Research on Cold Chain Logistics Path Optimization Considering Cascading Failure

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Abstract: Considering that the storage and transportation products in cold chain logistics are perishable and deteriorate easily, in the actual distribution process, the cascading failure of urban roads will affect the transit times and distribution costs of delivery vehicles. According to the cascading failure process under the edge failure condition, a new diversion rule is established, and then the distribution cost is associated with the transportation speed. The cold chain logistics distribution path optimization model is established, with minimal distribution costs as its objective function, and a Dijkstra-GA algorithm is developed. The Dijkstra-GA hybrid algorithm solves the model. The model is verified by simulation examples. The simulation results verify the applicability of the model and the algorithm.

1. Introduction
At present, mobile Internet and mobile app methods make e-commerce purchase methods increasingly convenient, and people's demand for cold-chain foods is also increasing. Cold chain logistics is undoubtedly the key link to ensuring the freshness of refrigerated products. However, cold chain logistics distribution mainly includes agricultural products, processed foods and special commodities, which are perishable, which makes the products more demanding in terms of time and environment during the distribution process and leads to stricter requirements on the timeliness of cold chain logistics distribution. The frequent occurrence of road and traffic congestion incidents has caused the traffic distribution in certain regional road networks to change, which causes successive failures of other road sections and cascading failures, which seriously affect the distribution process and prolongs the transit time of distribution vehicles. The cost of losing the goods in transit and the added energy costs of the distribution vehicle reduce the quality of the delivery service.

Cold chain logistics research focuses on strategic management of cold chain logistics [1-3], security monitoring[4-6], network optimization and so on. The research on the optimization of cold chain logistics networks includes four aspects: the cold chain logistics cargo loss problem, the cold chain logistics distribution centre inventory control problem, the site selection problem and the distribution route planning problem. This paper will start to study the cold chain logistics distribution route planning problem.

There has been some research on the problem of cold chain logistics distribution route planning. The first strain of research seeks to monitor the change of cargo quality and temperature in cold chain distribution. Due to the perishable nature of cold chain products, food quality loss costs should be integrated into production and distribution costs, and models should be built to provide decision support for designing and optimizing product supply chains and distribution routes [7-9]; In addition,
in order to reduce the cost of cargo damage in the cold chain distribution process, the cargo temperature is introduced as a factor, using wireless sensor modules and network monitoring technology for real-time monitoring [10-12]. Rong et al. [7] proposed a food quality degradation modelling method, integrating food quality levels into production and distribution costs and using mixed integer linear programming models to provide decision support for designing and optimizing food supply chains. The second strain of research seeks to optimize the Green Vehicle Routing Problem (GVRP) for low carbon emissions. GVRP mainly focuses on reducing fuel consumption and reducing CO2 emissions, and calculates fuel consumption by establishing a fuel consumption calculation model for vehicles, analyses the relationship with carbon emission factors, and rationally arranges the transportation route of vehicles to achieve the effect of green transportation [13-15]. Li et al.[15] developed the Cold Chain Logistics Green Vehicle Path Optimization Model (GVRPCCCL) to study the relationship between changing vehicle maximum load and cost and greenhouse gas emissions. The third strain seeks to optimize the cold chain distribution route under certain road conditions. Lan Hui et al. [16] and Ge Xianlong et al.[17] constructed a logistics distribution optimization model based on the traffic conditions of road sections at various times, and developed a hybrid genetic algorithm to solve the problem.

In sum, the previous research on the optimization of cold chain logistics distribution paths mainly focused on the changes of distribution goods quality and temperature monitoring, low carbon emissions, while few studies considered road emergencies in their optimization. Moreover, the dynamic process of roads from normal to cascading failure is not considered. Most of the literature does not consider sudden road situations in the optimization process, and set the speed variable to a certain value, that is, the driving speed of all the paths is set to be the same, which is inconsistent with actual traffic situations. To this end, this paper proposes a cold chain logistics distribution path optimization model in a case of cascading traffic network failure: First, considering the impact of road congestion on traffic flow distribution, the logistic velocity-density model is introduced to develop a new cascading failure diversion rule. Second, the influence of driving speed on the distribution cost of cold chain logistics is considered in the objective function; the impact of the road after cascading failure is analysed and predicted; the sections are predicted according to the degree of failure of each section of the cascade and the traffic speed, a cold chain logistics distribution path optimization model is established, and guidance on the optimization of cold chain logistics distribution path is developed.

