Research on the optimization model of cold chain logistics distribution path under the constraint of carbon emission

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Abstract. The optimization of cold chain logistics distribution path under the constraint of carbon emission is considered. The restriction of hard time window and carbon emission is added to the model design. The carbon emission is converted into the final objective function of economic cost, transportation cost and goods loss cost in the way of carbon trading price. The problem of energy consumption is considered from the perspective of Economics. The cost of carbon emission is added to the mileage saving method, and the improved algorithm is used to increase the applicability of this kind of algorithm.

1. Introduction

With the rapid development of China's economy, the overall development process of cold chain logistics industry is relatively slow, which can not meet the needs of Chinese people for cold chain logistics. To change the existing cold chain logistics development mode and optimize the overall configuration is the primary task to improve the efficiency of logistics services. There is a certain amount of carbon emissions in the distribution process. If carbon emissions are included in the distribution cost as a cost, it will have an impact on the selection of the original distribution path. How to calculate the carbon emission is a difficult problem. Woensel. Creten[1] studied the carbon emissions generated by different fuel consumption, roughly calculated the carbon emissions generated by various types of fuel, established multiple quantitative optimization models, and finally calculated the fuel consumption in transportation activities, which was proved feasible by empirical analysis; Cai Hao and Xie Shaodong[2] comprehensively measured various factors affecting the carbon emission coefficient of transportation vehicles, and successively constructed Lu Pin[3] considers the distance and weight of goods moving in the process of goods transportation as the influencing factors and the amount of carbon dioxide emissions. Xie Shian[4] studies the effects of carbon emission costs on vehicle distribution. Cost impact, using the inertia weight method, improved the traditional particle swarm optimization algorithm.

Through the analysis of literature, it is found that the carbon emission of vehicles is related to driving distance, vehicle load and other factors. In this paper, carbon emissions as an economic cost is added to the saving algorithm, and the optimal objective function is constructed together with the cost of goods damage and transportation cost. According to the improved C-W saving algorithm, the optimal path is obtained.
2. Modelling
Cold chain logistics is a system engineering involving many links. The whole process of goods must be kept at a low temperature, so the overall investment and operation costs are high. Considering the characteristics and distribution mode of cold chain logistics, it is necessary to compare the common VRP problems from many aspects, such as how to reduce carbon emissions and save the total cost during the cold chain transportation. Therefore, the types of cold chain logistics distribution path optimization problems studied in this paper are: single distribution center, multiple regional distribution outlets, single type of products required, known demand of products, known geographical location of regional distribution outlets, distribution vehicles to and from the distribution center and outlets, each regional distribution network is served by one vehicle. The objective function of distribution is to minimize the total cost of distribution, which includes the total cost of transportation, the cost of goods loss and the cost of carbon emission.

2.1. parameter description
The parameter symbols in the carbon constrained cold chain distribution path optimization model studied in this paper are as follows. m: total number of vehicles in distribution centre of logistics base; n: total number of regional distribution outlets; $C_0$: Transportation cost per unit distance of vehicle; $d_{xy}$: Distance from regional distribution point x to regional distribution point y; $t_{xy}$: Time from regional distribution point x to regional distribution point y; $d_y$: Regional distribution network y goods demand; $X_{xyk}$: it is a 0, 1 variable. If the k-th vehicle passes the road section ($v_x$, $v_y$), $X_{xyk}=1$, otherwise it is zero. $X_y$: a variable of 0, 1. If the regional distribution point is served by vehicle K, then$X_y=1$, otherwise it is zero. $P_0$: Unit price of carbon; F: carbon emission coefficient of fuel combustion; $Q_{xy}$: Carbon emission per unit distance; $q_{xy}$: refers to the vehicle load when the distribution vehicle travels from the regional distribution point x to the regional distribution point y; Q: maximum vehicle capacity; $\alpha$: cargo loss coefficient during cargo distribution; $\beta$: cargo damage coefficient of loading and unloading; P: unit price of fruits and vegetables; $t_y$: The time point when the vehicle arrives at the regional distribution network; ET_y: Upper limit of time for regional distribution network y; LT_y: Time limit of regional distribution network y.

