that, the drivers who are trained for skill level m should not be fired in the same period.

$$\sum_{m\prime} TD_{m\prime mjt} \times FD_{mjt} = 0 \;\; \forall m, j, t \tag{20}$$

Description of equation (20): summation of number of m'-level drivers at DC j trained to level m in period t × number of m-level drivers at DC j fired in period t = 0; for each driver level m, distribution center, and period.

- This constraint is a non-linear term and converting it to a linear term could be obtained by using an auxiliary binary variable and equivalent linear equations which are as follows:

$$\sum_{m\prime} TD_{m\prime mjt} \leq M \times Z_{mjt} \quad \forall m, j, t \tag{21}$$

Description of equation (20): *summation of number of m'-level drivers at DC j trained to level m in period t ≤ arbitrary big positive number × auxiliary binary variable; for each m level driver, distribution center, and period.*

$$FD_{mjt} \leq M\left(1 - Z_{mjt}\right) \quad \forall m, j, t \tag{22}$$

Description of equation (22): *number of m-level drivers at DC j fired in period t ≤ arbitrary big positive number × (1− auxiliary binary variable); for each m level driver, distribution center, and period.*

Where Z_{mjt} is an auxiliary binary variable, $Z_{mjt} \in \{0,1\} \quad \forall m, j, t$, and M is an arbitrary big number.

- Suppliers capacities in period t:

$$\sum_{j} Y_{kjlt} \leq CS_{klt} \qquad \forall\, k, l, t \tag{23}$$

Description of equation (23): *summation of total number of units of product type l to be shipped from supplier k to DC j in each period t $\leq$ maximum number of product type l that could be provided by supplier k in period t; for each supplier, product, and period.*

- Greenhouse gas (GHG) level allowable for each period t, the amount of CO_2 emissions produced depends on the number of vehicles needed of each type in each period, and the drivers assigned to these vehicles as well as on the distances between distribution centers and retailers. The drivers have an inverse effect on the GHG emissions depending on their $GDIs$. As the GDI of the driver increases the CO_2 emission decreases:

$$\sum_{j,r,g,o,m,n} XG_{ongmjrt} \times GHG_g \times d_{jr} \times \frac{1}{GDI_m} \leq GHL_t \quad \forall\, t \tag{24}$$

Description of equation (24): *summation of binary assignment variable ((1 if vehicle type g assigned to m-level driver to transport products from DC j to retailer r in period t; 0 otherwise) $\times$ CO_2 Emissions for vehicle type g per unit distance $\times$ distance, in km, between DC j and retailer r $\times$ (1/ green driving index for m-level driver) $\leq$ allowed CO_2 emissions level in period t; for each period.*

- The number of product type l shipped from DC j to retail store r, does not exceed the available of product l at the DC j in period t:

$$ID_{jl(t-1)} + \sum_k Y_{kjlt} \geq \sum_{r,g} X_{jrlgt} \quad \forall\, j, l, t \tag{25}$$

Description of equation (25): *inventory level of product type l at DC j at the end of period t + summation of total number of units of product type l to be shipped from supplier k to DC j in each period t ≥ summation of total number of units of product type l distributed to retailer r from DC j by vehicle type g in each period t; for each distribution center, product, and period.*

- The constraint ensures that, the inventory level at DC cannot exceed the available storage capacity at DC j in each period:

$$\sum_l v_l \times ID_{jlt} \leq w_j \quad \forall\, j, t \tag{26}$$

Description of equation (26): *summation of Volume of product l × inventory level of product type l at DC j at the end of period t ≤ product storage capacity of DC j; for each distribution center and period.*

- The constraint ensures that, the inventory level at retailer r cannot exceed the available storage capacity at retailer r in each period t:

$$\sum_l v_l \times IR_{rlt} \leq R_r \quad \forall\, r, t \tag{27}$$

Description of equation (26): *summation of Volume of product l × product storage capacity of retailer r ≤ inventory level of product type l at retailer r at the end of period t; for each retailer and period.*

- Non-negativity and integers constraints:

$$X_{jrlgt}, XG_{jrgt}, Y_{kjlt}, ID_{jlt}, IR_{rlt}, TD_{mm'jt}, FD_{mjt}, HD_{mjt}, ND_{mjt}, LD_{jt}, LR_{rt}, HLD_{jt}, FLD_{jt}, HLR_{rt}, FLR_{rt} \geq 0 \; and \; integers$$

$$XD_{ongmjrt}, TP_{m'mjt}, Z_{mjt} \in \{0,1\}$$

3.4 Summary

In this chapter, the proposed model for Green Supply Chain Management (GSCM) was described. This model was formulated as a MINLP and then converted to a linear one. The developed model deals with multi-site, multi product and multi period APP in GSCM. The aim of this model is to minimize the total costs across the entire supply chain network. In addition to guarantee that the CO_2 emissions do not exceed the predetermined level. This model contributes to the literature with a novel approach that integrating drivers' differences in managing and planning GSC at tactical and operational levels, with aims to optimal selection of drivers, training them and then introducing the optimum assignment between drivers, vehicles and the destinations (i.e. retail stores) in order to reduce the total cost and CO_2 emission across the supply chain network.

Chapter Four

Model Results

Chapter Four

Model Results

4.1 Overview

This chapter presents a numerical study to demonstrate the validity of the proposed model. In section 4.1, the description of the hypothetical problem will be shown. The results of hypothetical numerical example will be generated by using Matlab 2015a program. In section 4.2.1, some characteristics of Matlab program and the “intlinprog” solver will be presented. Finally, section 4.2.2 presents and discusses the numerical results of solving the hypothetical example.