2. Problem description and assumptions

2.1 Problem description

Accidents, regulations, congestion and other conditions will affect other road sections when the driving speed of one road section is affected, and cascading failure will occur, which will increase the distribution cost of cold chain logistics and reduce distribution efficiency. After the cascading failure occurs, it is necessary to re-plan the distribution path in time to find an optimal path to provide quality services to customers. The research questions in this paper are described as follows:

The research object is a single distribution centre, single vehicle, and vehicle path problem with a soft time window under cascading failure; that is, the distribution route of a certain vehicle is optimized, and the whole process is delivered. The centre no longer assigns other vehicles to serve the remaining customers; Vehicle fixed cost, unit product cost, unit transportation cost, cargo loss ratio, loading and unloading time, unit energy consumption cost, distance between customers, customer demand and time window restrictions, etc. are known; during the delivery, due to unexpected events, cascading failure of the traffic network occurs; in order to reduce the in-transit time and service delay caused by the cascading failure, the unserved customers need to be re-scheduled, and the remaining paths need to be arranged and re-planned; In the optimization process, take the node where the cascading failure occurs as the starting point, and take the location of the remaining unserved customers as the necessary nodes.
2.2 Research hypothesis
The relevant research considerations in the paper are described as follows:

**Hypothesis 1:** The vehicle encounters cascading failure during delivery, which makes the original delivery route unfeasible. The distribution centre no longer sends vehicles to complete the service, but continues to plan and distribute the completed service by the original vehicle.

**Hypothesis 2:** Only the path optimization of the vehicle's distribution service process is studied. The vehicle completes all services, and the path optimization of the process of returning to the distribution centre is beyond the scope of this paper.

**Hypothesis 3:** The basic information of the customer is known, such as the number of customers, the location of customers, the demand for the goods by the customer, and the time window for the customer to accept the service.

**Hypothesis 4:** Each customer has one and only one car to serve them, and other factors affecting product quality are not considered.

3. Model formulation

3.1 Analysis of cascade failure process based on edge failure

3.1.1 Measure the importance of the edge
According to the importance of the edge in the transportation network, combined with the inherent attributes of the road given during planning, the importance of different sections (edges) is comprehensively measured. In this paper, the network is represented by an undirected graph \( G = \{V, E\} \), where \( V = \{v_i\} \) represents the set of nodes in the network and \( E = \{e_{ij}\} \) represents the set of edges, \( i, j = 1, 2, \cdots N \).

The initial importance of any node \( v_i \) is \( S_i^0 = \frac{k_i}{\langle K \rangle} \) \hspace{1cm} (1)

The traffic impact coefficient \( \delta_{ij} \) of any node \( v_i \) to the adjacent node \( v_j \) can be expressed as:
\[
\delta_{ij} = \frac{1}{k_i} \times R_{ij} = \frac{k_i}{(k_i + k_j) \times <K>}
\] \hspace{1cm} (2)

The importance of edge \( e_{ij} \) is \( A_{ij} : A_{ij} = S_i^{0\delta_j} \times S_{ij}^{0\delta_j} \) \hspace{1cm} (3)

The comprehensive importance of edge \( e_{ij} \) is \( Q_{ij} : Q_{ij} = \alpha A_{ij} + (1 - \alpha) B_{ij} \) \hspace{1cm} (4)

In equation (1) (2) (4), \( k_i \) represents the degree of the node; \( \langle K \rangle \) represents the average of all nodes of the network; \( 1 / k_i \) represents the average partition coefficient; \( R_{ij} \) represents the influence weight of any node 1 on the adjacent node 2, \( B_{ij} \) represents the degree of importance of edge \( e_{ij} \); \( \alpha \) and \( 1 - \alpha \) respectively indicate the importance of the edge in the traffic network and the influence weight of its own importance.

