

Low-carbon city logistics distribution network design with resource deployment



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ABSTRACT

The Chinese government has now published its emission reduction goal of carbon dioxide by 2020 and any industrial player is obliged to take effective initiatives to decrease its carbon footprint. For the city logistics distribution system, as a significant energy-consuming and pollutant-emitting sector, energy saving and emission reduction are very meaningful especially for megacities like Beijing. With rational hypotheses and parameter design, meanwhile considering the deployment of low-carbon resources, a novel carbon tax-constrained city logistics distribution network planning model is proposed. The model is a bilinear non-convex mixed integer programming and is reduced to a pure linear mixed integer programming through proper linearization. To verify the effectiveness of the model, an empirical study is conducted on a city logistics operator in Beijing and the popular commercial optimization suite IBM ILOG CPLEX is adopted for optimization purpose. Through analysis of the optimization results and comparison with traditional optimization models, it is found that the proposed model can help the city logistics distribution operator save up to 9.2% of operational cost during a full service cycle, and meanwhile cut down its carbon dioxide discharge by around 54.5% or 2135 metric tons at most.

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1. Introduction

Wide consensus has been reached that greenhouse gases (GHG) emissions cause dramatic changes to the earth's climate system. The Chinese Government has declared its carbon emission reduction goal until 2020, when carbon dioxide discharge per unit of GDP growth will be decreased by 40–45% compared to 2005 (State Council Office Announcement, 2009). Increasing environmental consciousness of citizens requires the government to issue more stringent legislations so as to urge firms to take various effective initiatives. Carbon tax is deemed to be one policy of highest market efficiency (Baranzini et al., 2000).

China is expediting its urbanization accompanied with huge inflow of population and energy demands. Urban environment is deteriorating in many cities and they are all facing challenges of unsustainable development (Fei et al., 2013; Christine et al., 2012; Dhakal, 2009). As huge energy consumers and pollutant emitters, cities should play a key role in controlling the world GHG emissions (Granberg and Elander, 2007). In recent years, city logistics distribution sector develops rapidly particularly in large cities in China

due to strong supports from all levels of government. Despite its huge roles in promoting local economies, resolving employment and improving city's comprehensive competitiveness (Weika and Shouwen, 2008), its external diseconomy (Kennedy et al., 2010; Susan and Kumar, 2009; Teodor, 2000; Zhe, 2011) has been put in spot light of municipal managers and residents, such as emissions of pollutants, including carbon dioxide, intensive energy and resource consumption, etc.

In this article, we will study how to control carbon emissions from a new perspective of purely operations researches. A bi-level city logistics distribution network is formulated with some high carbon-efficient facilities to be allocated onto various distribution centers. Under the forthcoming carbon tax policy in China, we model the problem with the minimum operational cost as its goal, in which carbon tax cost is also integrated. Due to the medium scale of the problem, we use IBM CPLEX as core solver as the optimization tool. Result analysis shows that the proposed model in this article is very effective in reducing carbon emissions at much lower cost compared to others without effective carbon management. Some policy suggestions and conclusions are given finally.

2. Literature review

Recently, the continuous foggy days and high PM2.5 concentration in Beijing as well as some other regions within China have

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drawn worldwide attentions. It still has a long way to fulfill the goal of Green Beijing. City logistics sector, as a fresh pillar industry of Beijing, is receiving great supports from the municipal government of Beijing. However, Beijing is also becoming more congested and highly energy-intensive. Thankfully, the quickly growing public concerns have already become much powerful to push forward the government's legislations of carbon intensity evaluation and reduction (Fei et al., 2013). From perspectives of no matter city logistics operators or city management, most initiatives to reduce carbon reduction are focused on utilization of physical processes. Yet from viewpoint of operations research, quite a few works have paid attentions to operational strategies or tactics which may lead to most part of carbon dioxide. Given environmental constraints or carbon emissions limits, these works redesign their supply chain network strategically or tactically to ensure long-term sustainability of their operations.

Closed-loop supply chain, including forward logistics and reverse logistics network designs, is an option to be considered in designing a more environmental-friendly production or service system (Lieckens and Vandaele, 2007; Özkır and Başlıgil, 2013; Fleischmann et al., 2000; Guide et al., 2003; Schultmann et al., 2006; Pistikopoulos and Hugo, 2005). Sustainable supply chain design is a fresh field in response to integrate economic, environmental and societal decisions at the stage of supply chain design (Frota Neto et al., 2008; Seuring and Muller, 2008). Susan and Kumar (2009) finds that configurations of logistics distribution network have vital influences on its carbon efficiency and intensity. Although some literature does not explicitly refer to green or sustainable supply chains, in their mathematical formulations, environmental impacts of logistics activities have actually been taken into account. For example, Nagurney et al. (2006) formulates a supply chain in which manufacturers can produce homogenous products at various sites with different environmental emissions. Subramanian et al. (2008) introduces a non-linear programming model, incorporating traditional operation planning decisions with environmental considerations.