4.2 Hypothetical Data

The analysis was based upon data which was derived from the literature and addition to hypothetical data that covered all parameters and data needed. The multi-site retail stores company intended to plan its APP taking 3 periods as a planning horizon, with a single type of product. The supply chain network consist of two suppliers S1 and S2, two distribution centers DC1 and DC2, and two retailers R1 and R2, all supply chain sites spread out geographically. We assumed that the demand during planning horizon is known, as shown in Table 4.1. The storage capacity and holding cost at retailers and distances between retailers and DCs are also presented in Table 4.1. Inventory holding cost per unit of product and storage capacities at DCs, and the limit of greenhouse gas emission allowable per each period are presented in Table 4.2. vehicles' data that related to variable and fixed cost, amount of CO_2 emission and capacities for each type of vehicles are shown in Table 4.3. Initial workforce level at DCs and retailers, workers' related cost and the manpower needed to handle one product are given in Table 4.4. In Table 4.5, the Drivers' data are given, related to initial m-level driver available, drivers' costs, consist of hiring, firing, salaries and training costs, in addition to the Green Driving Index (GDI) for each m-level driver. And finally, maximum number of products can be provided by each supplier, lead time between suppliers and DCs, and the purchasing cost of unit product that can vary with different suppliers and DCs, are shown in Table 4.6.

Table 4.1: Demand Forecast, Distances between retailers and DCs in km, inventory costs and capacities at retailers.

	Period t			**Distance between DC j and Retailer r (in Km)**		**Holding cost ($)**	**Storage capacity (m^3)**
Retailer r	1	2	3	DC 1	DC 2		
1	360	360	290	25	200	6	5000
2	140	380	440	100	55	6	5000

Table 4.2: Inventory cost, storage capacities at DCs and GHG emission level in each period

DC j	**Holding cost ($)**	**Storage capacity (m^3)**	**GHG emissions level (Kg/period)** Period		
1	6	10000	1	2	3
2	6	12000	1000	8000	600

Table 4.3: Vehicles' Data

Vehicle g	**Rental cost ($/vehicle)**	**Fuel cost ($/$Km$)**	**CO_2 emission (Kg/Km)**	**capacity ($m^3/vehicle$)**
1	700	0.672	0.87	30
2	500	0.314	0.37	22.5
3	400	0.262	0.3313	20

Table 4.4: Workers' Data cost

Facility	Salary cost in ($/manpower)	Hiring cost in ($/manpower)	Firing cost in ($/manpower)	Initial workforce	Manpower needed/ product
DCs	180	20	60	5	0.01
Retailers	200	30	80	5	0.01

Table 4.5: Initial driver and driver cost in ($/Driver) and their GDI

Driver level m	Salary cost ($/Driver/ period)	Hiring cost ($/Driver)	Firing cost ($/Driver)	Training cost ($/Driver)			Initial Driver		GDI for Driver level m
				Driver level m			DC j		
				1	2	3	1	2	
1	180	50	60	-	15	25	3	2	0.80
2	200	60	80	-	-	15	3	4	1.00
3	220	70	100	-	-	-	2	1	1.20

Table 4.6: Suppliers Data

Supplier k	Production Capacity (in unit)			Lead time (period)		Purchasing cost ($/unit)	
	Period t			DC j		DC j	
	1	2	3	1	2	1	2
1	3500	3500	3500	0	1	9	7.5
2	3000	3000	3000	0	2	10	7

4.3 Results:

4.3.1 Matlab Solver and Algorithms

Matlab is one of the powerful software are using to solve optimization problems, it has an optimization toolbox that includes many solvers for linear programming, mixed-integer linear programming, quadratic programming, nonlinear and multi-objective optimization, and nonlinear least squares, data fitting, and non-linear equations.

In context of MILP, Matlab deals with MILP as a problem with

- Linear objective function, $f^T x$, where f is a column vector of constants, and x is the column vector of variables (unknowns).
- Bounds and linear constraints.

- Restrictions on some components of x to have integer values.

The Matlab has a specific solver to deal with MILP models, it is the "intlinprog" solver. This solver used many types of algorithms to deal with the MILP problem such as Gomory Cuts, Mixed Integer Rounding (MIR) Cuts (MIR cuts are generated by applying integer rounding on the coefficients of integer variables and the Right Hand Side (RHS) of a constraint) and Branch and Bound algorithms etc. In addition to Heuristics algorithms to provide many feasible solutions (Upper bound feasible solution) and Linear Programming (LP) algorithms to provide a lower bound feasible solution.

4.3.2 Numerical Results

All computations were run using Gomory cuts, MIR cuts and branch and bound Algorithms accessed via Matlab 2015a on a PC Intel® core™ i5 CPU M450 2.40 GHZ and 4.00GB RAM under win 10 pro, with total running time is 6.64 sec. The following results are gained from solving the numerical study's data that was previously mentioned.

❖ **Workforce plan for workers at retailers and DCs:**

The workforce plan at retailers and DCs related to number of workers needed, number of workers hired and fired are reported in Table 4.7. As shown in Table 4.7, DC 2 does not need any workers in period 1, because the lead times between all suppliers and DC 2 are more than or equal one. This leads to the number of workers needed to deal with the products is equal to zero at DC 2. In such a way that, the total number of workers are needed to handle products also equal to zero at DC 2. The DC 2 should be closed in this period. Other data are shown in Table 4.7.

Table 4.7: Workforce plan obtained from solving the proposed model

	DC *j*	**Period *t***			**Retailer *r***	**Period *t***		
		1	2	3		1	2	3
Labors needed	1	10	7	7	1	4	4	3
	2	0	8	8	2	2	4	5
Hiring Labor	1	5	0	0	1	0	0	0
	2	0	8	0	2	0	2	1
Firing labor	1	0	3	0	1	1	0	1
	2	5	0	0	2	3	0	0

❖ **Workforce plan for drivers at DCs:**

The drivers' plan shown in Table 4.8; this plan deals with the number of drivers needed from each level in each period at each DC, number of driver hired and fired from each level and the number of drivers who should be trained to an upper level in each period at each DC. In period 1 and 2, number of drivers' level 1 are the dominant, because the model tried to trade-off between the cost of drivers and their effect on fuel consumption and CO_2 emission with guarantee that the allowable level of CO_2 does not violated. In period 1 and 2, the allowable level of CO_2 is a tolerable level to select the drivers of level 1 in order to reduce cost without any violation of the CO_2 emission restriction. But with the GHG restriction become tighter in period 3, number of drivers' level 1 decreased and number of drivers' level 2 and 3 increased, specifically in DC 2. And the model in this period selected 14 drivers of level 1 at DC 2 to be trained to level 2. Because the distance between DC 2 and retailers is more than DC1, so the selection of drivers become more critical as the distance increases and GHG emission level become tighter, we will show that later in a sensitivity analysis chapter.

