Research on the Distribution Path Optimization of Electric Refrigerated Vehicles Based on Time-Variable Network

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Abstract: China's cold chain industry has ushered in a period of rapid development. However, with the enhancement of environmental awareness, the government is constantly guiding logistics enterprises to adopt new energy models, so as to reduce the environmental problems caused by the carbon emissions of traditional fuel refrigerated vehicles. In response to the distribution route optimization problem of electric refrigerated vehicles, a mathematical model for distribution route optimization under a time - varying network was constructed. An improved genetic algorithm was employed to conduct an empirical analysis of the distribution business data of Company M. Eventually, a route optimization plan with the lowest cost was listed for Company M. Meanwhile, through the comparison between the time - varying network and the static network, the necessity of considering the time - varying network in route optimization was demonstrated. This provides corresponding suggestions and considerations for logistics enterprises when they choose to use electric refrigerated vehicles to carry out distribution business.

1. Background analysis of path optimization of electric refrigerated vehicles

According to the China Cold Chain Logistics Development Report, the total amount of cold chain logistics reached 3.1 trillion yuan, up 3.7% year on year. Fresh cold chain logistics industry has entered an unprecedented period of rapid development, the market scale expanded expansion. The government has created a positive policy environment for the development of the cold chain logistics industry. For example, the "14th Five-Year Development Plan" issued by The General Office of the State Council focuses on improving the terminal cold chain facilities and equipment, connecting the production and marketing to establish the whole cold chain distribution system, and constantly guiding logistics enterprises to adopt new energy models.

In cold - chain logistics, road - based cold - chain transportation holds a dominant position. With the increasing awareness of the public, carbon emissions in road - based cold - chain transportation have drawn more and more attention. Road - based cold - chain transportation accounts for nearly three - quarters of carbon emissions, making it a major source of carbon emissions in the transportation industry. Currently, traditional fuel - powered refrigerated trucks remain the top choice in the industry, with diesel - powered refrigerated trucks still monopolizing the market [1]. In the first half of 2023, 21,599 diesel - powered refrigerated trucks were sold, accounting for 82.97% of the total sales. Thanks to the continuous improvement of China's charging pile infrastructure and the continuous advancement of battery technology, the "range anxiety" and "charging anxiety" associated with refrigerated trucks have gradually subsided. In the first half of 2023, 1,149 new - energy refrigerated trucks were sold nationwide. Among them, 783 were pure - electric refrigerated trucks, representing a 34.77% year - on - year increase; 153 were natural - gas - powered refrigerated trucks, with a 51.49% year - on - year growth; and methanol - hybrid refrigerated trucks achieved a "zero - breakthrough", as depicted in Figure 1.

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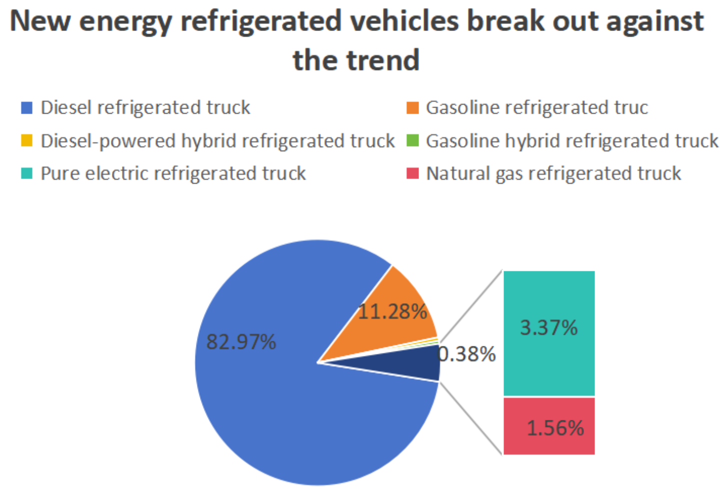

Figure 1 The proportion of refrigerated vehicle sales in the first half of 2023 (by power score).