2.2. Distribution path optimization model

2.2.1. Carbon emission cost.
The carbon emission generated in the distribution mainly comes from the combustion of vehicle fuel and the operation of refrigeration equipment. This paper mainly studies the carbon emission of mechanical refrigeration vehicle in the distribution. For the convenience of research, it mainly considers the carbon emission generated by the driving distance of transport vehicles and the load of freight cars. The calculation formula (1) is as follows:

$$c_1 = \sum_{x=0}^{n} \sum_{y=0}^{n} \sum_{k=1}^{m} Q_{xy} d_{xy} P_0 F$$

The traditional VRP Problem generally aims to minimize the vehicle transportation cost. In fact, the transportation cost is positively related to the vehicle driving distance, and the carbon emission cost is also related to the vehicle driving distance. In this paper, the calculation formula of carbon emission cost considers the carbon emission of distribution vehicles under different load capacities. A mechanical refrigerator car with a load capacity of 4 tons has the following relationship between its carbon emission per unit distance and its load capacity:

$$Q_{xy} = 1 + 0.25q_{xy}$$

$C_1$ represents the cost of carbon emission during driving. In this paper, we choose to use carbon emission suggestion mechanism to cost carbon.

2.2.2. Transportation cost.
Because the refrigerated vehicles in this paper have been purchased, only the transportation cost of distribution vehicles is considered, which is proportional to the driving distance. The calculation formula (3) is as follows

$$c_2 = \sum_{x=0}^{n} \sum_{y=0}^{n} \sum_{k=1}^{m} c_0 d_{xy} X_{xy}$$

Where$X_{xy}$ is a 0, 1 variable. If the k-th vehicle passes the road section ($v_x$, $v_y$), then $X_{xy}=1$, otherwise it is zero.
2.2.3. Cost of goods damage.

The quality of fresh fruits and vegetables will change due to the temperature change and the time-consuming transportation. Therefore, it is necessary to consider the impact of the cumulative impact of loading and unloading, which leads to a certain proportion of goods loss, which is the cost of goods loss. In order to facilitate the study of this paper, only two factors are considered, one is the cumulative impact of temperature change and the time-consuming transportation on the quality of goods, the other is the impact of opening the door on the quality of goods when loading and unloading goods. The calculation formula (4) is as follows:

\[ C_3 = P \sum_{x=0}^{n} \sum_{y=0}^{n} \sum_{k=1}^{m} x_{xy}^k (\alpha t_{xy} q_{xy} + \beta d_{xy}) \]  

(4)

The objective function of the calculation model of fruit and vegetable product distribution cost is obtained from the above formula. The objective function model and its constraints are as follows:

\[
\min \ c = P_{xy} \sum_{x=0}^{n} \sum_{y=0}^{n} Q_{xy} \cdot d_{xy} + \sum_{x=0}^{n} \sum_{y=0}^{n} \sum_{k=1}^{m} c_0 \cdot d_{xy} \cdot x_{xy}^k + P \sum_{k=0}^{n} \sum_{y=0}^{n} \sum_{k=1}^{m} x_{xy}^k (\alpha t_{xy} q_{xy} + \beta d_{xy})
\]

(5)

Subject to

\[
\sum_{y=0}^{n} d_{xy} x_{xy}^k \leq Q \quad (k = 1, 2, ..., n)
\]

(6)

\[
\sum_{k=1}^{m} x_{xy}^k = 1 \quad (k = 1, 2, ..., n)
\]

(7)

\[
\sum_{k=1}^{m} x_{xy}^k = x_{xy}^k \quad (y = 0, 1, ..., n; k = 0, 1, ..., m)
\]

