Research progress on logistics network optimization under low carbon constraints

Xiaohong Fang¹, Li Nie¹* and Hua Mu²

¹ School of Intelligent Manufacturing and Control Engineering, Shanghai Polytechnic University, Shanghai, 200120, China
² Wuhan KM Information Technology Co., Ltd., Wuhan, Hubei, 430076, China
*Corresponding author’s e-mail: nieli@sspu.edu.cn

Abstract. In this paper, a literature review was conducted on the optimization of logistics network under low carbon constraints. This paper summarized the basic research process of logistics network optimization, and discussed the basic problems of logistics network optimization (distribution center location and vehicle distribution route optimization) and the compound optimization problems of logistics network (forward logistics network optimization and reverse logistics network optimization). In this paper, we mainly discuss the mathematical model constructed by one or more of the goals of minimum carbon emissions, minimum sum of total costs, minimum total delivery time and minimum total delivery distance, and the solving strategies using heuristic algorithms such as particle swarm optimization, genetic algorithm, and ant colony algorithm. It provided the latest technology in this field for the researchers of enterprise logistics network model and points out the future development trend.

1. Introduction

The word "low-carbon" originated from the concept of "low-carbon economy" discussed by the British Ministry of Trade and Industry in 2003 in the energy white paper "Our Energy Future: Creating a Low-carbon Economy". At present, China has issued many specific laws and regulations on energy conservation and emission reduction, such as "Energy Conservation Law of the People's Republic of China", "Comprehensive Work Plan for Energy Conservation and Emission Reduction", and "Circular Economy Promotion Law of the People's Republic of China" [1], which shows that China is paying more and more attention to carbon emissions and energy issues.

The concept of "low carbon" has been deeply applied to various industries, such as the logistics industry with relatively large carbon emissions in China. In 2008, China Federation of Logistics and Purchasing introduced the concept of "low carbon" into the logistics industry, and discussed the low carbon development of the logistics industry in China [2]. Then, many scholars have studied the connotation, characteristics, significance, operation mode, existing problems and coping strategies of low-carbon logistics [3].

The carbon emission of logistics industry mainly comes from the process of logistics transportation, so low-carbon optimization of logistics network has gradually become a research hotspot. At present, many scholars have deeply studied the logistics network optimization problems under the low-carbon constraints, such as considering the location of low-carbon logistics distribution centers, vehicle routing problems, and reverse logistics network design problems.
2. Basic problems of logistics network optimization

2.1. Logistics network optimization process
The optimization process of logistics network under low carbon constraints mainly includes: ① To determine the measurement formula of carbon emissions. The carbon emissions in logistics network mainly include the carbon emissions in the operation of distribution centers and the carbon emissions in the process of vehicle distribution. ② Establish models, which are mostly mixed integer programming models, including single-objective optimization models with minimum total cost considering carbon emission costs or multi-objective optimization models with minimum carbon emission costs and minimum other costs. ③ To determine the solution strategy and solve the model. LINGO software and Heuristic algorithms such as genetic algorithm and ant colony algorithm can be used to solve the problem. ④ Comparative analysis. Different models can be solved by the same algorithm, and the accuracy of the proposed model can be verified by comparing the solution results, or different algorithms can be used to solve the same model to verify the accuracy of the proposed algorithm.

To determine the measurement formula of carbon emissions → Establish models → To determine the solution strategy and solve the model → Comparative analysis

Figure 1. Flow chart of logistics network optimization under low carbon constraints.

2.2. Distribution center location under low carbon constraints
Choosing a suitable distribution center location can effectively reduce the total carbon emission and total cost of logistics network [4]. The problem of distribution center location under low-carbon constraint refers to: in a limited number (for example, two) of distribution center locations to be selected, one or more locations are selected as distribution centers, and goods are provided for N customers while receiving goods from M suppliers, so that the total cost including carbon emission cost is the lowest while meeting the requirements of supplying all customers.

Supplier 1 → Supplier 2 → ... → Supplier M → Distribution center 1 → Distribution center 2 → Customer 1 → Customer 2 → ... → Customer N

Figure 2. Schematic diagram of basic structure of logistics network for location problem.

At present, there are many articles about the location of distribution centers, but there are relatively few articles about how to reduce carbon emissions [5–8]. There are two optimization methods for distribution center location problem under low carbon constraints: single-objective optimization with minimum total cost including carbon emission cost and multi-objective optimization with minimum carbon emission cost and other costs.

In the future, the following aspects can be considered in the optimization of distribution center location under low carbon constraints: ① Comprehensive consideration of distribution center budget constraints, surrounding human resources constraints and convenient transportation; ② Two or more factors, such as time window, heterogeneous fleet, traffic congestion, uncertain demand, and different cargo capacity, are considered comprehensively to achieve the goal that the model is closer to reality.
Table 1. Research literature on distribution center location under low carbon constraints.

| References | Optimization objective | Problem solving method | Uncertain factors |
|------------|------------------------|------------------------|-------------------|
| [5]        | The sum of logistics cost and low carbon cost of distribution center location is the smallest. The sum of distribution center operating cost, route carbon emission cost, distribution center opening cost and transportation cost is the smallest. The sum of distribution vehicle cost, warehouse cost, fuel consumption and CO₂ cost is the smallest. The economic cost (including site selection cost and distribution cost) is the smallest, and the carbon emission is the smallest. | Using LINGO software to solve. Intelligent optimization algorithm based on quantum evolutionary algorithm and local search algorithm. Evolutionary super-heuristic algorithm. Improved non-dominated sorting genetic algorithm. | Uncertain demand. Uncertain road network. Multi-model and simultaneous pickup. The situation of road congestion. |

2.3. Low carbonization optimization of vehicle distribution route

Low-carbonization optimization of vehicle distribution path requires planning suitable distribution path, which can minimize the time cost, total distance and carbon emissions in the distribution process and maximize customer satisfaction [9]. Figure 3 is a schematic diagram of vehicle distribution route selection, which randomly selects a route planning mode between a distribution center and a plurality of customer points, and the starting point and ending point of the route are both distribution centers.