In the previous distribution optimization scheme, the distance between customers will be considered to measure the change of cost, and the distribution vehicles will be assumed to move forward at a uniform speed. Although necessary assumptions can be made when solving the model, the related factors such as morning and evening peak, road type and other distribution time cannot be ignored in the actual cold chain logistics[2]. To sum up, this paper studies the optimization of cold chain distribution of electric refrigerated vehicles in the background of time-changing network, provides certain ideas for logistics enterprises in the relevant decisions of cold chain business, accelerates the transformation of cold chain enterprises to new energy refrigerated vehicles, and makes due contributions to energy conservation and emission reduction under the goal of "double carbon".

2. Build a model

2.1. Correlation theory

The Vehicle Routing Problem (VRP) encompasses elements such as distribution centers, distribution networks, customers, vehicles, objective functions, and constraints. Generally, taking customer demand, vehicle load capacity, time requirements, and other related constraints as limitations, it ensures that distribution vehicles traverse all customer locations. Ultimately, the aim is to formulate a distribution route plan that either minimizes the distribution cost or maximizes customer satisfaction [3], as depicted in Figure 2.

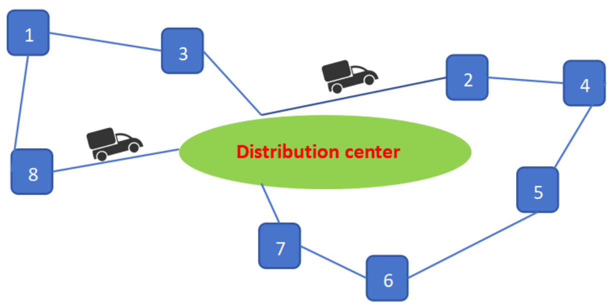

Figure 2 Schematic diagram of vehicle path problem (VRP).

Cold chain logistics is the product of the combination of logistics mode and cold chain technology. In the whole process and link of the product, temperature has strict requirements, supervision and management[4]. In the whole link, distribution is an important link to directly contact with customers. The high level of this link will greatly improve customer satisfaction and reduce cargo loss. The distribution link has timeliness, high nature, high technology and coordination, so the top priority of cold chain logistics is the distribution link.

Electric refrigerated vehicle is the "new favorite" in cold chain logistics, the advantages and disadvantages are obvious, the good place is the power as a driver, low cost, no carbon emissions, no vibration, small noise, simple structure, no right of way limit; the short range, long charging time and supporting facilities are not perfect, but whether from the enterprise to reduce distribution costs, or from the national energy conservation and emission reduction, environmental protection, electric refrigerated truck must be an inevitable option.

2.2. Model factor analysis

According to the law of vehicle speed change caused by the urban implementation traffic situation, we will be close to the reality in the form of multiple time periods corresponding to different speeds, as shown in Figure 3.

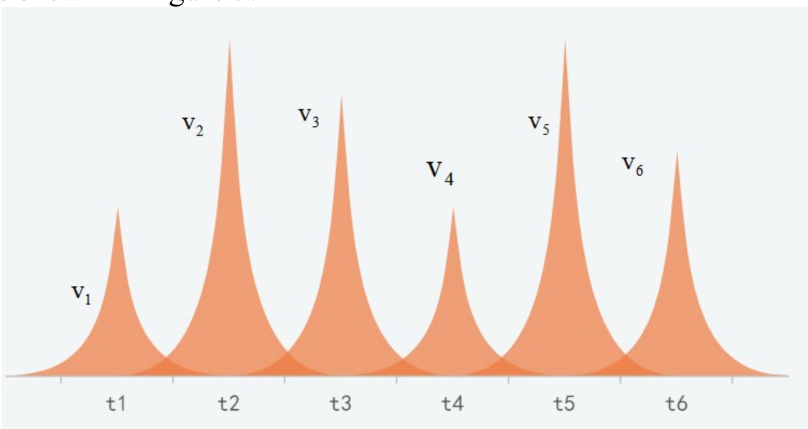

Figure 3 Schematic diagram of the corresponding speed in different time periods.