3.1.2 Measure the degree of edge failure
The load capacity is described by the capacity-load model, and the initial load is \( L_{ij} \):
\[
L_{ij} = (Q_{ij})^c \times (1 + \text{rand} \ast (P - \text{1} \ast \text{rt}) \ast A_{ij})
\] \hspace{1cm} (5)

The load capacity of edge \( e_{ij} \) is \( C_{ij} : C_{ij} = P \ast L_{ij} \) \hspace{1cm} (6)

The introduction of road saturation describes the traffic pressure on the road, and road saturation is represented by the Logistic velocity-density relationship.
At moment \( t \), the density \( \rho_j(t) \) of the edge \( e_j \) is:

\[
\rho_j(t) = \frac{L_j(t)}{C_j(t)} \tag{7}
\]

Degree of failure of edge \( e_j \) is \( M_j \):

\[
M_j = \frac{1}{u} \left( \frac{1}{\rho_j(t)} - \frac{1}{\rho_{\text{min}}(t)} \right) \tag{8}
\]

In equation (5)(6)(7)(8), the load capacity of the edge \( e_j \) is \( C_j \), the initial load is \( L_j \), \( P \) is the network tolerance parameter \( (P \geq 1) \), \( e \) represents an adjustable weight parameter, \( \text{rand} \) is a random number between 0 and 1, \( rt \) is a parameter that controls the entire network system \( (0 \leq rt \leq 1) \), the value is positively correlated with the size of the entire network; the larger the value, the larger the network size. Considering that the load capacity represents the number of vehicles on the side, they are all integers that need to be rounded in the calculation. \( u \) is the maximum speed limit of the road segment; \( \rho_{\text{max}} \) is the maximum congestion density of edge \( e_j \), specifically the density of the load \( C_j \) of the road segment; \( \rho_j(t) \) is the congestion density of the road segment at time \( t \); \( L_j(t) \) is the load of edge \( e_j \) at time \( t \).

### 3.1.3 Develop a flow distribution rule

If a complete failure occurs, the adjacent edge needs to be shunted. The shunting is based on the importance of the adjacent edge in the network; that is, the more important the adjacent edge, the more it receives of the failed edge \( e_j \) ’s load. The adjacent edge \( e_{pq} \) receives the load distribution \( \Delta L_{jp}^* \) from the failed edge \( e_j \) as:

\[
\Delta L_{jp}^* = \Theta_{jp} L_j = \frac{Q_{jp}}{\sum_{e_{pq} \in \Gamma_{pq}} Q_{pq}} L_j \tag{9}
\]

This paper also considers the impact of the degree of edge failure on the driver's path selection. The new load distribution rules are:

\[
\Delta L_{jp} = \frac{Q_{jp}}{\sum_{e_{pq} \in \Gamma_{pq}} Q_{pq}} (1 - M_{jp}) L_j \tag{10}
\]

The load \( L_{jp}(t) \) of any adjacent edge \( e_{jp} \) at moment \( t \) is:

\[
L_{jp}(t) = L_{jp}(t-1) + \Delta L_{jp} \tag{11}
\]

In equation (9)(10)(11), \( \Theta_{jp} \) is the distribution ratio of the load on the failed edge obtained by the adjacent edge \( e_{jp} \), \( \Gamma_{pq} \) is the set of adjacent edges at the \( v_p \) end of the node; \( L_{jp}(t-1) \) is the real-time load of the adjacent edge \( e_{jp} \) at time \( t-1 \).

To re-determine the relationship between the load distribution \( L_{jp}(t) \) of the adjacent edge and the maximum load capacity \( C_{jp} \). If \( L_{jp}(t) \geq C_{jp} \), \( e_{jp} \) will trigger a new round of failed load distribution for the failed edge; If \( L_{jp}(t) < C_{jp} \), the edge \( e_{jp} \) does not fail during this period.