Table 4.8: Drivers plan obtained from solving the proposed model

	DC j	**Driver level m**	**Period t**		
			1	2	3
Drivers needed	1	1	12	12	11
		2	3	3	3
		3	2	2	2
	2	1	0	20	6
		2	0	0	14
		3	0	0	0
Hiring Driver	1	1	9	0	0
		2	0	0	0
		3	0	0	0
	2	1	0	20	0
		2	0	0	0
		3	0	0	0
Firing Driver	1	1	0	0	1
		2	0	0	0
		3	0	0	0
	2	1	2	0	0
		2	4	0	0
		3	1	0	0
Upgrading Driver	2	1 → 2	0	0	14

❖ **Calculations of vehicles needed**

In Table 4.9, the number of vehicles of each type that are required to ship products from the distribution centers to retail stores was calculated. For example, 12 vehicles of type 1 are used to transport product from DC 1 to retailer 1 in period 1, and 17 vehicles of type 3 are used to transport product from DC 1 to retailer 1 in period 2, etc.

Table 4.9:Number of vehicle *g* used to ship product from Dc *j* to retailer *r*

DC *j*	Retailer *r*	Vehicle *g*	Period *t*		
			1	2	3
1	1	1	12	0	1
		2	0	0	0
		3	0	17	13
	2	1	4	0	0
		2	0	0	0
		3	1	0	2
2	1	1	0	0	0
		2	0	0	0
		3	0	1	0
	2	1	0	0	0
		2	0	0	0
		3	0	19	20

❖ **The assignments between vehicles, drivers and retailers.**

Table 4.10, shows that the assignments between vehicles, drivers and Retailers at each DC. Each driver will be assigned to one and only one vehicle to transport products to one and only one retailer, and each vehicle will be assigned to one and only one drivers to transport products to one and only one retailer. For example, 12 vehicles of type 1 were assigned to 12 driver of level 1 to transport products from DC 1 to retailer 1 in period 1 and one vehicle of type 1 was assigned to one driver of level 2 to transport product from DC1 to retailer 1 in period 3 etc.

Table 4.10: Number of assignments between driver level m, vehicle type g and retailer r at Dc j in each period t.

DC j	Retailer r	Vehicle g	Driver level m	Period t		
				1	2	3
1	1	1	1	12	0	0
			2	0	0	1
			3	0	0	0
		2	1	0	0	0
			2	0	0	0
			3	0	0	0
		3	1	0	12	11
			2	0	3	2
			3	0	2	0
	2	1	1	0	0	0
			2	2	0	0
			3	2	0	0
		2	1	0	0	0
			2	0	0	0
			3	0	0	0
		3	1	0	0	0
			2	1	0	0
			3	0	0	2
2	1	1	1	0	0	0
			2	0	0	0
			3	0	0	0
		2	1	0	0	0
			2	0	0	0
			3	0	0	0
		3	1	0	1	0
			2	0	0	0
			3	0	0	0
	2	1	1	0	0	0
			2	0	0	0
			3	0	0	0
		2	1	0	0	0
			2	0	0	0
			3	0	0	0
		3	1	0	19	6
			2	0	0	14
			3	0	0	0

❖ **Calculation of the amount of products that will be shipped from Suppliers to DCs**

In Table 4.11, the interaction between DCs and suppliers are presented. The number of products that will be shipped from each supplier to each DC in each period was calculated, (i.e. at period 1, DC 1 received 500 products from suppliers 1, and there is no interaction between DC 1 and supplier 2, and there is no interaction between DC 2 and suppliers at all).

Table 4. 11: The quantities to be shipped from supplier *k* to Dc *j* in each period *t*

Supplier *k*	**DC *j***	**Period *t***		
		1	2	3
1	1	500	340	330
	2	0	400	0
2	1	0	0	0
	2	0	0	400

❖ **Calculation of the amount of products that will be shipped from DCs to retailers**

In Table 4.12, the interaction between DCs, Retailers and the vehicles type are presented. The number of products that will be shipped from each DC to each retailer by using vehicles of type g was calculated.

For example, 360 unit of products will be shipped from DC 1 to retailer 1 by using vehicles type 1 in period 1 and 20 unit of products will be shipped from DC1 to retailer 2 by using vehicle 3 in period 1.

Table 4. 12: The quantities to be shipped from DC j to retailer k in period t

DC j	Retailer r	Vehicle g	Period t		
			1	2	3
1	1	1	360	0	30
		2	0	0	0
		3	0	340	260
	2	1	120	0	0
		2	0	0	0
		3	20	0	40
2	1	1	0	0	0
		2	0	0	0
		3	0	20	0
	2	1	0	0	0
		2	0	0	0
		3	0	380	400

- **Objective functions components**

In Table 4.13, the objective function components and the proportion of each of them from the total cost of the SC were presented. As shown in Table 4.13, the largest component of supply chain costs is the transportation costs with 46.87% of the total supply chain cost and then the drivers' cost with 21.06% of the total cost. In the next chapter, the sensitivity of these components to the GHG emission level will be analyzed.

Table 4.13: Objective Function Components in ($)

	Purchase cost	Workers' cost	Drivers' cost	Transportation Cost	Total cost
Value	16,330	12,830	19,160	42,635	90,550
Percentage	17.96	14.11	21.06	46.87	100

4.4 Summary

This chapter presented a numerical study to verify the solvability of the proposed model. The results were obtained by using Matlab 2015a program. The workforce plan for drivers and workers, the interactions between suppliers and DCs, the interactions between DCs and retailers, the vehicles needed, the assignment between vehicles, drivers and destinations, and the objective function components have been shown. A brief discussion of these results was presented. In the next chapter, the analysis and discussion of the input data and their sensitivity on some of these results will be presented in more details.