In the distribution task, the electric refrigerated vehicle will deliver the goods according to the time window. The range of the time window is set by the customer, and it may complete the delivery task across one, two or even more time periods. Therefore, it can try to avoid regular time points during the delivery.

2.3. Model construction

2.3.1. Basic assumptions

Based on the characteristics of electric refrigerated vehicles in the actual distribution business, this paper makes the following assumptions:

(1) The location of charging stations is known, and there is no difference in power and electricity price;

(2) If the vehicle cannot be discharged at any time (less than 20%), the power is not enough to support the following distribution task and needs to be charged according to the congestion in the previous period, the vehicle should be charged nearby and does not need to queue [5];

(3) The vehicle is charged slowly in the distribution center, and the distribution business can only be carried out with full power;

(4) The charging station on the way to work, no more than 80% of the electricity;

2.3.2. Symbol parameters

Based on the simplicity of the model construction, the following settings are made:

(1) Collection

O :The collection of all nodes, including distribution center 0 , customers C and charging stations S ;

C :A collection of all the customers, $C = 1、2、3......c$;

S :A collection of all of the charging stations, $S = 1、2、3......s$;

K :A collection of all of the vehicles, $K = 1、2、3......k$;

(2) Parameters

i/j :Nodes, including customer points or charging stations; d_{ij} :Distance between nodes i to nodes j, $i \neq j$; t_{ij} :The time it takes an electric refrigerated vehicle to go from node i to node j; t_i :The time when the electric refrigerator truck arrives at the node i; t_i^e :The time when the electric refrigerated vehicle leaves the node i; $Q_{\max}$:The upper power limit of an electric refrigerated car; q_i :The power quantity displayed when the electric refrigerator truck reaches the node i; q_i^e :The power quantity displayed when the electric refrigerated vehicle leaves the node i; C_F :Fixed cost of electric refrigerated truck, yuan / vehicle; C_{change} :Changing cost of electric refrigerated truck, yuan / km; C_{charge}: Charging cost of electric refrigerated car, yuan / kwh; C_{cold}^1: The refrigeration cost of the electric refrigerated vehicle in the closing state, yuan / min; C_{cold}^2: The refrigeration cost of the electric refrigerated vehicle when serving the customers, yuan / min; C_{goods}: Average average price of cold chain products; G_i: Customer i demand; G^*: Rated payload of the vehicle; G_i^e: The remaining quantity of goods when leaving the customer i; θ_1 / θ_2: Goods damage coefficient of electric refrigerated vehicle in the closed state / customer service; $[T_e - T_l]$: Customer satisfaction of the delivery time morning and evening value, that is, the time window; T_D: The latest receiving time for the allowed delivery, after the time exceeds, the customer to reject; $\varepsilon_e / \varepsilon_l$ Penalty factor to be paid earlier or later than the time window.

(3) Decision variables

x_i^k :When the electric refrigerator truck k arrives at the customer i, the value is 1, otherwise it is 0; y_i^k :When the electric refrigerated vehicle k provides the service to the customer i, the value is 1, otherwise it is 0; x_{ij}^k :When the electric refrigerated vehicle k arrives at the customer j from the customer i, the value is 1, otherwise it is 0; z_i^k :When the electric refrigerated vehicle k is at the charging station i, the value is 1, otherwise it is 0.

2.3.3. Objective function

When building the path optimization model, this paper considers the distribution costs including fixed cost, variable cost, cooling cost, cargo loss cost, fine and charging cost, which are as follows:

(1) Fixed cost

The fixed cost is only related to the number of vehicles of the electric refrigerated vehicle, so the total fixed cost can be expressed by Equation (1):

$$C_1 = \sum_{k \in K} \sum_{j \in C} x_{0j}^k \cdot C_F \tag{1}$$

(2) variable cost

The electric refrigerated vehicle has a linear relationship with the driving distance, so the total variable cost can be expressed by Equation (2):

$$C_2 = \sum_{k \in K} \sum_{i \in O} \sum_{j \in (C+S)} d_{ij} \cdot x_{ij}^k \cdot C_{\text{change}} \tag{2}$$