![Figure 3. Schematic diagram of vehicle distribution route selection.](image)

The optimization of vehicle distribution route is a hot issue, and many scholars have proposed a low-carbon model which comprehensively considers one or more factors such as traffic conditions, heterogeneous vehicles, load capacity, speed and distance [9~13]. Some scholars choose to reduce carbon emissions indirectly by reducing fuel consumption when studying low-carbon VRP. When measuring the carbon emissions of different routes, the carbon emissions of most models are polynomial functions closely related to speed, while other factors such as road congestion, slope and friction coefficient indirectly affect the carbon emissions of vehicles by affecting speed.

In the future, the low-carbon optimization of vehicle distribution path can be started from the following aspects: ① considering the problem of vehicle transshipment with different load capacity; ② According to the different traffic jams in cities, time zones with different speeds are divided, and the goal of reducing carbon emissions is achieved through reasonable combination of time zones [9].

3. Compound optimization problems of logistics network

3.1. Optimization of forward logistics network under low carbon constraints

At present, the research on low carbonization of forward logistics network is mostly optimized by building a mixed integer programming model and choosing the corresponding algorithm to solve it.
Low-carbonization optimization of forward logistics network is mostly a single-objective optimization with the smallest total cost including carbon emission cost, while a few study multi-objective optimization with the smallest carbon emission cost and other costs. When solving this kind of model, most scholars choose to use genetic algorithm [14–18].

Table 2. Literature on vehicle routing optimization under low carbon constraints.

| References | Optimization objective | Problem solving method | Uncertain factors |
|------------|------------------------|------------------------|-------------------|
| [9]        | The total amount of carbon emissions, total vehicle travel time and vehicle travel distance are the smallest. | Hybrid ant colony algorithm. | Flexible Path, Dynamic Load and Heterogeneous Fleet. Multi-channel, time-varying. |
| [10]       | Minimum fuel consumption. | Double-cycle simulated annealing algorithm. Simulated annealing ant colony algorithm with chaotic disturbance. | Dynamic load. |
| [11]       | The lowest cost of carbon emission. | Using GAMS/XPRESS software to solve the problem. | Flexible path. |
| [13]       | Maximum speed, minimum transportation cost and fuel consumption. | Genetic algorithm. | |

Table 3. Research literature on low carbonization of forward logistics network.

| References | Optimization objective | Model name | Problem solving method |
|------------|------------------------|------------|------------------------|
| [14]       | Minimum total cost. | Multi-mode express logistics network model. | Genetic algorithm. |
| [15]       | The total logistics cost and total carbon emission of the network are the smallest. Total expected cost Total expected carbon dioxide emission equivalent is the smallest. | Multi-objective logistics network planning model. Multi-objective fuzzy mathematical programming model based on credibility. | Genetic algorithm. Interactive fuzzy solution method. |
| [16]       | Minimum total cost. | Linear mathematical model. | IPSO-ACO hybrid algorithm. |

In the future, the low-carbonization optimization of forward logistics network can be started from the following aspects: ① to study the multi-level logistics network in which multiple enterprises form alliances and cooperate with each other; ② Combine different intelligent optimization algorithms to form a more suitable intelligent optimization algorithm.

3.2. Optimization of reverse logistics network under low carbon constraints

Reverse logistics is a kind of reverse and reverse flow activity, that is, products flow reversely from downstream to upstream of supply chain and from consumers to enterprises, including product recovery, reproduction, reuse and waste treatment [19]. The optimization model of reverse logistics network is usually solved by mixed integer model solving software such as LINGO, and can also be solved by intelligent algorithm [20–23].

In the future, the low-carbonization optimization of reverse logistics network can be started from the following aspects: ① Combining different intelligent optimization algorithms to form a more suitable intelligent optimization algorithm; ② Considering the uncertainty and dynamics of logistics network, more factors such as economy, environment and society are brought into the study of the model, aiming at designing a more realistic model.

4. Summary

In this paper, a literature review of logistics network optimization under low-carbon constraints is carried out, and the basic research process of logistics network optimization is summarized. The basic problems of logistics network optimization (distribution center location and vehicle distribution path optimization) and the compound optimization problems of logistics network (forward logistics network optimization and reverse logistics network optimization) are discussed.
Table 4. Literature on low carbonization of reverse logistics network.

| References | Optimization objective | Model name | Problem solving method |
|------------|-------------------------|------------|------------------------|
| [20]       | The processing workload is the smallest, and the profit and recovery capacity are the largest. | Network model of sustainable recycling of scrapped cars. | LINGO software. |
| [21]       | Minimum total cost.     | Four-layer reverse logistics network model of scrapped vehicles. | LINGO software. |
| [22]       | Maximize the total profit. | Optimization model of multi-product and multi-level carbon constrained reverse logistics network. | LINGO software. |
| [23]       | Minimum total cost.     | Design Model of Reverse Logistics Network Based on Carbon Footprint | LINGO software. |

In the future, we can study the optimization of logistics network under low carbon constraints from the following aspects: ① When establishing the model, we should consider two or more factors such as time window, heterogeneous fleet, traffic congestion, uncertain demand and different cargo capacity, so as to make the model closer to reality; ② Combining different intelligent optimization algorithms to avoid the occurrence of local optimum and find a more suitable intelligent optimization algorithm for solving low-carbon model; ③ Study the multi-level low-carbon logistics network in which many enterprises form alliances and cooperate with each other.

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