(8)

\[
\sum_{y=0}^{n} \sum_{x=0}^{n} x_{xy}^k + \sum_{y=0}^{n} \sum_{x=0}^{n} x_{xy}^k \leq E_{xy} \quad (y = 1, 2, ..., n)
\]

(9)

\[ ET_p \leq t_p \leq ET_y \quad (y = 1, 2, ..., n) \]

(10)

3. Model solution

Generally, C-W saving algorithm is used to solve the problem. This paper studies the path optimization problem of minimizing the total distribution cost, which is constrained by vehicle load and time. It is different from the traditional algorithm in algorithm, so it needs to add time window and vehicle load constraints to improve the algorithm to meet the research needs of this paper.

3.1. Optimal target improvement

The optimal objective function of the problem studied in this paper is the sum of carbon emission cost, transportation cost, and goods damage cost. Therefore, when calculating the distance saving value (ΔL), it is necessary to convert the distance to the cost saving value (expressed in s(x, y)).

\[ S(x, y) = C_{0x} + C_{0y} + C_{xy} \quad (x \neq y, 0) \]

is the distribution centre, where C represents the sum of three costs.

(1) After connecting regional distribution network x and regional distribution network y, the carbon emission cost saved is s_1(x, y),

\[ s_1(x, y) = (C_{0x} + C_{x0} + C_{xy} + C_{xy0}) - (C_{0x} + C_{x0} + C_{xy} + C_{xy0}) = C_{x0} + C_{xy} - C_{xy0} \]

(2) After connecting regional distribution network X and regional distribution network y, the transportation cost saved is s_2(x, y),

\[ s_2(x, y) = (C_{2x} + C_{x0} + C_{xy} + C_{xy0}) - (C_{2x} + C_{x0} + C_{xy} + C_{xy0}) = C_{2x} + C_{xy} - C_{xy0} \]

Because the transportation cost and carbon emission cost are calculated separately in this paper, the transportation cost is only related to the driving distance, so \( C_{2x} = C_{2x} \), similarly, \( C_{2y} = C_{2y} \).

(3) After connecting regional distribution network x and regional distribution network y, the cost of goods loss saved is s_3(x, y),

\[ s_3(x, y) = (C_{3x} + C_{x0} + C_{xy} + C_{xy0}) - (C_{3x} + C_{x0} + C_{xy} + C_{xy0}) = C_{3x} + C_{xy} - C_{xy0} \]

The objective function of the calculation model of fruit and vegetable product distribution cost is obtained from the above formula. The objective function model and its constraints are as follows:

The optimal objective function of the problem studied in this paper is the sum of carbon emission cost, transportation cost saved is

\[ C_0 x \]

...
The cost of goods damage discussed in this paper is affected by two factors, one is the loss caused in the course of distribution, the other is the loss caused by loading and unloading operations. The combination of lines will not change the cargo damage rate during loading and unloading operation, so the reduction of cargo damage rate is related to the reduction of driving distance saving, so the principle of saving is the same as that of saving transportation cost, so the principle of saving is the same as that of saving transportation cost. Therefore,
\[ C_0 \cdot x_3 = C_x \cdot 0, \]
similarly
\[ C_0 \cdot y_3 = C_y \cdot 0. \]

4) After connecting regional distribution network X and regional distribution network y, the total distribution cost saved is \( s(x, y) = s_1(x, y) + s_2(x, y) + s_3(x, y) \)

Finally, the time window constraint is added to the traditional saving algorithm, and the optimization target is changed to the minimum total cost, that is, the optimized algorithm is obtained.

3.2. Improve calculation steps
Step 1: select the base point. Based on logistics base, the distribution centre is set as P0. N regional distribution networks are connected with logistics base to form n initial solutions.