Chapter Five

Sensitivity Analysis

Chapter Five

Sensitivity Analysis

5.1 Overview

In this chapter the sensitivity analysis will be conducted, which means that the numerical parameters used in solving the model will be examined and then the results obtained will be analyzed. Conducting sensitivity analysis will be on the three important parameters such as the GHG emission level, the distances between DCs and retailers and the cost of drivers. After identifying these sensitive parameters, the sensitivity analysis will be conducted to see how much the model's results are sensitive to changing in these parameters. So, the effect of the allowable GHG emissions level on the total costs and the selection of drivers, the effect of distances between DCs and retailers on the selection of drivers, and the effect of differences in cost between drivers on the selection of drivers will be analyzed.

5.2 Conducting a Sensitivity Analysis on the GHG emission level

In this section, we conduct a sensitivity analysis on the allowable GHG emissions level and its effect on the total cost and the selection of drivers.

5.2.1 The effect of GHG emission level on the total costs of supply chain

We conducted a sensitivity analysis in this section, to examine the change in total cost at each level of GHG emission. The right hand side of GHG emission is our concern. At first, we put a large value for the allowable amount of GHG emission to solve the problem, as expected, we have the minimum total cost. After that, the allowable amount of GHG emissions has been reduced gradually and then analyzed the impact of this on the total cost at each level. The results are presented in Figure 5.1. As shown in Figure 5.1, when GHG emission is relaxed, the minimum total cost of supply chain will be incurred and the upper value of GHG will be (1000 kg/ period) with total cost is ($90430). This means that the model try to minimize the total cost without any restriction on environment issue, so the optimum solution is a tradeoff between transportation costs (i.e. vehicles' costs), drivers' costs and inventory cost to minimize the total cost in the supply chain. When we impose that the GHG will be reduced to the lowest level (435), the total cost will increased by (~4.14%) with total cost is ($94174). The GHG limit is not arbitrary value, but it could be explained as an ethical issue or a green strategy which companies have a willing to adopt or as threshold putting by the governments, any violation of this limit could cost the company to pay extra taxes, these results are compatible with (Mirzapour et Al, 2013) results.

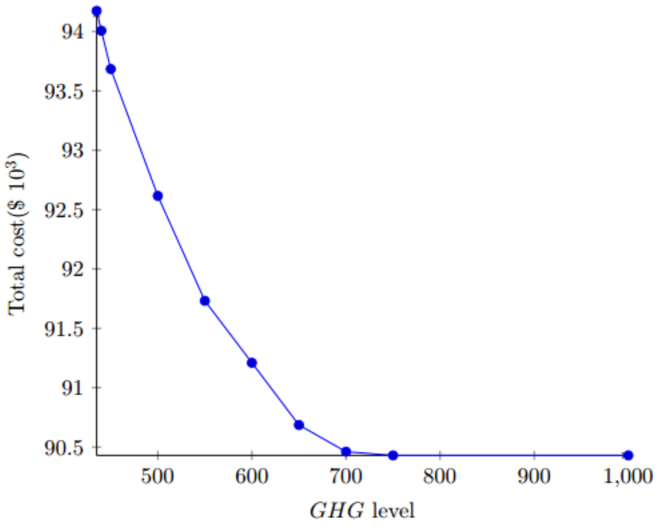

Figure 5.1: Total cost against greenhouse emission limitation.

5.2.2 The effect of *GHG* emission level on the drivers' plan

In this section a sensitivity analysis has been performed on the number of drivers' level m which is needed to achieve the desired level of GHG emissions. At first, we put a large value for the allowable amount of GHG emission to solve the problem, and then, it has been reduced gradually and analyzed the impact of this on the number of drivers from each level. The results are presented in Figure 5.2. The result as expected that, the level dominant on the number of drivers who had been selected is the level 1 with number of drivers is 79 (~81.50%) and then level 2 and 3 with number of drivers is 9 for each level with (~9.28%). This means that the model tries to minimize the total costs without any restriction on the environment issue, so the optimum solution is a tradeoff between the costs of each drivers' level and the effect of driver from each level in fuel consumption cost, so the drivers selection depends on the distance between DCs and retailers (as we will show later in another sensitivity analysis between distances and driver selection), and depends on the vehicle type will be used. When the upper limit of GHG emission level imposed to be (600 kg), as expected, the number of drivers level 1 is decreased by (~26%) with 51 driver, and the number of drivers level 2 needed is increased by (~20%) with 27 driver, also the number of level 3 drivers is increased by (~6%). When GHG upper limit decrease from (600) to (550) the percentage of drivers' level 2 from the total drivers selected is increased to (~ 42%), level 1 with (~42.55%), and level 3 with (~15.96%). After reducing the GHG upper limit to the lowest level (435), the number of drivers level 3 selected is increased to become (~73.96%) among the total number of drivers had been selected. This result indicates that, to which extent the firm can achieved GHG emission level depend on the number of drivers available from each m-level. This emphasis that, the important of green human resources management (GHRM) on implanting the Green supply chain management, as Jabbour and de Sousa Jabbour (2015), have shown that the importance of integrated GHRM with GSCM to truly sustainable supply chains, by selecting, training, motivating, rewarding, empowerment and performance evolution of employee such as Drivers on implementing green practices in GSCM.