(3) Refrigeration cost

Electric refrigerated vehicles in the refrigeration process, because the stage is different, the refrigeration cost is different. In the closing state, the cost is small, corresponding to the frequent opening and closing of the cost of serving customers, so the total cooling cost can be expressed by formula (3):

$$C_3=\sum_{k\in K}\sum_{i\in O}\sum_{j\in(C+S)} t_{ij}\cdot x_{ij}^k\cdot C_{\text{cold}}^1+\sum_{k\in K}\sum_{j\in C}(t_i^e-t_i)\cdot y_i^k\cdot C_{cold}^2 \quad (3)$$

(4) A fine

In the process of distribution, the cold chain logistics company needs to arrange the delivery time with the customer in advance and complete the delivery within the specified time range. If the electric refrigerated truck does not arrive within the time window, a certain fine shall be paid; if the electric refrigerated truck arrives within the time window, the fine and the delivery service can be paid; when the electric refrigerated truck exceeds the latest delivery time allowed by the customer, the customer refuses the penalty in form (4):

$$\mathrm{f}(t_i)=\begin{cases}\varepsilon_1(T_e-t_i), & t_i\prec T_e\\ 0 & T_e\le t_i\le T_l\\ \varepsilon_2(t_i-T_l), & T_D\succ t_i\succ T_l\end{cases}$$

$$C_4=\sum_{k\in K}\sum_{i\in O}\sum_{j\in(C+S)} f(t_i)\cdot x_{ij}^k \quad (4)$$

(5) Goods damage cost

The cargo loss of cold chain products is related to the driving time and condition of the electric refrigerated vehicle, that is, the natural loss of the goods over time; in serving customers, at the time of the goods will flow in different links, so they are subjected to various tests and the cargo loss is large, so the total cargo loss cost is indicated by Equation (5):

$$C_5=\sum_{k\in K}\sum_{i\in O}\sum_{j\in(C+S)} C_{goods}\cdot G_{\mathrm{i}}\cdot t_{ij}\cdot\theta_1\cdot x_{ij}^k+\sum_{k\in K}\sum_{j\in C} C_{\text{goods}}\cdot G_{\mathrm{j}}^e\cdot(t_i^e-t_i)\cdot y_j^k \quad (5)$$

(6) Charging cost

Limited by their own range, electric refrigerated vehicles need to go to social charging stations to supplement the power in the distribution process. When the charging efficiency reaches 80%, the rate is significantly slowed down. Therefore, this paper assumes that the power in social charging stations is at most 80%, so the total charging cost can be expressed by formula (6):

$$C_6=C_{\text{charge}}\cdot\sum_{k\in K}\sum_{i\in S}(0.8Q_{\max}-\mathrm{q}_i)\cdot z_i^k \quad (6)$$

(7) The combined cost obtains the target function

The target function distribution cost is the sum of the above fixed cost, variable cost, cooling cost, fine, cargo loss cost and sufficient charging. Based on this, the distribution path optimization model of electric refrigerated vehicle constructed in this paper can be expressed by formula (7):

$$\min\mathrm{F}=C_1+C_2+C_3+C_4+C_5+C_6$$

$$=\begin{cases}\sum_{k\in K}\sum_{j\in C} x_{0j}^k\cdot C_F+\sum_{k\in K}\sum_{i\in O}\sum_{j\in(C+S)} d_{ij}\cdot x_{ij}^k\cdot C_{\text{change}}\\ +\sum_{k\in K}\sum_{i\in O}\sum_{j\in(C+S)} t_{ij}\cdot x_{ij}^k\cdot C_{cold}^1+\sum_{k\in K}\sum_{j\in C}(t_i^e-t_i)\cdot y_i^k\cdot C_{cold}^2\\ +\sum_{k\in K}\sum_{i\in O}\sum_{j\in(C+S)} f(t_i)\cdot x_{ij}^k+C_{charge}\cdot\sum_{k\in K}\sum_{i\in S}(0.8Q_{\max}-\mathrm{q}_i)\cdot z_i^k\\ +\sum_{k\in K}\sum_{i\in O}\sum_{j\in(C+S)} C_{goods}\cdot G_{\mathrm{i}}\cdot t_{ij}\cdot\theta_1\cdot x_{ij}^k+\sum_{k\in K}\sum_{j\in C} C_{goods}\cdot G_{\mathrm{j}}^e\cdot(t_i^e-t_i)\cdot y_j^k\end{cases} \quad (7)$$

