Optimization model and algorithm of logistics distribution path based on urban road network time-varying

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Abstract. In the urban road network, the speed of different sections is different; In the same road section, the speed is different at different times. Therefore, on the basis of considering the temporal variability of the road network, this paper takes the shortest delivery time as the optimization objective to find the optimal logistics distribution path between the urban logistics distribution nodes in different time periods. Based on this, an urban logistics distribution path optimization model with the shortest delivery time as the optimization objective is established. In order to improve the solution quality and efficiency of the model, the time impedance matrix of urban logistics distribution network was constructed and an improved distance matrix algorithm was designed to solve the model. Finally, an example is given to verify the effectiveness of the model and algorithm.

1. Introduction

With the acceleration of the pace of economic development, people are demanding more and more time for logistics and distribution. However, urban traffic congestion has become a pain point that hinders the optimization of logistics and distribution time. Therefore, how to flexibly optimize the logistics distribution path, improve the driving speed of logistics vehicles, and minimize the increase of logistics distribution time caused by urban traffic congestion has become an urgent problem to be solved.

Vehicle Routing Problem (VRP) was proposed by Dantzig and Ramser in 1959, which was used to study the optimal design of transportation route for Vehicle dispatching from Atlanta refinery to each gas station [1]. Subsequently, many experts and scholars at home and abroad have conducted extensive and in-depth research on mathematical model and intelligent algorithm of VRP. Many excellent research results have been obtained abroad [2-3]. In China, Bao chunling established an optimization model of joint distribution path of cold chain logistics that took time window, carbon emission cost and cargo loss cost into account. By introducing a virtual car yard, the problem of multiple distribution centers was transformed into a single distribution center problem, and an improved genetic algorithm solution model was designed[4]. Liu Yanqiu classifies nodes according to the characteristics of customer demand nodes, establishes an integer linear programming model aiming at minimizing the sum of vehicle invocation cost, vehicle transportation cost and transportation cost of third party logistics to solve the optimal distribution path among logistics nodes, and modifies the operation mode of probability selection in the traditional algorithm. A new intelligent optimization
algorithm is proposed, and the performance of genetic algorithm is compared and analyzed [5].

Among the domestic and foreign scholars' researches on the optimization of logistics distribution path, few scholars have considered the influence of urban road network traffic state variability on the optimization of logistics distribution path. Therefore, this paper considers the real-time road traffic situation, proposes different logistics path optimization schemes in different time periods, and establishes an urban logistics distribution optimization model with the shortest delivery time as the optimization objective. Based on the improved impedance matrix algorithm and the example data, the effectiveness of the model is verified.

2. Logistics distribution path optimization model analysis

2.1. Problem description
In the urban traffic network, the traffic condition of the network is different in different time periods, so the speed of vehicles is different in different time periods in the same section. The optimization model of urban logistics distribution path with the objective of time optimization is to find the shortest distribution path suitable for the current road traffic conditions in different periods of time in the urban road network.

The optimization model of logistics distribution based on the time variability of urban network can be described as: in the urban logistics distribution network \( G=(V,A) \), \( V \) is the collection of network logistics distribution node \( v_i \); \( A \) is the collection of \( a_{ij} \) between nodes of logistics distribution network; \( t_{ij}^{n} \) is the passage time of the section between node \( i \) and node \( j \) at time \( n \). Find the shortest path between nodes.

2.2. Model building
In order to reduce the impact of traffic congestion on urban logistics and distribution, the decision-making layer encourages the operation of urban logistics and distribution to stagger the peak hours of urban road traffic and carry out staggered distribution. In the actual logistics distribution, due to the limitation of customer delivery time, logistics distribution is often carried out in each period. In different periods of time, the traffic conditions of urban traffic network are different, so it is necessary to design different logistics distribution path optimization schemes for the traffic conditions in different periods.

Objective function of minimum road impedance: this model takes \( t_{ij}^{n} \), the passing time of each section, as the impedance value of each section, and designs the distribution path with the minimum time impedance between each node \( v_i \) in urban logistics distribution network \( G=(V,A) \) to meet customers' demand for logistics distribution time. Let \( \min Z \) be the minimum impedance time of urban logistics distribution optimization path; \( N \) is the total number of urban logistics distribution nodes; \( n=1 \) is the flat peak period of urban traffic network; \( n=2 \) is the peak period of urban traffic network; \( t_{ij}^{n} \) is the time impedance of the section between node \( i \) and node \( j \) during the flat peak period; \( t_{ij}^{2} \) is the time impedance of the road section between node \( i \) and node \( j \) during peak period; Equation (2) gives the time impedance value rule between nodes.

\[
\min Z = \begin{cases} 
\sum_{i=1}^{N} \sum_{j=1}^{N} t_{ij}^{1} & \text{(flat peak period)} \\
\sum_{i=1}^{N} \sum_{j=1}^{N} t_{ij}^{2} & \text{(peak period)} 
\end{cases}
\]  

(1)
Constraints of the model: In order to stabilize the road traffic state in each period of urban road traffic network, urban road traffic network sections should satisfy the following constraints:

\[ 0 \leq x_{ij}^n \leq c_{ij}^n, \quad a_{ij} \in A \]  

(3)

Formula (3) represents that all sections in the urban road network are unblocked sections, in which \( x_{ij}^n \) is the flow between node \( i \) and node \( j \) in period \( n \), and \( c_{ij}^n \) is the maximum capacity between node \( i \) and node \( j \) in period \( n \).