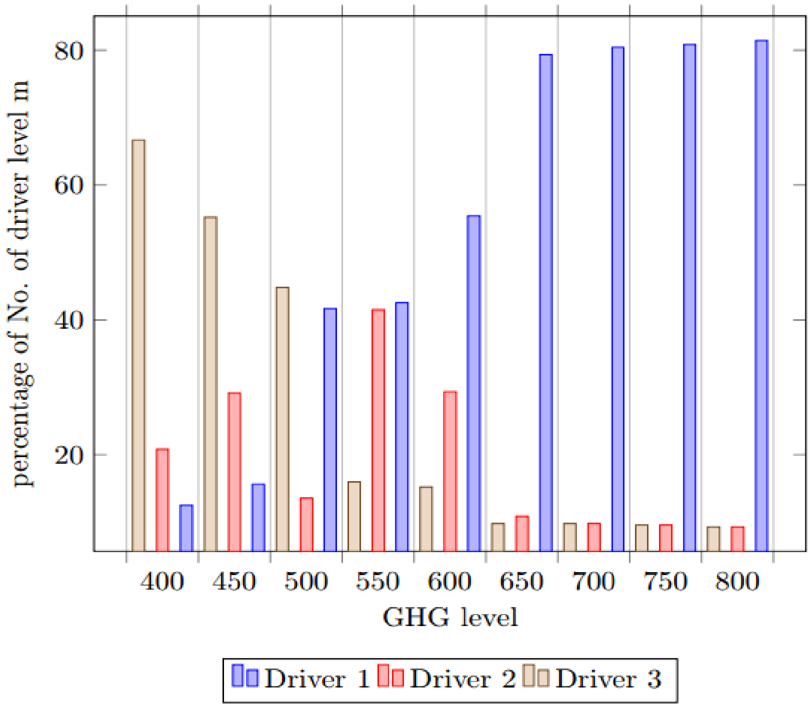

Figure 5.2: The relation between number of m-level driver and greenhouse limitation.

5.3 Conducting a Sensitivity Analysis on the distances between DCs and retailers

In this section sensitivity analysis will be conducted between the number of drivers needed from each level and the distances between DCs and retailers. After solving the problem by relaxing the GHG emission constraint, and unification the distance between DCs and Retailers, and then increase the distances gradually in order to analyze the distance impact on the selection among levels of drivers as shown in Figure 5.3. As Shown in Figure 5.3, when the distance between each DC and each retailer is less than 300 km, the dominant number of drivers are selected from driver level 1 with percentage equals to (~81.44%) and driver level 2 and 3 with (9.28%) for each level. When distance increased to 500 km, the percentage of drivers' level 1 selected had been reduced to (~2.08%), with increased the number of drivers' level 2 to (~91.67%) and drivers' level 3 reduced to (~6.25%). And with increasing the distance to higher than 600 km, the number of drivers' level 3 is increased to (~97.98%), and number of drivers' level 2 reduced to (~2.02%) with 0.00% of drivers' level 1. Finally, by increasing the distance to be higher than 900 km, the number of drivers' level 3 is increased to 100% with 0.00% to each of drivers' level 1 and 2. This could be due to the effect of drivers on fuel consumption will be increased with increasing the distance. So the model try to tradeoff between the fuel consumption saving can achieved by driver and the cost of driver. This can indicate that the criticality of selection drivers depend on the distance that will be assigned to drivers. And to check the effect of vehicles' types on selection of the drivers, we conduct a test, which the distance between DC1 and retailer1, and the distance between DC2 and retailer1 are equal to 1000 km, on the other hand, the distance between DC1, DC2 with retailer 2 is equal to 50 km, the assignments between vehicles and drivers are shown in Table 5.1. As seen in Table 5.1, in long distances, such as between DC1 and retailer 1, most the assignments were between vehicles of type 3 and drivers of type 3. On the other hand, in short distance, most the assignment were between vehicles of type 3 and drivers of type 1, other assignments are shown in Table 5.1.

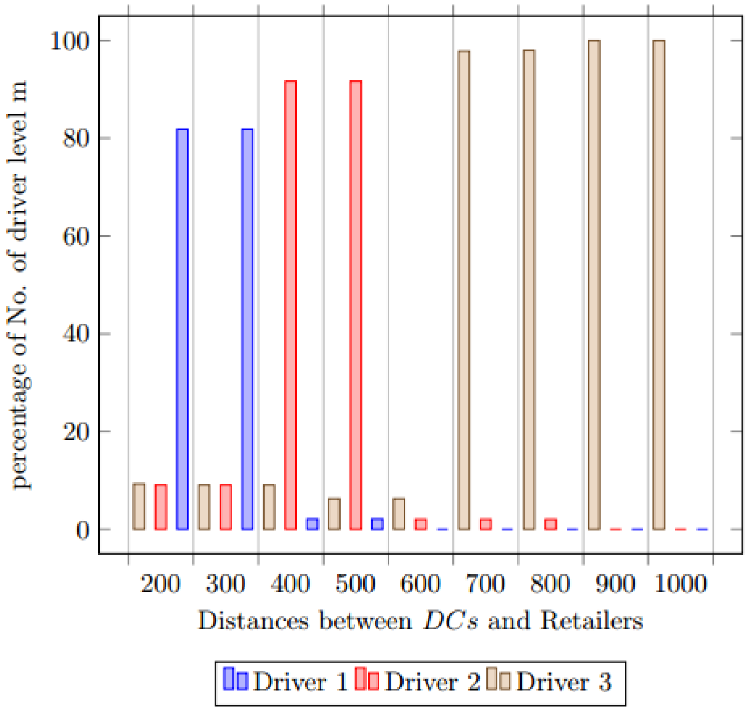

Figure 5.3: The relation between number of m-level driver and the distance between DCs and Retailers.

Table 5.1: Number of assignments between driver level m, vehicle type g and retailer r at DC j in period t

DC j	Retailer r	Vehicle g	Driver level m	Period t		
				1	2	3
1	1	1	1	0	0	0
			2	0	0	1
			3	0	0	0
		2	1	0	0	0
			2	0	0	0
			3	0	0	3
		3	1	0	0	0
			2	1	0	0
			3	17	17	10
	2	1	1	2	0	0
			2	0	1	0
			3	2	0	0
		2	1	0	0	0
			2	0	0	0
			3	0	0	3
		3	1	0	0	0
			2	1	0	0
			3	0	0	4
2	1	1	1	0	0	0
			2	0	0	0
			3	0	0	0
		2	1	0	0	0
			2	0	0	0
			3	0	0	1
		3	1	0	0	0
			2	0	0	0
			3	0	1	0
	2	1	1	0	1	0
			2	0	0	0
			3	0	0	0
		2	1	0	0	0
			2	0	0	0
			3	0	0	0
		3	1	0	10	11
			2	0	0	0
			3	0	0	0

5.4 Conducting a Sensitivity Analysis on the cost of drivers

In this section, the sensitivity analysis will be conducted on the drivers' cost such as the salaries, firing and hiring cost. Differences in costs depend on the level of drivers. We assume that the difference in cost will be constant between each two successive levels (i.e. the difference in cost between driver level 1 and driver level 2 will be equal to the difference in cost between driver level 2 and driver level 3). At the first, we put the difference in cost between the three levels of drivers equal to zero and then the difference will be increased step by step and the number of drivers needed from each level was computed. The results are shown in Figures 5.4, 5.5 and 5.6.

