Research on model of city logistics network and Effects of different carbon policies

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Abstract
A programming model for a four-layer urban logistics distribution network is constructed and revised under three types of carbon emissions policies such as Carbon tax, carbon emissions Cap, Carbon Trade. Effects of different policies on logistics costs and carbon emissions is our future research work.

Key words: low-carbon policy, city logistics, carbon emissions

Introduction

There is growing consensus about urban logistics because it involves environmental pollution, traffic jams and traffic accidents which are three most prominent problem of the city. The most difficult problem to solve is environmental pollution. Recent empirical studies estimate that urban freight vehicles account for 6 to 18% of total urban travel (Figliozzi,2010)and 21% of CO_2 emissions(Schoemaker et al.2006). Governments are under growing pressure to enact legislation to curb the amount of these emissions, such as Carbon Tax, Emission Cap, Carbon Trade and so on. In order to predict the effectiveness of a carbon policy and to decide the right parameters for the policy, it is important to understand the response of freight shippers to carbon policies. A carbon policy's impact on a company may include the redesign of its logistics network, different choices of transportation modes, and better logistics management (Mingzhou Jin et al, 2013).

This paper will investigate the impact of the three most common carbon policies on the city logistics distribution, also including the design of the city logistics network. Optimization models are proposed for the decision making of the city logistics under various carbon policies.

The remainder of the paper is organized as follows. Section 2 states a literature review. Section 3 provides the urban logistics network structure and the optimization formulations of designing the logistics network for a retailer under various carbon policies. Section 4 ends with conclusions and provides future research directions.

Literature review

The literature review for this paper covers two main areas of research: the research on city logistics network design and study of carbon policies. City logistics distribution is mainly refers to the logistics activities in the city. The ideal mode is most of the goods transported into the logistics park first, then dispatched to the logistics center according to the logistics information, and transferred to the distribution center through the centralized storage, finally distributed to retailers by the distribution center.

There are several studies focusing on the impact of carbon policies on the logistics distribution. Ming Zhou Jin et al.(2013) studied the impact of carbon policies on supply chain design and logistics of a major retailer, they showed that different policies have different impacts on the costs and the effectiveness of emission reduction.

Hoen et al.(2014) proposed optimization model including transportation costs and emission costs, studied the results for different types of emission regulation, and found that even though large emission reductions can be obtained by switching to a different transport mode, the actual decision depends on the regulation and non-monetary considerations. Benjaafar et al. (2013) designed optimization models for supply chain operational decision making under several carbon policies: strict carbon caps, carbon tax, carbon cap-and-trade, and carbon offsets. Roumboutsos et al (2014) introduces a methodology based on the Systems of Innovation approach to examine the process by which electric vehicles may be introduced in city logistics. Yang et al (2014) developed a model with the minimum operational cost as the goal in which carbon tax cost was also integrated, and a bi-level city logistics distribution network was formulated with some high carbon-efficient facilities to be allocated onto various distribution centers. Guy et al (2014) analyzed Telematics, urban freight logistics and low carbon road networks. Their findings showed that the topology of urban street patterns interacts strongly with the level of telematics and the route guidance. Diabat and Simichi-Levi (2010) formulated a mixed-integer program for a company to design their optimal supply chain network while meeting their carbon cap. Their model focused on the impact of one carbon policy and did not consider transport vehicle type choice. In this paper, we design a four-layer urban logistics distribution network and introduce programming models under three carbon policies: carbon tax, carbon emissions cap and carbon trade.

Optimization models for the urban logistics distribution network design under various carbon policies

The urban logistics distribution network is formed by four layers: a set of logistics bases(LBs), a set of logistics centers(LCs), a set of distribution centers(DCs),and a set of a set of retailers, illustrated in Fig.1. The problem is to study how the specifics of carbon policies would affect the costs and emissions of various firms.

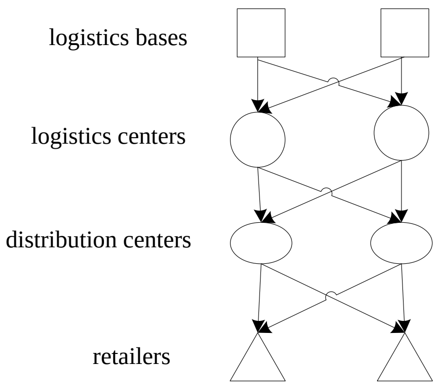

Fig.1. the structure of urban logistics distribution network

We make some assumptions as follows:

(i)The position and capability of LBs,LCs,DCs and the demanded quantity of retailers are known. The position is fixed permanently for a long time.

(ii)The goal of urban logistics distribution is minimum distribution cost integrated with carbon emission cost.

(iii) Distribution costs and the amount of carbon emissions are linear proportional to the distance and volume. They are only based on the traveled distance between facilities.