It could also be found that much limited attentions are also explicitly discussing green or sustainable supply chain designs under carbon emission background. Ramudhin et al. (2010) proposes a supply chain strategic planning model under carbon trading market scheme. Test conducted in a real case within aluminum sector shows that effective carbon management is of great importance in designing firm's sustainable supply chains. Benjaafar et al. (2011) studies the way to associate carbon emission parameters with various decision variables and shows how the traditional models should be modified to consider the cost of carbon dioxide. Their concepts are materialized in a multi-period EOQ model and displays how to control the total cost through simple adjustments to order quantities in each period, meanwhile reduce the carbon emissions tremendously. Chaabane et al. (2013) considers a supply chain design problem under carbon trading scheme. A mixed integer model is established and tested on a small-scale case. Lindo software is used to solve the model. In the above three works, carbon emission is assumed to be linearly proportional to decision variables due to insufficient statistics and difficulties in collecting carbon emission data. No literature is found to study the city logistics network design with consideration of high carbon-efficient resource deployment problem under low-carbon economy. Even some related papers touch on green supply chain network design, verification of their models are oversimplified at small-scale experiments. Furthermore, current studies lack detailed analyses to the actual optimization results of their models and therefore, corresponding suggestions to policy makers or logistics operators are seldom proposed to conclude their studies. In this article, a dual-level city

logistics distribution network, made up of logistics centers, distribution centers and retail terminals, is discussed. Not limited to traditional facility location-allocation problems on the network, both the capacity design and low-carbon resource deployment are considered. A more comprehensive non-linear mixed integer programming model is set up. Measures, both at strategic and tactic levels, to be taken by logistics operators to minimize its total operational cost under varying carbon tax rates are addressed. Some suggestions are finally put forward for city planners and industrial players.

3. Problem description and formulation

This section describes the specific problem and its mathematical model. In a city, demands of chain stores or E-businesses are mostly met through city logistics distribution operators. Usually, it is undertaken by the third-party logistics providers (3PLs), which are responsible for goods delivery services from several large retailers. 3PLs collect goods from logistics centers (LCs) located in suburban areas of the city, and then transport them to selected distribution centers (DCs) for further processing procedures (storage, packaging, encoding, cutting, dismantling, combing, loading and unloading, etc), and finally, these goods are distributed to widely distributed sales terminals (STs) of the distribution network. The work flow chart of the 3PLs is described in Fig. 1. Some already-known parameters include locations and goods supplies of LCs, independent demands and locations of numerous STs and candidate sites used for the construction (or leases) of DCs. The objective is to select fixed number of sites for DCs' construction and design their individual throughput. Due to capital expenditure restrictions, only few DCs will be equipped with higher carbon efficient facilities (such as expensive equipment consuming liquid natural gas as fuel or more complex physical structures in design DCs with higher carbon utilization rates). Moreover, like common facility-location problems, we need to decide how much goods from which DCs should be delivered to which STs and to which LCs each DC should to be allocated. Meanwhile, considering the upcoming carbon tax policies in China, which will result in fresh cost pressures to this 3PLs, the cost of carbon emissions should be considered. The final goal is the total operational costs to be minimized.

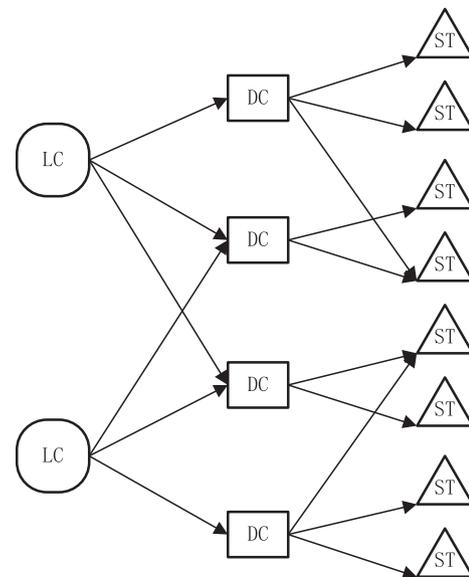


Fig. 1. Work flow chart of the 3PLs

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