### 3.1.4 Calculate the degree of failure

The loss ratio of the edge is used as an evaluation index of the network damage degree after the cascading network failure. The larger the index value, the greater the destructiveness of the cascading failure towards the network and the lower the network stability. This is calculated by:

\[
CF = \frac{\sum_{e \in E_f} CF_e}{N_f (N_E - 1)} \tag{12}
\]

In equation (12), \( E_f \) is the set of completely dead edges, \( N_E \) is the number of network edges \( N_f \).
is the number of initial dead edges, \( CF_{ij} \) is the number of complete failures of other edges caused by the initial failed edge \( e_{ij} \), \( 0 \leq CF_{ij} \leq N_{E} - 1 \).

3.2 Analysis of cold chain logistics distribution costs

The model takes the lowest comprehensive cost as the objective function, and the comprehensive cost consists of four costs: transportation cost, cargo damage cost, energy cost and time window penalty cost.

The calculation formula of transportation cost \( C_1 \) is:

\[
C_1 = C_a \cdot \sum_{i=0}^{m} \sum_{j=0}^{m} x_{ij} \cdot d_{ij}
\]  
(13)

This paper considers that the cascading failure will indirectly affect the network traffic speed, which in turn affects the cargo damage cost. The cargo damage cost \( C_2 \) is expressed as:

\[
C_2 = C_b \cdot \left( \sum_{i=0}^{m} \sum_{j=0}^{m} \sum_{p=1}^{n} \left( \xi_1 \cdot t_p + x_{ij} \cdot \frac{d_{ij}}{u_{ij}} \cdot W'_p \right) + \sum_{p=1}^{n} \left( \xi_2 \cdot t_p \cdot W_p \right) \right)
\]  
(14)

The cost of energy consumption refers to the temperature regulation of the vehicle in order to keep the cargo at a suitably low temperature during the distribution process. The energy consumption is the same as the cost of the cargo damage. When the cascading failure occurs, it will indirectly affect the network traffic speed and thus affect the impact. Energy cost \( C_3 \) can be expressed as:

\[
C_3 = \sum_{i=0}^{m} \sum_{j=0}^{m} \alpha_i \cdot \left( t_p + x_{ij} \cdot \frac{d_{ij}}{u_{ij}} \right) + \sum_{p=1}^{n} (\alpha_2 \cdot t_p)
\]  
(15)

Penalties include advance delivery, early delivery, timely delivery, delayed delivery, and late delivery of five cases, so the penalty cost \( PC_{(p)} \) can be expressed as:

\[
PC_{(p)} = \begin{cases} 
\frac{1}{10} C_{W_p} \cdot T_p < AET_p \\
\min \left( \frac{1}{10} C_{W_p} \cdot a(BET_p - T_p) W_p \right) \cdot AET_p < T_p < BET_p \\
0, \text{ if } BET_p < T_p < BLT_p \\
\min \left( C_{W_p} \cdot b(T_p - BLT_p) W_p \right) \cdot BLT_p < T_p < ALT_p \\
C_{W_p}, T_p > ALT_p
\end{cases}
\]  
(16)

Therefore, the time window penalty cost \( C_4 \) is:

\[
C_4 = \sum_{p=1}^{n} PC_{(p)}
\]  
(17)

In equation(13)(14)(15)(16), \( x_{ij} \) represents the choice of the vehicle path. If the vehicle passes the edge \( e_{ij} \), the \( x_{ij} \) value is 1, otherwise it is 0; \( d_{ij} \) is the distance of the edge \( e_{ij} \); \( u_{ij} \) is the speed at which the goods are transported from point \( v_i \) to point \( v_j \); it is related to the degree of failure \( M_{ij} \) of the edge \( e_{ij} \); \( C_a \) is the average price of the product; \( x_{ij} \) indicates whether the goods are delivered from point \( v_i \) to point \( v_j \); \( \xi_1 \) is the rate of loss per unit time during transportation; \( \xi_2 \) is the rate of loss per unit time during loading and unloading. \( t_p \) is the time taken for the goods to be loaded and unloaded at the customer node \( v_p \); \( W'_p \) is the quantity of goods remaining on the vehicle after the completion of point
$v_p$ distribution; $W_p$ is the quantity of goods required at point $v_p$; $\omega_1$ and $\omega_2$ are the energy costs per unit time of the vehicle during transportation and handling, respectively; $T_p$ is the time when the vehicle arrives at customer $p$, $AET_p$ is the earliest arrival time acceptable to the customer, $BET_p$ is the earliest arrival time to satisfy the customer, $BLT_p$ is the latest arrival time for customer satisfaction, $ALT_p$ is the latest arrival time that the customer can accept.