Firstly, when the difference is equal to zero, the result as expected, the dominant level on the number of drivers who had been selected is the level 3 with number of drivers is 73 (80.22%) and then level 2 and 3 with number of drivers is 9 for each level with (9.89%) from the total drivers have been selected, as shown in Figure 5.4. In specific, at DC 1 the percentage of drivers' level 3 who are needed is equal to 68.42% from the total drivers needed at this DC, while the drivers' level 1 and level 2 have a percentage equal to 15.79%. Due to the DC 1 has an initial drivers at the beginning of the planning horizon from level 1, level 2 and level 3. The model will be tried to minimize the cost without violating the allowable CO_2 level. In this situation, the trade-off between firing all the drivers from level 1 and level 2 and then hiring a drivers from level 3 or maintain the drivers from level 1 and level 2 and any needed to hiring drivers should be from level 3, because the hiring cost is equal regardless of the drivers' level. The model conducted a trade-off between the effect of drivers on fuel consumption (Transportation variable cost) and CO_2 emission and the cost of hiring and firing of drivers. This can be a sufficient explanation of why the model did not selected all the drivers from the level 3, these results are shown in Figure 5.5. At DC 2 all the drivers were selected form level 3, because DC 2 in period 1 closed as mentioned in the previous chapter (DC 2 cannot received any product from suppliers in period 1 due to the length of the lead time), so the model laid off all the drivers who are available at the beginning of the period 1. In period 2 and 3, the model selected all the drivers from level 3 to be hired as shown in Figure 5.6. When the difference in cost between each two successive levels of the drivers is equal to ($ 5), the results were as follows; the total number of driver level 3 is decreased by 71.23% with 8 drivers, and the total number of drivers' level 1 is increased by 37.30% with 42 drivers, also the total number of drivers' level 2 is increased by 33.93% with 39 drivers.

These results can be decomposed into results related to DC1 and DC 2. In DC 1, number of drivers' level 1 is increased by 54.80% with 36 drivers, the percentage of drivers level 2 is increased by 1.86% with the same number of drivers needed that equals to 9 drivers, but the total number of drivers' level 3 who are needed is decreased by 56.96% with 6 drivers. While at DC 2, number of drivers' level 1 who are selected is increased by 15.79% with 6 drivers, also the number of drivers' level 2 is increased by 78.95%, but number of drivers' level 3 are decreased by 94.74% with 2 drivers. The dominant level of drivers who are selected in DC 1 is the level 1 and in DC 2 is the level 2, this could be explained by the distance between DC 2 and retailers is higher than the distance between DC 1 and retailers, so the effect of drivers is increased with the distance increased as mentioned in earlier analysis section. As the difference in cost between drivers' level increased, the complexity of selection driver increased, which depends on the distance, the allowable level of GHG emission and on the variable transportation cost (maintenance and fuel cost). These data and the remainder data for total drivers needed at all DCs, drivers needed at DC 1 and at DC 2 are shown in Figure 5.4, 5.5 and 5.6 respectively.

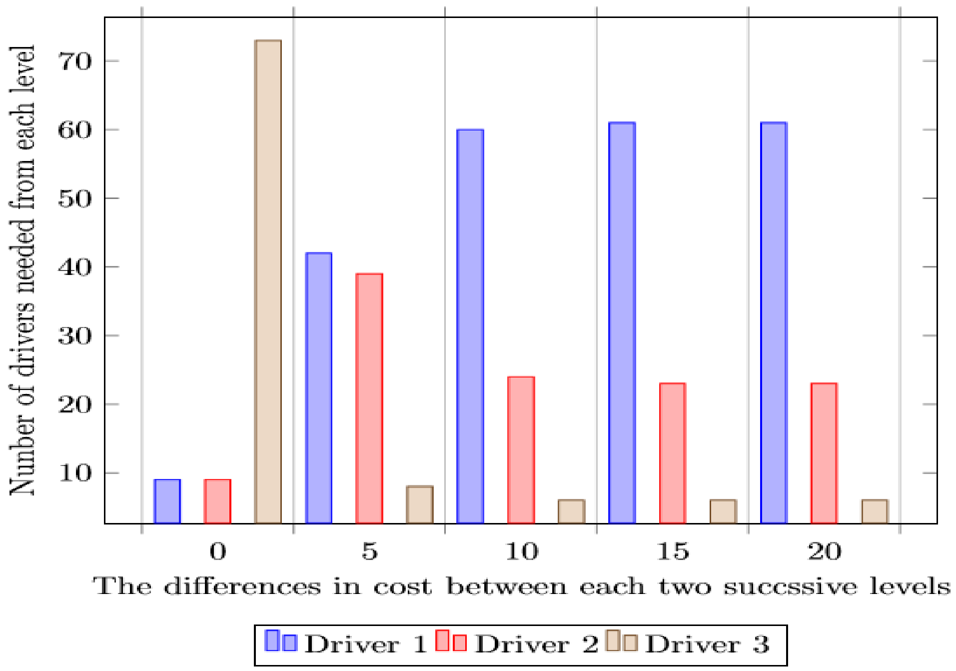

Figure 5.4: the effect of differences in cost between drivers levels on the selection of drivers in DCs.

