Green supply chain planning considering consumer's transportation process

Jingzhe Gao, Zhongdong Xiao*, Binbin Cao, Qiangfei Chai

School of Management, Xi'an Jiaotong University, No. 28 Xianning Road, Xi'an, Shaanxi 710049, China

A B S T R A C T

This article addresses a product delivery and store network layout strategy problem considering not only firms' but also consumers' cost. The study presents several mathematical programming models to minimize the cost or maximize the profit. Then, we design a two-step solution method for exact solutions and present an implementation. The results show that a carbon cap will do more good than harm for the environment. Trying to minimize the cost from both sides will not only improve the efficiency of social resource use but also enable stores to attract more consumers. Limiting emissions for firms will result in significant emissions reduction without an excessive cost increase.

1. Introduction

In the 21st century, many countries have begun to pay more attention to environmental issues and have developed their national development strategies based on a low-carbon economy. In 2003, the UK government put forward the low-carbon economy for the first time with the purpose of developing an economy with low energy consumption, low pollution and low emissions as basic features (Britain, 2003). Many countries have enacted laws or adopted measures, such as carbon taxes, carbon caps and trading mechanisms, to reduce carbon emissions from production and transportation. For firms, increased consumer awareness of the environment makes it imperative to develop strategies to reduce carbon emissions from production operations. Particularly in China, because of its complex road conditions, great market demand and frequent manufacturer replenishment, the logistics industry consumes much energy and produces substantial carbon emissions. Therefore, it is necessary to reduce the carbon emissions from the logistics process and improve the efficiency of energy use (Xiao et al., 2015).

Currently, the urban environment in many countries is deteriorating, and people are facing challenges of unsustainable development (Gracht and Darkow, 2016). Most of the current emission reduction measures affect the carbon emissions from production processes. Even if these policies are very effective, we cannot ignore the emissions from the supply chain. Some firm decisions, such as facility location and transportation mode selection, can significantly influence their carbon footprint. Therefore, it is important to consider emission reduction issues in supply chains (SC) and logistics systems (Choudhary et al., 2015). In addition, increasing numbers of consumers are concerned about the emissions associated with the products they buy. These include emissions from the production process, supply chain and logistics. The environmental aspect is important for consumers when considering stores, as consumers can gain psychological benefits and become willing to pay for the products if they are produced in an environmentally friendly way (Sheu, 2014). Logistics network design models typically focus on minimizing fixed and variable costs in SC. Practice and research in green supply chain management (GSCM) is becoming a hot topic (Baud-Lavigne et al., 2014, Brandenburg, 2015, Fahimnia et al., 2015a,b,c). Most of the research seeks to build an effective system that allows companies to take the initiative to

---

* Corresponding author.
E-mail addresses: gaojingzhe@stu.xjtu.edu.cn (J. Gao), xzd@mail.xjtu.edu.cn (Z. Xiao), caobinbin89@stu.xjtu.edu.cn (B. Cao), qiangfei@stu.xjtu.edu.cn (Q. Chai).

reduce their own carbon footprint. However, more than 65% of the carbon emissions generated during transport are derived from the consumption of gasoline in private cars (EPA, 2012). Hence, when we study low-carbon logistics management, the emissions from consumers are non-ignorable.

Generally, when consumers consider a purchase, they pay attention to the quality, price and convenience of getting the product. This article considers logistics. Therefore, we assume the quality of the product is intrinsic. We focus on the product price and buying convenience. Consumers view convenience as the time they spend and the cost they must bear to go shopping. Therefore, we use consumers' transportation cost to represent convenience. However, increasing consumer awareness of the environment makes the emissions associated with the product an attractive point. These kinds of emissions are generated from the production process and supply chain process. While we do not study the production process, the latter processes are important to us. For firms, factors of a supply chain network that influence emissions include not only fuel efficiency and facility location but also the distance traveled and the weight carried. As the density of stores increases, a denser network is created in the market area, and the average distance between consumers and stores decreases, such that they need not travel far to shop (Glaeser, 2011, Owen, 2010). In contrast, the firm must travel farther to replenish its stores. Under normal circumstances, firms' decision makers aim to minimize the total supply chain cost to gain more profits, and government usually imposes a carbon threshold policy on enterprises. However, if managers want to attract more consumers by tactical supply chain decision making such as delivery schemes and store density, they should enhance the store's appeal to consumers in market areas. Making the purchasing process more convenient can attract more consumers because the consumers' transportation cost is reduced. Controlling firms' logistic emissions can also gain the goodwill of environmentalists and encourage them to buy from the concerned stores. This research proposes four models to consider whether the firm takes account of consumers' transportation cost and whether the carbon cap is necessary. Then, we compare the results obtained using CPLEX software and draw some conclusions. We also propose another model to study firms' profit maximizing decision.