### 3.3 Building a distribution path optimization model

The established cold chain logistics distribution path optimization model with minimum distribution costs as its objective function is as follows:

$$Min(C_1 + C_2 + C_3 + C_4)$$

s.t. \[ \sum_{i=1}^{n} y_i r_i \leq W, i = 1, 2, \ldots, n \] \hspace{1cm} (19)

\[ x_i = 1, i = 1, 2, \ldots, n \] \hspace{1cm} (20)

\[ \sum_{j=1}^{n} x_{ji} = \sum_{a=1}^{n} x_{aj}, a = 1, 2, \ldots, m \] \hspace{1cm} (21)

Equation (19) is a weight constraint, indicating that the total demand of the transportation line is not greater than the capacity of the transportation vehicle; Equation (20) is a service number constraint, indicating that each customer has one and only one vehicle providing for their delivery service; Equation (21) is the balance constraint, which indicates that the number of times the delivery vehicle arrives and leaves each node is the same.

### 3.4 Algorithm Design

According to the structural characteristics of the model and the feasible domain of the decision variables, the Dijkstra-GA algorithm is used to solve the model. The overall solution process is based on the genetic algorithm steps. The Dijkstra algorithm participates in the solution of each chromosome in the model. The specific steps of the algorithm’s solution are as follows:

**Step 1:** Encoding to generate the initial population. The starting node of the vehicle is the node in the direction of travel of the vehicle’s current path. The coded form is real coded, that is, the real number 1, 2, 3, .., n, represents the delivery point number of the unfinished service.

**Step 2:** Calculate chromosome fitness. First, obtain the distribution cost for each edge in the current situation. Then, determine the initial node to be searched, and generate three arrays of length $n$ for storing the minimum distribution cost lengths, the last node path of the node’s minimum distribution cost path, the known node set, the maximum at the beginning, while only the initial node is in the known collection. Finally, calculate the minimum distribution cost, look at the adjacency matrix, and if there is a path from the starting node to the target node, change the length (i) value to the value in the matrix and change path (i) to the destination. Find the minimum unknown length value, add the corresponding node to the known values, and use this node to judge the node value. If the cost to node $v_i$ plus node $v_i$ to node $v_j$ is less than the current record for the cost of node $v_j$, the node $v_j$ value is updated and repeated until the minimum cost of the initial node to the target node is found.

**Step 3:** Select a regenerative individual. Individuals with high chromosomal suitability were selected using a roulette and passed on to the next generation as a parent.

**Step 4:** Crossover. Individuals in the population are randomly sorted into pairs, and some genes in the paired individuals are exchanged with a certain crossover probability to obtain a new generation of individuals.

**Step 5:** Mutation and two-point exchange operation on the children. The fitness is calculated before and after the exchange. If the fitness is better than before, the value after the mutation is used. If
it is worse, the random mutation is performed again.

**Step 6:** The operation is terminated. After completing the gene generation inheritance, stop the operation and output the optimal solution; otherwise, return to step 3.

4. Model Experiment

4.1 Experimental Design

A city vehicle, A, departs from distribution centre node 22 and serves customers of nodes 4, 6, 15, 26, 31, 36, and 38. It is known that the rated load of A is 7805 kg, the transportation cost per unit of distance is 3.4RMB/km, the time taken by the cargo handling unit per unit of weight is 0.2 h/t, the unit price of goods is 2000RMB/t, the proportion of cargo loss per unit of time in transportation is 0.012, and the unit of time is measured from loading to unloading. The cargo loss ratio is 0.014, the temperature-controlled energy loss cost per unit of time in transportation is 1RMB/h, the temperature-controlled energy loss cost from loading and unloading is 1.2RMB/h, and the penalty cost coefficient exceeding the optimal time window constraint is 100RMB/(h•t). At 4 o'clock, the vehicle found that the road in front of it was seriously congested due to traffic accidents, which began to affect other roads by 5:30. The distribution traffic network structure is shown in Figure 1. The customer demand and time window requirements are shown in Table 1. The distance between nodes in the road network is shown in Table 2. The genetic population size is 40, the genetic frequency is 100, the crossover probability is 0.6, and the mutation probability is 0.05.