Step 2: calculate the distance saving value \( \Delta L(x, y) \) after the connection of regional distribution point X and regional distribution point y, and then define them as arrays;

Step 3: if the values of \( \Delta L(x, y) \) are all 0, the calculation will be stopped, otherwise, the saving values will be arranged in descending order from large to small, forming the saving distance value matrix;

Step 4: select the regional distribution network with the lowest total distribution cost as the first network of the first line. Connect the distribution centre with n outlets respectively, and calculate the total cost of vehicles from the distribution centre to each outlet, which is recorded as \( G_{C1}... G_{Cn} \). Find out the outlet with the lowest total cost of vehicle distribution by observation method. If it meets the requirements \( E_{E_k} < L_{T_k} \) and \( q_k < Q \), it is recorded as \( P_{k1} \).

Step 5: calculate the second node after the first node. Connect the remaining regional distribution outlets with \( p, k \) respectively, and calculate the total cost savings of each outlet after connection compared with the total cost savings of the original direct connection with the distribution centre, \( s(k, y) = C_{0k} + C_{0y} - C_{ky} \) (k \( \neq y, 0 \) is the distribution centre), \( C \) represents the sum of the three costs, and find out the outlets with the largest total cost savings in the total cost savings obtained table;

Step 6: test the \( s(k, y) \) obtained from step 5. When it meets (1), (2) or (1), (3), skip to step 7. Otherwise, skip to step 5 and find out the outlets with the largest total cost saving among the remaining outlets.

\[ (1) \quad q_k + q_y < Q \]
\[ (2) \quad E_{ky} = a_k + t_k + t_{ky} - a_y > 0 \quad \text{and} \quad \Delta y^+ = L_{T_y} - a_y > E_{ky}; \]
\[ (3) \quad E_{ky} = a_k + t_k + t_{ky} - a_y < 0 \quad \text{and} \quad \Delta y^- = a_y - E_{T_y} > |E_{ky}|; \]

Step 7: determine the second regional distribution network of the path as \( p_{k2} \);

Step 8: repeat step 5-step 7. If the time and load force constraints cannot be met after the distribution network in any area is added, the combination of the lines ends;

Step 9: repeat step 4-step 8 to merge the new distribution path. When all regional distribution outlets are planned into the distribution path, the calculation ends.

4. Example
4.1. distribution data
For simple calculation, Suning logistics base is set as \( P_0 \), and 12 regional distribution outlets in Nanning are numbered as \( P_1, P_2, ..., P_{12} \). The distance and demand between the distribution centre and the regional distribution network are shown in table 1, and the service time window and service time of each regional distribution network are shown in table 2. In order to simplify the calculation, the shortest driving distance from each regional distribution network to the logistics base on the map is used for the distribution distance data.
Table 1. Distribution distance and demand matrix

| d/km | P0  | P1  | P2  | P3  | P4  | P5  | P6  | P7  | P8  | P9  | P10 | P11 | P12 |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| P0   | 0   |     |     |     |     |     |     |     |     |     |     |     |     |
| P1   | 12  | 0   |     |     |     |     |     |     |     |     |     |     |     |
| P2   | 48  | 50  | 0   |     |     |     |     |     |     |     |     |     |     |
| P3   | 60  | 38  | 72  | 0   |     |     |     |     |     |     |     |     |     |
| P4   | 92  | 80  | 127 | 98  | 0   |     |     |     |     |     |     |     |     |
| P5   | 50  | 62  | 131 | 110 | 60  | 0   |     |     |     |     |     |     |     |
| P6   | 92  | 100 | 150 | 130 | 98  | 38  | 0   |     |     |     |     |     |     |
| P7   | 120 | 124 | 168 | 159 | 156 | 96  | 58  | 0   |     |     |     |     |     |
| P8   | 110 | 107 | 144 | 147 | 187 | 172 | 160 | 117 | 0   |     |     |     |     |
| P9   | 22  | 28  | 77  | 67  | 110 | 100 | 157 | 117 | 76  | 0   |     |     |     |
| P10  | 42  | 36  | 49  | 65  | 130 | 164 | 193 | 154 | 98  | 36  | 0   |     |     |
| P11  | 42  | 35  | 96  | 95  | 140 | 72  | 117 | 77  | 84  | 42  | 67  | 0   |     |
| P12  | 24  | 34  | 94  | 64  | 94  | 50  | 69  | 140 | 118 | 48  | 64  | 60  | 0   |