The remainder of the paper is composed of the following sections. Section 2 systematically reviews the related literature and previous models to build a foundation for the presented research and clarifies the paper's position and relative contribution to the literature. In Section 3, we present a series of mathematical programming models. Section 4 presents real case data and designs a solution method based on the reality of the problem for the computational experiments. Then, it provides a discussion of the results from the above four models and we come up with a profit maximizing model including some omitted details. Section 5 discusses the managerial implications of the paper. Section 6 concludes this research with a note for future research directions.

2. Foundational literature background

GSCM has been the subject of much recent study (Brandenburg et al., 2014, Sarkar et al., 2016, Yu et al., 2014). GSCM is the integration of environmental thinking into supply chain management; it covers everything from production to recycling and requires a high level of research and detailed planning (Beamon, 1999, Hafezalkotob, 2017, Sheu and Talley, 2011, Chin et al., 2015). Zhu (2004) assessed the relationship between GSCM practices and environmental and economic performance.

Detailed overviews of GSCM and low carbon logistics with their solution techniques are presented in Fahimnia et al. (2015a,b,c), Malviya and Kant (2015), Varsei (2016) and Singh et al. (2016). Dekker et al. (2012) reviewed operational management issues that consider carbon emissions and other environmental factors. They outlined present and future developments, particularly in planning, design and control for inventory, transportation and facility decisions in a supply chain.

For inventory optimization and decisions, Chen and Monahan (2010) analyzed the impacts of different environment policies on firms' decisions of production basing on a stochastic model. They proposed an additional planned stock level called an "environmental safety stock" that firms could reserve as a voluntary control approach. Cheng et al. (2017) solved a green inventory routing problem involving a heterogeneous fleet and constructed a mixed-integer program. They found that a high carbon price does not necessarily imply benefit to the environment, which can provide reference to governments when implementing carbon policies. Rahimi et al. (2017) presented a multi-objective mathematical framework that considers the environmental footprint to address uncertainty by introducing fuzzy distributions. They showed that there are some negative economic impacts when service level objects are exogenous.

For transportation decisions, Hoen et al. (2014) examined the trade-offs between transportation costs and lead times under the influence of carbon policies when selecting a transport mode. They found that even though great emission reductions can be achieved by switching to an optimal mode, the firm's decision depends on non-monetary and regulatory considerations. Xiao and Konak (2016) proposed a model that allows vehicles to stop on arcs and could reduce emissions up to an additional 8% on simulated data. They also designed a hybrid algorithm to solve the mixed integer linear programming problem. Chen and Wang (2016) studied transportation mode selection and retailers' ordering problems with stochastic customer demand and investigated the optimal transport mode selection and ordering decisions under different emission reduction policies. Their analytical results verified that there are thresholds for transport mode shifts under different emissions reduction policies. Wang et al. (2017) investigated an optimization of the vehicle routing problem considering time windows for cold-chain logistics with a carbon tax in China. The authors designed a cycle evolutionary genetic algorithm to solve the problem, and the results provided implications that are relevant not only for the government in considering carbon tax policy but also for companies in controlling emissions from distribution. Sheu and Kundu (2017) addressed the dynamic and stochastic challenges with a multi-methodological approach that is the basis of international logistic network reconfiguration. Although their method did not consider a green supply chain, it is still useful for the study of a low-carbon logistics network. Song et al. (2017) built a two-stage stochastic model to study the capacity expansion problem under cap-and-trade and carbon tax policies in logistics. They argued that the carbon tax has different impacts on optimal capacity expansion decisions, and the volatility of capacity investment cost can strongly affect optimal capacity expansion.