Run the Matlab program and simulate under normal conditions. At this time, each road in the network runs well and is in an equilibrium state. Enter the basic information of each node in the traffic network, as shown in Figure 2. The points in the figure indicate that the node is connected to the node. The network node degree distribution is shown in Figure 3. Obtain the initial load and rated load on each side of the network as shown in Table 2.

| Customer node | Demand (tons) | [BET,BLT] | [AET,ALT] | Customer node | Demand (tons) | [BET,BLT] | [AET,ALT] |
|---------------|---------------|-----------|-----------|---------------|---------------|-----------|-----------|
| 4             | 1             | 4:20      | 4:50      | 26            | 0.4           | 8:10      | 8:40      | 7:40      | 9:20      |
| 6             | 1.2           | 5:00      | 5:30      | 36            | 0.8           | 9:00      | 9:30      | 8:30      | 10:00     |
| 15            | 1.6           | 5:50      | 6:20      | 5:20          | 6:00          | 38        | 0.6       | 6:30      | 7:00      | 6:00      | 7:30      |
| 31            | 1.2           | 7:00      | 7:30      | 6:30          | 8:00          |           |           |           |           |

Fig. 1 Traffic network structure within the scope of vehicle A distribution
4.2 Simulation Analysis

4.2.1 Distribution simulation under normal conditions

Perform the solution under the initial, normal conditions of the network, as shown in Figure 5. The optimal delivery order is 22-4-6-15-8-31-26-36; that is, the delivery vehicle starts from the distribution centre at the 22nd node, and makes deliveries in the order of 4, 6, 15, 38, 31, 26, and 36. At this time, the total distribution cost was 683.44 RMB, and the delivery distance was 49,920 metres. The total
time to complete the delivery was 5 hours and 13 minutes. The optimal delivery path is: 22-17-9-10-3-4-3-2-6-8-7-13-16-15-20-25 -32-33-38-33-32-31-32-25-26-35-36.

4.2.2 Distribution Simulation in the Case of Sudden Cascading Failure

The path optimization when cascading failure occurs is divided into two phases. The first phase is before the cascading failure occurs, when the distribution centre plans the distribution route of the vehicle according to normal distribution traffic network conditions, and obtains the normal situation above. The cost, time, route, etc. of the distribution path. The second stage re-plans the distribution route according to the traffic network after the failure. According to the different sources of failure, the distribution path failure and the non-distribution path failure are carried out separately. The algorithm process is the same as it was in the first phase. The final total distribution cost is the sum of the distribution costs before and after the failure. Assume that the failure condition occurs at 5:30: the normal distribution route is calculated, and when the time is known, the vehicle is sent to node 3 and node 2, and the delivery service of the customer point 4 has been completed. 7:00 is set as the failure stop time, and the failure degree of each path at this time is used as the final failure degree to predict the traffic conditions of each path.

It is assumed that the delivery path failure occurs between node8 and node7, the non-distribution path failure occurs between node18 and node 29. According to the cascading failure process and the load diversion rules formulated in this paper, the failure degree of the traffic network cascade is calculated, where CF1 represents the final failure condition of the distribution path, and CF2 represents the final failure condition of the non-distribution path. The results are shown in Table 3.