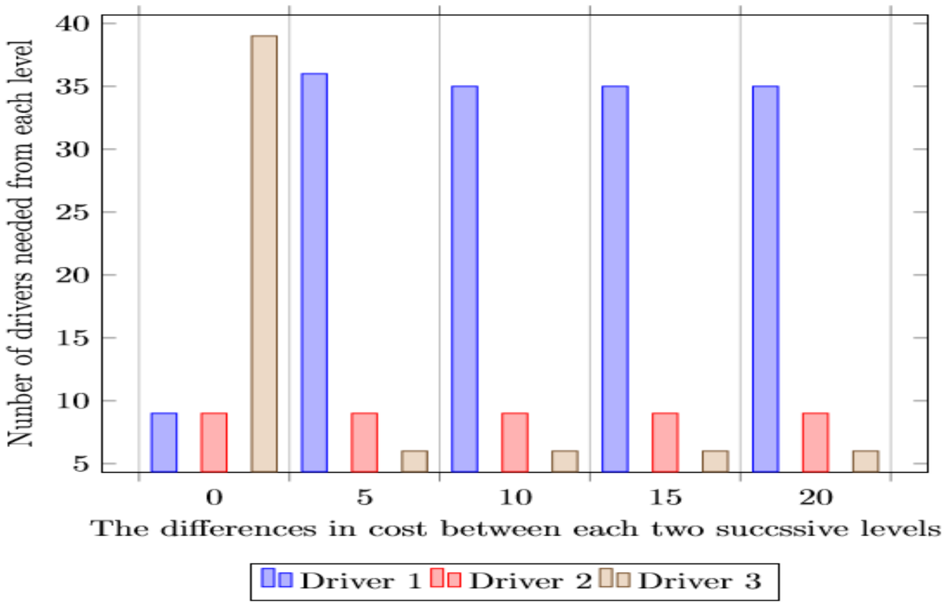

Figure 5.5: the effect of differences in cost between drivers levels on the selection of drivers at DC 1.

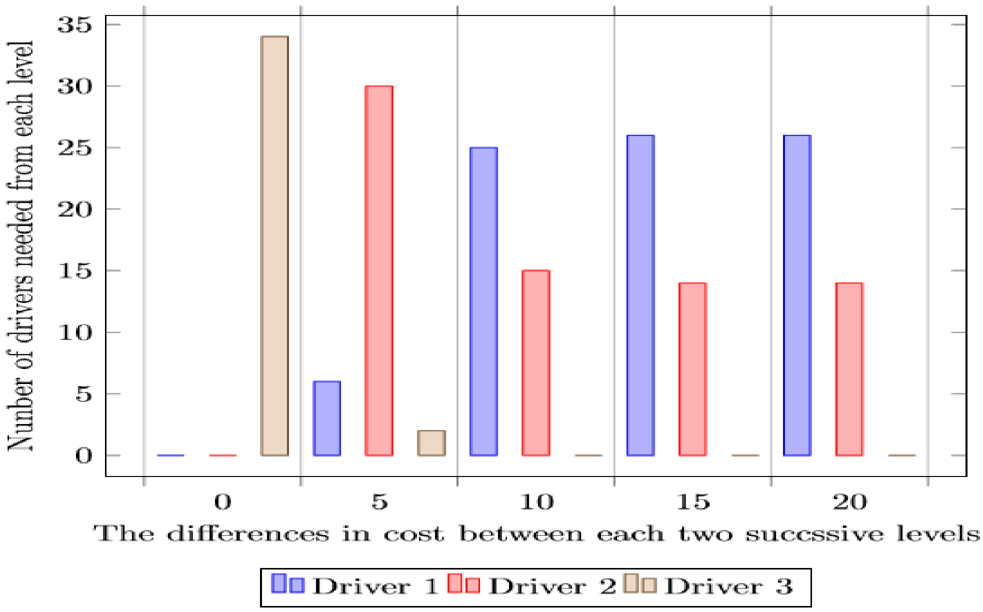

Figure 5.6: the effect of differences in cost between drivers levels on the selection of drivers at DC 2.

5.5 summary

This chapter presented the sensitivity analysis on the numerical parameters that used in solving the proposed model. We first conduct a sensitivity analysis on the GHG emission level and its effect on the total cost across the supply chain. The results showed that, as the allowable GHG emission level decreases the total cost increases. Second, we conduct a sensitivity analysis on the GHG emission level and its effect on the selection of drivers. The results showed that, when the GHG emission level becomes tighter, the need to high level drivers is increased. This emphasizes on the important of drivers in adopting the green strategies and to help organizations to comply with the allowable GHG emission level. Third, we conduct a sensitivity analysis on the distances between nodes in supply chain and its effect on the selection of drivers. The results indicated that, whenever the distances become longer, the need to high level drivers has increased. Finally, the sensitivity analysis was conducted on the difference in cost between the levels of drivers. This analysis was conducted with GHG emission level considers to be high according to the presented problem (i.e. 1000, 800, and 600 Kg CO_2 emission/ period), so the model tries to trade-off between the cost of drivers and their effect on fuel consumption (Variable costs).

Chapter Six

Conclusions and Recommendations

Chapter Six

Conclusions and Recommendations

6.1 Summary

In this research, a novel approach for incorporating drivers' differences with aggregate production planning in a green supply chain management is proposed. Some characteristics of the proposed model are as the following: (1) considering the major cost parameters of supply chain such as transportation, inventory, purchasing and human related costs; (2) considering the green concepts in transportation issues; (3) considering drivers' levels in terms of green driving index (GDI) with different effect on fuel consumption and CO_2 emission, different salaries (a sort of motivation), hiring and firing costs, and possibility of drivers' training and upgrading; (4) considering the types of vehicles used in transportation with different capacities, cost, and different effect on environment; (5) considering the assignment between drivers and vehicles.

The proposed model was formulated as mixed integer nonlinear programming and then converted to a linear one. The model formulation and description was presented that include the model's assumptions, sets, parameters, decision variables, objective function components and constraints. And then a hypothetical numerical study was conducted and solved using Matlab 2015a to demonstrate the validity, applicability and solvability of the developed model. The results of this study were presented and discussed such that the quantities to be shipped from suppliers to DCs and from DCs to retailers, the workforce plan for workers and drivers, number and type of vehicles should be used, the assignment between drivers, vehicles and then to the destinations (retail stores). In addition, the sensitivity analysis was conducted on the GHG emissions level, the distances between DCs and retailers, and the differences in cost between drivers. The results of conducting sensitivity analysis demonstrate that, after considering green issues (reducing the allowable GHG emissions level) the total cost across the supply chain was increased. And the number of drivers for each level varies with different GHG emission level, so the CO_2 emission level that the company wants to achieve depends on the level of drivers' available. Also the assignments between vehicles and drivers varies with different GHG emission level and different distances.