Table 2. Service time and time window of each outlet (after quantification)

| Distribution point | service time window | service time /h | Distribution point | service time window | service time /h |
|--------------------|---------------------|-----------------|--------------------|---------------------|-----------------|
| P0                 | [0,7]               | 0               | P7                 | [3,5]               | 0.2             |
| P1                 | [1,3]               | 0.4             | P8                 | [2.5,5]             | 0.2             |
| P2                 | [1,3]               | 0.4             | P9                 | [1,3]               | 0.4             |
| P3                 | [2.5,5]             | 0.25            | P10                | [1,3]               | 0.35            |
| P4                 | [2,4]               | 0.25            | P11                | [2,4]               | 0.3             |
| P5                 | [2.5,5]             | 0.25            | P12                | [1,3]               | 0.35            |
| P6                 | [3,6]               | 0.3             | P7                 | [3,5]               | 0.2             |

4.2. model parameters

The average price of fruit and vegetable products in the distribution of Suning logistics base is \( p = 30000 \) yuan / ton (from the average price of the investigated products). The vehicles are mechanical refrigerated vehicles, with the maximum load \( Q = 4 \) tons, the average transportation cost \( C_0 = 1 \) yuan / km, the average vehicle speed \( v = 60 \) km / h, the ratio coefficient of goods loss \( \alpha \) is 0.02% (1 / h), the ratio coefficient of goods loss \( \beta \) is 0.01%, and the carbon dioxide emission coefficient \( f \) is 2.82 (kg / L), the unit cost of carbon emission is 0.05 yuan / kg (select the average price in the carbon trading market from October 2016 to April 2019).

4.3. Distribution path solution

According to the improved saving algorithm, the steps to solve the cold chain distribution path of Nanning Suning are as follows:

(1) Calculate that the time taken to drive from Suning logistics base to each regional distribution network is \( t_{0i} \), in which the time window of regional distribution network \( i \) is \([ET_i, LT_i] \), and table 3 is obtained by calculating \( t_{0i} \). 

Table 3. Travel time of logistics base to all regional distribution outlets

| t01 | t02 | t03 | t04 | t05 | t06 | t07 | t08 | t09 | t10 | t11 | t12 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.20| 0.80| 1.00| 1.53| 0.83| 1.53| 2.00| 1.83| 0.37| 0.70| 0.70| 0.40|

\( a_i \) (i = 1, 2, 3 … 12) is the time point from Suning logistics base to 12 regional distribution outlets. If \( t_{0i} \leq ET_i \), then \( a_i = ET_i \); if \( ET_i \leq t_{0i} \leq LT_i \), then \( a_i = t_{0i} \), so the initial solution of \( a_i \) is shown in table 4.
Table 4. Time point of arrival of logistics base at all regional distribution outlets

|   | a1 | a2 | a3 | a4 | a5 | a6 | a7 | a8 | a9 | a10 | a11 | a12 |
|---|---|---|---|---|---|---|---|---|---|----|----|----|
| 1 | 1  | 2.5| 2  | 2.5| 3  | 3  | 2.5| 1  | 1  | 2   | 1   |

(2) Calculate the distance saving value ΔL after connecting regional distribution network i and regional distribution network j. Since the data in the distribution distance matrix in table 4-1 is taken from the actual distance between two points in the map, not the straight-line distance, there will be negative values in the saving value matrix, and negative values will not affect the calculation and solution in this paper.