| i  | j  | CF1 | CF2 | i  | j  | CF1 | CF2 | i  | j  | CF1 | CF2 | i  | j  | CF1 | CF2 |
|----|----|-----|-----|----|----|-----|-----|----|----|-----|-----|----|----|-----|-----|
| 1  | 2  | 0.97| 0.84| 10 | 11 | 1.05| 1.01| 19 | 24 | 0.85| 0.88| 34 | 0.91| 1.21| 29 | 34 | 0.91| 1.21|
| 1  | 7  | 1.03| 0.87| 11 | 14 | 1.03| 1.08| 20 | 21 | 0.89| 0.91| 31 | 0.89| 0.86| 30 | 31 | 0.89| 0.86|
| 2  | 3  | 0.9 | 0.84| 12 | 13 | 1.18| 0.96| 20 | 25 | 0.8 | 0.86| 37 | 0.78| 0.82| 30 | 37 | 0.78| 0.82|
| 2  | 6  | 0.87| 0.78| 12 | 15 | 1   | 0.84| 21 | 22 | 0.81| 0.83| 32 | 0.77| 0.83| 31 | 32 | 0.77| 0.83|
| 3  | 4  | 0.88| 0.76| 12 | 19 | 0.98| 0.91| 22 | 27 | 0.84| 0.86| 33 | 0.77| 0.78| 32 | 33 | 0.77| 0.78|
| 3  | 10 | 0.88| 0.83| 13 | 16 | 1.09| 0.93| 22 | 28 | 0.81| 0.97| 35 | 0.84| 0.83| 33 | 35 | 0.84| 0.83|
| 4  | 5  | 0.81| 1.03| 14 | 18 | 1.03| 1.06| 23 | 24 | 0.86| 0.8 | 38 | 0.93| 0.84| 33 | 38 | 0.93| 0.84|
| 4  | 11 | 0.8 | 0.78| 15 | 16 | 0.88| 0.83| 23 | 30 | 0.9 | 0.77| 36 | 0.95| 1.02| 34 | 36 | 0.95| 1.02|
| 5  | 14 | 0.88| 1.08| 15 | 20 | 0.8 | 0.81| 24 | 25 | 0.79| 0.8 | 36 | 0.92| 0.89| 35 | 36 | 0.92| 0.89|
| 6  | 8  | 1.3 | 0.86| 16 | 17 | 0.95| 1.08| 24 | 31 | 0.88| 0.73| 38 | 0.92| 0.87| 35 | 38 | 0.92| 0.87|
| 6  | 9  | 1.19| 0.86| 16 | 21 | 0.81| 0.98| 25 | 26 | 0.85| 0.87| 39 | 0.97 | 1  | 36 | 39 | 0.97| 1  |
| 7  | 8  | --  | 0.83| 17 | 18 | 0.93| 1.22| 25 | 32 | 0.85| 0.83| 38 | 0.86| 0.89| 37 | 38 | 0.86| 0.89|
| 7  | 13 | 1.24| 0.88| 17 | 22 | 0.94| 1.13| 26 | 27 | 0.8 | 0.86| 40 | 0.84| 0.85| 37 | 40 | 0.84| 0.85|
| 8  | 9  | 1.21| 0.84| 18 | 29 | 0.81|--  | 26 | 35 | 0.88| 0.81| 39 | 0.84| 0.87| 38 | 39 | 0.84| 0.87|
| 9  | 10 | 1.06| 0.9 | 19 | 20 | 0.86| 0.91| 27 | 28 | 0.8 | 1.01| 40 | 0.9 | 0.91| 39 | 40 | 0.9 | 0.91|
| 9  | 17 | 1   | 0.93| 19 | 23 | 0.87| 0.87| 28 | 29 | 0.86| 1.17|--  | --  | --  | --  | --  | --  | --  | --  |

After the burst cascading failure occurs, the optimal distribution path is first calculated according to the normal situation, and the total cost of distribution, time consumption, optimal delivery sequence, driving distance, and optimal path are obtained, as shown in Table 4.