The results of this study are important in a number of aspects. Foremost among these, the proposed model in this thesis conducted numerous assignment matrices to ensure that each driver will be assigned to one vehicle and one retail store, and each vehicle will be assigned to one driver and one retail store. So the effect of each combination between vehicles and drivers on fuel consumption and CO_2 emissions will be computed by taking into account the distances. So the proposed model will try to conduct an optimally assigning between vehicles, drivers and the destination (i.e. retail stores) to reduce the CO_2 emission, fuel consumption and the total shipping cost across the supply chain with taking into account the differences impact of drivers and vehicles on CO_2 emission and fuel consumption as well as on the total cost.

6.2 Contribution

This research contributes to the literature with a more realistic model that takes drives selecting, training, motivating and assigning to vehicles into account in managing and planning supply chain at tactical and operational levels. In contrast to previous researches that have completely ignored the differences between drivers in design and managing GSC. This approach allow us to address integrating drivers' differences (in term of GDI) to determine the best scenario for selecting, training and assigning drivers to fulfill a company's aims for reducing their fuel consumption and CO_2 emission in their supply chains. The results showed that the level of carbon dioxide emissions that the company's willing to achieve depends heavily on the level of available drivers have and on how to select, train and assign those drivers. Therefore, this research provides decision-makers with more realistic model. This model will support the company's management with a sufficient knowledge about how to achieve a desired level of CO_2 emission by considering drivers', vehicles', and distances' effect, and on the other hand minimizing the total cost incurred across the supply chain. Implementing green supply chain is a human responsibility and without considering human aspects the truly implementing of GSCM cannot be achieved.

6.3 Limitations and Future Recommendations

In spite of the model's strengths, the proposed model has a number of limitations that can make the results unrealistic. These limitations and the proposed recommendations can be described as follows:

- Although the model gives logical results, it is relied on hypothetical data represents the researchers' experience in addition to data derived from the related literature, such that the drivers' performance parameters. Evaluating drivers' performance based on fairly performance evaluation methodology such as the methodology that developed by Liimatainen (2011) he integrated incentive system based on fairly performance evaluation of the drivers. Also, integrating qualitative method such as AHP, fuzzy logic and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) in selecting drivers based on green criteria (i.e. experiences, Eco-driving training, ages, personalities, awareness and education; may be each driver has a profile include the average of fuel consumption per km) may give more realistic output.
- All parameters in the developed model are assumed to be deterministic and known such as that all cost parameters, lead time and drivers' performance. Solving the model using stochastic approach may give a more robust results.

6.4 Future Works

It is evident that the research of GSCM did not reach the end, and the opportunity is still exist to develop the proposed model to become more comprehensive and realistic. The proposals for future research can be described as follows:

- Implementing the proposed model by using real cases which is one of the promoting future work, to demonstrate the importance of integrating drivers' differences in improving the supply chain's ecological and economic performance.
- Integrating other factors that may affect fuel consumption and CO_2 emission such as vehicles weight with considering weight of the products and route selection by modeling the relation between vehicle's weight or route condition, fuel consumption and CO_2 emission are promising areas for future research.
- Considering other gases emission such as CO, NOx, etc.
- Integrating other green issues in GSC optimization model such as green design (designing the product based on its environmental impact by integrating Life Cycle assessment (LCA) of the products).
- Integrating other human aspects such as the effect of human factors in the process of designing and producing the green products. And demonstrate the need to green training and selection of the employees.

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جامعة النجاح الوطنية
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نماذج الأمثلة في أدارة سلاسل الأمداد الخضراء

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قدمت هذه الأطروحة أستكمالا لمتطلبات الحصول على درجة الماجتسير في الادارة الهندسية بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين

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الملخص

لقد حظيت سلاسل الامداد الخضراء على اهتمام كبير من الباحثين في العقود القليلة الماضية، ولكن تم تجاهل تأثير العوامل البشرية في تصميم وأدارة السلاسل الخضراء. في هذا البحث، نحن نطور نهجا جديدا لدمج اختلافات السائقين لدراسة تأثيرهم على استهلاك الوقود وانبعاثات ثاني اكسيد الكربون في امثلة سلاسل الامداد الخضراء على المستوى التكتيكي و التشغيلي. و بشكل اكثر تحديدا، تم اقتراح نموذج برمجي غير خطي مختلط من المتغيرات الصحيحة وغير الصحيحة ليتعامل مع تخطيط الانتاج التجميعي مع مراعاة اختلاف المستويات بين السائقين و اختلاف انواع المركبات. يهدف النموذج لتقليل التكلفة الكلية و انبعاثات غاز ثاني اكسيد الكربون عبر سلسلة التوريد. بالاضافة الى ذلك، يهدف النموذج لاستنباط التعيين الأمثل بين السائقين والمركبات و الوجهات، فضلا عن الاختيار و التدريب الامثل للسائقين. تم اجراء دراسة عددية للتأكد من صلاحية النموذج المقترح و قابليته للتطبيق. و أظهرت نتائج تحليل الحساسيه،أنه وبعد أعتبار القضايا الخضراء فأن التكلفة الاجمالية عبر سلسلة التوريد تزداد. و عدد السائقين المطلوبين من كل مستوى يختلف باختلاف مستوى ثاني اكسيد الكربون المسموح به. لذلك فان مستوى انبعاثات ثاني أكسيد الكربون التي تسعى الشركات لتحقيقه يعتمد على مستوى السائقين المتوفر لديها. وكذلك التعيينات بين السائقين والمركبات تختلف باختلاف مستوى ثاني اكسيد الكربون واختلاف المسافات بين مرافق سلسة الامداد.