Based on the above optimization model, the following constraints are made:

(1) The vehicle cannot be discharged deeply, that is, if the power display is less than 20%, the charging will be forced;

$$\mathrm{q}_i\ge 0.2Q_{\max},\qquad \forall i\in C \quad (8)$$

(2) Before and after the customer service, the remaining power is consistent, that is, no power consumption;

$$q_i^e = q_i \qquad \forall i \in C \tag{9}$$

(3) Vehicles cannot be directly driven from the distribution center to the charging station;

$$x_{0j}^k = 0, \qquad \forall j \in S, k \in K \tag{10}$$

(4) Each customer can only accept the service once;

$$\sum_{k \in K} \sum_{i \in O} x_{ij}^k = 1, \qquad \forall j \in C \tag{11}$$

(5) The amount of goods delivered by each refrigerated vehicle shall not exceed the rated load of the vehicle;

$$\sum_{k \in K} \sum_{i \in O} x_{ij}^k \cdot q_i \le G^*, \qquad \forall j \in C \tag{12}$$

3. Algorithm design

In this paper, genetic algorithm is used to solve this type of problem, which is suitable for large-scale vehicle path problem, simple operation and good stability [6]. The algorithm initially generates the initial population, and then judges the adaptive function to retain or eliminate simulated genetics, crossover and variation, to continuously obtain new populations and achieve the purpose of iterative population, so as to continuously optimize the quality of the solution, and the new population also continuously enhances its adaptability, until the optimal solution [7] is produced.

(1) Natural number coding. Since the nodes (distribution centers, customers, charging stations) in the distribution path planning are all practical factors, natural number coding should be used for coding;

(2) Set the initial population. In this paper, we set the initial population to 100;

(3) Determine the fitness function, taking the inverse of the total cost function in the distribution path planning as the fitness function;

(4) Fitness value selection, according to the individuals of the initial population, the size of the fitness value ranking, the large one is to be retained;

(5) Cross operation, using the adaptive cross improvement idea of the golden section method to avoid premature local optimum;

(6) Variation operation, using the same idea for variation;

(7) Update the population, and update the population after variation;

(8) Determine whether the stop condition is met. If it is, the optimal solution is output; otherwise, the cycle continues.

4. Empirical analysis

In this paper, the daily operation data of M cold chain logistics company is selected for example analysis.Founded in 2015,20 M company is rooted in the B2B company of fresh collection, sales and distribution. It has established a direct purchasing channel and incorporated customers in the region into the distribution network to complete daily timely distribution. In this paper, 15 stores in a certain area are selected as the service objects, among which 0 is the company distribution center, 1-15 represents each store, and 16-18 is the charging station.

The distribution center's own electric refrigerated vehicle model is Wuling EV50, Battery capacity of 60.8kwh, Total weight of 2,900 kg, Rated load of 1100kg, Purchase price of 126,000 yuan, According to the depreciation, personnel salary, and other fixed cost is 345 yuan per vehicle, Changing cost is 0.5 yuan / km, Social charging cost is 1.5 yuan / kwh, The cooling cost in the closing state is 0.2 yuan / min, The refrigeration cost when serving the customer is 0.5 yuan / min, The average price of cold chain products is 15 yuan kg, The penalty is 1.5 yuan / min, 4 yuan / min, The cargo loss coefficient is 0.01 / 0.02.