Then, optimize again to obtain the optimal distribution path under cascading failure. According to the failure prediction, the delivery route is changed, and the network is updated with the final failure result. The current location of the vehicle is the starting point, the current load is the initial weight, and the current time is the departure time. The customer nodes for which delivery has been completed are deleted, and the remaining nodes are distributed. The task is performed, and the delivery order of the remaining nodes is finally obtained. The results of the total distribution cost, time consumption, optimal delivery sequence, driving distance, and optimal path of the final delivery route and the non-distribution route failure are shown in Table 4.
version rules are formulated to better describe the impact of the cascading failure. A greater than
improved by combining the dynamic process of cascading failure, an improved urban distribution environment.
considered.
considering the transportation cost of the vehicle, various cost factors, such as the soft time window requirement and the cargo damage cost during the transportation loading and unloading process, are also considered. The model established by this paper not only considers the characteristics of urban road network cascading failure but also considers the characteristics of urban road congestion speed change. Compared with the traditional cold chain vehicle path planning problem, this approach is closer to the real urban distribution environment. In the future, the distribution process can be further optimized and improved by combining the dynamic process of cascading failure, and the adaptability of the distribution path to the real-time change of vehicle transportation status can be improved.

Table 4 Comparison of experimental results

|                        | Normal          | Delivery path failure | Non-delivery path failure |
|------------------------|-----------------|-----------------------|---------------------------|
| Distribution cost as normal | 683.44(RMB)     | 2532.56(RMB)          | 2078.62(RMB)              |
| Optimized distribution cost | -              | 1787.89(RMB)          | 1785.01(RMB)              |
| Time-consuming as normal | 313(min)        | 422(min)              | 399(min)                  |
| Optimized time-consuming | -              | 377(min)              | 364(min)                  |
| Travel distance as normal | 49.92(km)       | 55.63 (km)            | 52.35(km)                 |
| Optimized driving distance | -              | 52.88(km)            | 50.4(km)                  |
| Optimal delivery order  | 22-4-6-15-38-31-26-36 | 6-15-31-26-36-38 | 6-15-31-26-36-38           |
| Optimal path            | 3-16-15-20-25-2-33-38-33-3 | 7-16-15-20-25-32-31-32-2 | 3-16-15-20-25-32-31-32-25 |
|                        | 2-31-32-5-26-35-36 | 25-26-35-36-39-38    | 26-35-36-39-38             |

Experiments are carried out in the above situation. It can be seen from Table 4 that, after the failure of the distribution route and the non-distribution route, the distribution cost, delivery time, and delivery distance greatly increased, indicating that cascading connection failure will occur after the cold chain distribution occurs. This will have a substantial impact. However, through the optimization of the model, the goals of reducing the distribution cost, shortening the driving distance and reducing the delivery time are achieved.

It can be seen from Tables 3 and 4 that the final failure degree of the network when the distribution path fails is greater than the final failure degree of the network when the non-distribution path fails, and the delivery time, delivery cost, and delivery distance of the delivery path failure are greater than those of the non-distribution path. From the distribution time, distribution cost and distribution distance, it can be seen that the impact of the delivery path failure on the traffic along other distribution paths is greater than the impact caused by non-distribution path failure.

5. Conclusion and future work

In this paper, first, road congestion is judged according to the driving speed of the vehicle, and then the road is judged to be invalid. In this paper, firstly, according to the vehicle speed to judge the road congestion, and then judge whether the road is invalid, according to the importance of the edge, make the diversion rules, better depict the cascading failure effect. and according to the importance degree of the edge, the diversion rules are formulated to better describe the impact of the cascading failure. Second, considering the distribution cost, not only the transportation cost, the distance is related to the delivery time. When cascading failure occurs, it will affect the network traffic speed indirectly, which will affect the delivery time and distribution cost. The model's cost function is fully considered to affect the cost of the vehicle. Finally, according to the particularity of the cold chain distribution requirements, when constructing the model with minimum distribution costs, in addition to considering the transportation cost of the vehicle, various cost factors, such as the soft time window limitation and the cargo damage cost during the transportation loading and unloading process, are also considered.

The model established by this paper not only considers the characteristics of urban road network cascading failure but also considers the characteristics of urban road congestion speed change. Compared with the traditional cold chain vehicle path planning problem, this approach is closer to the real urban distribution environment. In the future, the distribution process can be further optimized and improved by combining the dynamic process of cascading failure, and the adaptability of the distribution path to the real-time change of vehicle transportation status can be improved.

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