(3) Select P0 base point of logistics base, and connect P0 with P1, P2… P12 respectively, and 12 lines are obtained. GC1 and Gc12 are calculated respectively, and the lowest total cost \( P_k \) is selected, which meets the requirements of \( E_k < L \) and \( q_k < Q \). Get the cost of distribution.

It can be seen from that the total distribution cost from the logistics base to P1 is the minimum, and it is required to check whether P1 meets the time window and load constraints. \( a_1 = 1 < L, \) and \( q_1 = 0.88 < Q = 4 \), so P1 meets the constraint, and P1 is determined as the first regional distribution network of the first path.

The second, third, fourth and fifth distribution outlets can be determined respectively. After calculation, the time for vehicles to arrive at other regional distribution outlets after the completion of regional distribution outlets P5 does not meet the time window constraints, so the optimization of the route is over.

According to this method, the first path is p0-p1-p3-p4-p5-p0. Repeat the above steps to get all the path planning. Three vehicles are needed. The arrangement is as follows:

- The first distribution route: p0-p1-p3-p4-p5-p0, 258km distribution distance, 2.54t vehicle load;
- The second distribution route: p0-p9-p8-p7-p6-p0, the distribution distance is 365km, and the vehicle load is 2.37t;
- The third distribution route: p0-p12-p11-p10-p2-p0, distribution distance: 235km, vehicle load: 2.96t;

The C-W method is also used to solve the distribution path planning when Suning enterprises do not consider carbon emissions, and to find the path arrangement.

According to the solution results, three vehicles are needed, arranged as follows: the first distribution route: p0-p1-p2-p10-p9-p0, the distribution route is 169km, and the vehicle load is 3.3t; the second distribution route: p0-p12-p4-p5-p3-p0, the distribution distance is 348km, and the vehicle load is 2.43t; the third distribution route: p0-p11-p8-p7-p6-p0, 392km distribution distance, 2.96t vehicle load.

5. Conclusion

When considering the carbon constraints, three vehicles are needed to complete the distribution task. The total distance travelled by the distribution task vehicles is 858km, the carbon emission cost is 65.58 yuan, the cost of goods damage is 45.04 yuan, and the total cost is 969.02 yuan. However, without considering the carbon constraints, three vehicles are needed to complete the distribution task. The total distance travelled by the whole distribution task is 879km, the carbon emission cost is 115.42 yuan, the cost of goods loss is 65.54 yuan, and the total cost is 1059.96 yuan.

The results show that the optimal path model with carbon constraints is lower in carbon emission cost, goods loss cost and total cost than the optimal path model without carbon constraints. According to the analysis, if transport cost and goods damage cost are taken as the objective, the actual optimal solution may not be obtained, and if carbon emission constraints are added to the distribution optimization objective, the operation cost may not be increased.

Acknowledgement

This work is supported by Western project of NSFC (19XGL025), Guangxi Philosophy and Social Sciences Project (17FJY007) and Innovation Project of Guangxi Graduate Education (YCSZ2014203).
References

[1] Woensel TV, Creten R, Vandaele N. Managing the Environmental Externalities of Traffic Logistics: The Issue of Emissions[J]. Production Operations Management, 2001(10): 207-223.

[2] Cai Hao, Xie Shaodong. Determination of vehicle emission factors of different emission standards in China[J]. Journal of Peking University, 2010 (46): 319-326.

[3] LV pin. Study on optimization model of logistics network considering carbon emission[J]. Computer application research, 2013, 30.

[4] Xu conger, Qiu rongzu. Distribution path optimization considering carbon emission and transportation cost [J]. Mathematical practice and understanding, 2016, 46 (21): 89-94.

[5] Xie Shian. Research on the optimization method of delivery and delivery integrated distribution path considering carbon emission and time window [D]. Beijing Jiaotong University, 2017.

[6] Li Jin, Zhang Jianghua. Study on the influence of carbon trading mechanism on the optimization decision of logistics distribution path [J]. System engineering theory and practice, 2014, 34 (7): 1779-1787.