Based on the above parameters, the mathematical model of the constructed objective function, where the population size of 100, is implemented by Matlab 2019 version.The improved genetic algorithm reduces the distribution cost (average) by 7.83% compared with the traditional algorithm. Although the solution time is a little longer, the solution stability is better.In this paper, the relevant data of M Company are selected. Due to the low demand of customers in the region, when electric refrigerated vehicles were used for distribution, only one electric refrigerated vehicle was charged in the distribution path, which reduced the impact of range anxiety of electric vehicles.

In this paper, the driving speed of the vehicle is adjusted to obtain the optimization results of the model under the time-varying network.

Assuming that the speed of the electric refrigerated vehicle is 20 km/h and 40 km/h under the static network, the distribution cost [8] at these two speeds is compared with the distribution cost of the vehicle at the time-varying speed state.When electric refrigerated car speed in 20 km/h, distribution mileage and the cost is lower, when the speed adjustment to 40 km/h, distribution cost has increased a lot, so the distribution cost with the model assumes the speed of certain correlation, and in the actual business, the vehicle speed can not be unchanged, so the time-varying network distribution path optimization will be more close to the actual, can provide authors efficiency, energy reduction and energy conservation and emissions reduction

5. Conclusion and outlook

This paper addresses the distribution route optimization problem of electric refrigerated vehicles by constructing a mathematical model for distribution route optimization under a time - varying network. An improved genetic algorithm is applied to conduct an empirical analysis of the distribution business data of Company M. Eventually, a route optimization plan with the lowest cost is presented for Company M. Meanwhile, through the comparison of values between the time - varying network and the static network, the necessity of considering the time - varying network in route optimization is illustrated, providing corresponding suggestions and considerations for enterprises when making business decisions.

This study still has certain limitations. For example, to simplify the difficulty of model solving, although the time - varying network is taken into account, the driving speed in each time period is fixed, which is inconsistent with the actual speed changes of vehicles during driving. Therefore, in future research, the distribution route optimization problem of electric refrigerated vehicles will continue to be explored in this regard.

References

[1] Zhao Yibo. Research on the optimization of the cold chain logistics distribution path under the time-varying network [D]. Tianjin University of Technology, 2023.DOI: 10.27360/d.cnki.gtlgy. 2023.000562.

[2] Cao Xin. Research on the optimization of low-carbon cold chain distribution path of fresh agricultural products based on mixed ant colony algorithm [D]. Jiangxi University of Finance and Economics, 2023.DOI:10.27175/d.cnki.gjxcu. 2023.001794.

[3] Yang Lizhao. Research on the optimization of JD Fresh Food logistics distribution path based on electric logistics vehicles [D]. Beijing Jiaotong University, 2020.DOI:10.26944/d.cnki.gbfju. 2020.002786.

[4] Wei Ziqiu, Gou Jinglin. Cold chain distribution path optimization from a low-carbon multi-factor perspective [J]. Logistics Technology, 2024,47 (03): 148-153.DOI: 10.13714/j.cnki.1002-3100.2024.03.035.

[5] Ye Si. Research on the Optimization of Cold Chain Logistics Distribution Routes for Fresh Agricultural Products of Company A [D]. Zhejiang University, 2023. DOI: 10.27461/d.cnki.gzjdx. 2023.001954.

[6] Guo Jia. Research on logistics distribution path optimization of electric refrigerated vehicles based on improved genetic algorithm [D]. Tianjin University of Technology, 2023. DOI: 10.27360/d.cnki.gtlgy. 2023.000341.

[7] Zhang Yong, He Guoxian. Research on Optimization of Fresh Fruit Based on Genetic Algorithm [J]. China Storage and Transportation, 2024,(07):96-97.DOI:10.16301/j.cnki.cn12-1204/f. 2024.07. 122.

[8] Ding Lin. Research on the optimization of electric vehicle distribution path considering changes in customer time window under time-changing road network [D]. Dongbei University of Finance and Economics, 2023. DOI:10.27006/d.cnki.gdbcu. 2023.000345.