To formulate the problem, the following notations is used:

I :The number of logistics bases, indexed by *i*;

J :The number of logistics centers, indexed by *j*;

K :The number of distribution centers, indexed by *k*;

M :The number of retailers, indexed by *m*;

A_i :The capacity of logistics bases;

B_j : The capacity of logistics centers;

C_k : The capacity of distribution centers;

N :set of vehicle type.

x_{ij}^{n} : The amount in tons shipped from logistics base *i* to logistics center *j* with vehicle type *n*.

b_{ij}^{n} :Cost of shipping one ton from logistics base *i* to logistics center *j* per kilometer with vehicle type *n*.

y_{jk}^{n} :The amount in tons shipped from logistics center *j* to distribution center *k* with vehicle type *n*.

b_{jk}^{n} :Cost of shipping one ton from logistics center *j* to distribution center *k* per kilometer with vehicle type *n*.

z_{km}^{n} :The amount in tons shipped from distribution center *k* to retailer *m* with vehicle type *n*.

c_{km}^{n} : Cost of shipping one ton from distribution center *k* to retailer *m* per kilometer with vehicle type *n*.

d_m :The daily demand in tonnage at retailer *m*;

e_{ij}^{n} :Carbon emission in kilograms (kg) of shipping one ton from logistics base *i* to logistics center *j* with vehicle type *n*.

e_{jk}^{n} :Carbon emission in kilograms (kg) of shipping one ton from logistics center *j* to distribution center *k* with vehicle type *n*.

e_{km}^{n} :Carbon emission in kilograms (kg) of shipping one ton from distribution center *k* to retailer *m* with vehicle type *n*.

l_{ij} :Distance from logistics base *i* to logistics center *j*;

l_{jk} : Distance from logistics center *j* to distribution center *k*;

l_{km} : Distance from distribution center *k* to retailer *m*.

Basic Model

In the following Model, there is no carbon policy so that the retailer considers logistics cost and carbon emissions in the transportation.

Model I:

$$\min \sum_{i=1}^{I}\sum_{n=1}^{N}\sum_{j=1}^{J} x_{ij}^{n} a_{ij}^{n} l_{ij} + \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{k=1}^{K} y_{jk}^{n} b_{jk}^{n} l_{jk} + \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{m=1}^{M} z_{km}^{n} c_{km}^{n} l_{km} \tag{1}$$

$$\min \sum_{n=1}^{N}\sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij}^{n} e_{ij}^{n} l_{ij} + \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{k=1}^{K} y_{jk}^{n} e_{jk}^{n} l_{jk} + \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{m=1}^{M} z_{km}^{n} e_{km}^{n} l_{km} \tag{2}$$

s.t.

$$\sum_{k=1}^{K}\sum_{n=1}^{N} z_{km}^{n} = d_m \tag{3}$$

$$\sum_{j=1}^{J}\sum_{n=1}^{N} x_{ij}^{n} \le A_i \tag{4}$$

$$\sum_{k=1}^{K}\sum_{n=1}^{N} y_{jk}^{n} \le B_j \tag{5}$$

$$\sum_{m=1}^{M}\sum_{n=1}^{N} z_{km}^{n} \le C_k \tag{6}$$

$$\sum_{j=1}^{J}\sum_{n=1}^{N} x_{ij}^{n} = \sum_{k=1}^{K}\sum_{n=1}^{N} y_{jk}^{n} = \sum_{m=1}^{M}\sum_{n=1}^{N} z_{km}^{n} \tag{7}$$

$$x_{ij}^{n}, y_{jk}^{n}, z_{km}^{n} \ge 0 \tag{8}$$

The objective function equation (1) minimizes the sum of the distribution costs. equation (2) minimizes the carbon emissions. Constraint set (3) ensures that the demand of each retailer is satisfied. Constraint set (4)-(6) represent the capacity restriction of every layer. Constraint set(7) keeps the flow conservation at every layer.

Model under Carbon Tax

A Carbon Tax is an effective means of reducing carbon emissions,which considers as the tax on CO_2 emissions.Suppose a carbon tax with the rate of *t* dollars per kg of CO_2, we modify the objective function (1)and(2)into (9) as follows:

Model II:

$$\begin{aligned}
\min &\sum_{i}^{I}\sum_{j}^{J}\sum_{n}^{N} x_{ij}^{n} a_{ij}^{n} l_{ij} + \sum_{j}^{J}\sum_{k}^{K}\sum_{n}^{N} y_{jk}^{n} b_{jk}^{n} l_{jk} + \sum_{k}^{K}\sum_{m}^{M}\sum_{n}^{N} z_{km}^{n} c_{km}^{n} l_{km} + \sum_{i}^{I}\sum_{j}^{J}\sum_{n}^{N} t x_{ij}^{n} e_{ij}^{n} l_{ij} \\
&+ \sum_{j}^{J}\sum_{k}^{K}\sum_{n}^{N} t y_{jk}^{n} e_{jk}^{n} l_{jk} + \sum_{k}^{K}\sum_{m}^{M}\sum_{n}^{N} t z_{km}^{n} e_{km}^{n} l_{km} \\
= &\sum_{i}^{I}\sum_{j}^{J}\sum_{n}^{N} x_{ij}^{n} u_{ij}^{n} l_{ij} + \sum_{j}^{J}\sum_{k}^{K}\sum_{n}^{N} y_{jk}^{n} u_{jk}^{n} l_{jk} + \sum_{k}^{K}\sum_{m}^{M}\sum_{n}^{N} z_{km}^{n} u_{km}^{n} l_{km}
\end{aligned} \tag{9}$$

Here $u_{ij}^{n} = a_{ij}^{n} + t e_{ij}^{n}$, $u_{jk}^{n} = b_{jk}^{n} + t e_{jk}^{n}$, $u_{km}^{n} = c_{km}^{n} + t e_{km}^{n}$.

The objective function (9) together with constraint sets(3)-(8). The objective function equation (9) minimizes the model when a carbon tax is charged. Carbon Tax Model is similar to Model I except considering carbon emission costs.

Model under Carbon Cap

A carbon cap is another popular means of controlling emissions. E(in kg) is the carbon cap of the retailer. Carbon Cap Model as follows:

Model III:

$$\min \sum_{i}^{I}\sum_{j}^{J}\sum_{n}^{N} x_{ij}^{n} a_{ij}^{n} l_{ij} + \sum_{j}^{J}\sum_{k}^{K}\sum_{n}^{N} y_{jk}^{n} b_{jk}^{n} l_{jk} + \sum_{k}^{K}\sum_{m}^{M}\sum_{n}^{N} z_{km}^{n} c_{km}^{n} l_{km} \tag{10}$$

s.t.

$$\sum_{i}^{I}\sum_{j}^{J}\sum_{n}^{N} tx_{ij}^{n} e_{ij}^{n} l_{ij} + \sum_{j}^{J}\sum_{k}^{K}\sum_{n}^{N} ty_{jk}^{n} e_{jk}^{n} l_{jk} + \sum_{k}^{K}\sum_{m}^{M}\sum_{n}^{N} tz_{km}^{n} e_{km}^{n} l_{km} \le E \tag{11}$$

The Carbon Cap Model is a minimum network cost problem with constraint sets(3)-(8). Constraint(11) is carbon emissions in the transport process. logistics activities should be carried out within the prescribed limit carbon emissions.

Model under Carbon Trade

Carbon Trade is a market mechanism for various industries. They will be included in a carbon trade market and can meet the carbon cap by selling or buying carbon quote. b^{+} (b^{-})is the amount of carbon in kg sold (or bought) in a carbon trade market. p is the carbon selling (buying) price per kg in the carbon market. The objective function of the Carbon Market Model becomes (12).

Model IV:

$$\min \sum_{i}^{I}\sum_{j}^{J}\sum_{n}^{N} x_{ij}^{n} a_{ij}^{n} l_{ij} + \sum_{j}^{J}\sum_{k}^{K}\sum_{n}^{N} y_{jk}^{n} b_{jk}^{n} l_{jk} + \sum_{k}^{K}\sum_{m}^{M}\sum_{n}^{N} z_{km}^{n} c_{km}^{n} l_{km} - pb^{+} + pb^{-} \tag{12}$$

s.t

$$\sum_{i}^{I}\sum_{j}^{J}\sum_{n}^{N} tx_{ij}^{n} e_{ij}^{n} l_{ij} + \sum_{j}^{J}\sum_{k}^{K}\sum_{n}^{N} ty_{jk}^{n} e_{jk}^{n} l_{jk} + \sum_{k}^{K}\sum_{m}^{M}\sum_{n}^{N} tz_{km}^{n} e_{km}^{n} l_{km} = E - b^{+} + b^{-} \tag{13}$$

The objective function (12) together with constraint sets (3)-(8). The objective function equation (9) minimizes the model when the carbon is sold (or bought). Constraint (13) presents a certain quantity of the carbon is sold (or bought) when the carbon emission is less (greater) than E. $p(b^{-} - b^{+})$ is the cost of the carbon trade.

Conclusion and future research

In this paper, we introduced a four-layer urban logistics distribution network problem with a carbon emission constraint. Three relevant models are proposed under carbon policies. Our future work is to find practical applications of these models. Referencing the space layout of Beijing's logistics infrastructure ,we preliminary design the example of a supermarket logistics distribution system and will be conducted to better understand how various carbon emission policies influence a supermarket's logistics operations.

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