Urban road traffic network nodes should meet the following constraints:

When the node is the intermediate point:

\[ \sum_{v \in V} x_{ij} - \sum_{v \in V} x_{ji} = 0 \]  

(4)

When nodes are source and sink points

\[ \sum_{v \in V} x_{sj} = \sum_{v \in V} x_{is} \]  

(5)

Formula (4) indicates that the traffic flow into the intermediate node in the urban road traffic network is equal to the traffic flow out of the intermediate node; Equation (5) indicates that the total traffic flow emitted from the source point is equal to the total traffic flow imported at the junction point. Where \( s \) is the source point in the urban road traffic network; \( t \) is the junction of urban road traffic network.

In terms of urban logistics distribution, the following constraints should be met:

\[ 0 < t_{ij}^n \leq T_{ij}^n \]  

(6)

Equation (6) represents the time constraint between urban logistics distribution nodes. Where, \( T_{ij}^n \) is the maximum bearing value of distribution time between node \( i \) and node \( j \) in period \( n \).

3. Algorithm design based on distance matrix method

In solving the shortest path problem between two points, Dijkstra algorithm is generally recognized as a better algorithm at present, but it is more complicated to solve the shortest path problem between any two points. If there are \( n \) nodes in the network \( G = (V, A) \), it needs to repeat calculation \( n \) times. However, the distance matrix algorithm only needs to calculate once to solve the shortest circuit between any two points in the network, which is relatively simple. Therefore, the distance matrix algorithm is selected in this paper to solve the problem.

Step 1: first construct a time impedance matrix \( T \):

\[ T = \begin{bmatrix} t_{ij}^n \end{bmatrix} \]

The element \( t_{ij}^n \) in \( T \) is defined as follows:

\[ t_{ij}^n = \begin{cases} \text{given time impedance} & \text{a distribution path between } i \text{ and } j \\ 0 & i = j \\ \infty & \text{no distribution path between } i \text{ and } j \end{cases} \]

Step 2: calculate the minimum time impedance matrix \( T \) that can reach a certain point after one
step;

Step 3: calculate the minimum time impedance matrix \( T_2 \) that reaches a certain point through two steps at most.

\[
T^{(2)} = T^{(1)} \bullet T^{(1)} = \left[ t_{ij}^{n(2)} \right]
\]

\[
t_{ij}^{n(2)} = \min \left[ t_{ik}^{n} + t_{kj}^{n} \right] \quad (k=1,2,\cdots,m)
\]

Where: \( m \) is the number of nodes; \( \bullet \) is the logical operator;

Step 4: similarly, it can obtain the minimum time impedance matrix \( T_3 \) that reaches a certain point through a maximum of three steps.

\[
T^{(3)} = T^{(2)} \bullet T^{(1)} = \left[ t_{ij}^{n(3)} \right]
\]

\[
t_{ij}^{n(3)} = \min \left[ t_{ik}^{n(2)} + t_{kj}^{n} \right] \quad (k=1,2,\cdots,m)
\]

Step 5: calculate until \( T_w \), \( T_w = T_{w-1} \), that is, each element in \( T_w \) equals the corresponding element in \( T_{w-1} \). At this point, \( T_w \) is the minimum time impedance matrix between any nodes in the urban logistics distribution network.

4. Examples

As shown in Figure 1 flat peak period for A city logistics distribution network, A total of four logistics nodes, each node between A total of five sections, each section of the length of time between impedance as shown in the above. Based on the above algorithm steps, the distribution path of the minimum time impedance between any node is calculated.

According to the calculation of the above algorithm steps, the maximum time impedance matrix \( T_i^f \) and \( T_i^p \) are the minimum time impedance matrices between the logistics distribution nodes in the city during flat peak period and peak period. The total minimum distribution time of each logistics distribution node in the city during flat peak period and peak period is 38 unit time and 52 unit time, respectively.

\[
T_i^f = \begin{bmatrix} 0 & 3 & 2 & 6 \\ 3 & 0 & 1 & 3 \\ 2 & 1 & 0 & 4 \\ 6 & 3 & 4 & 0 \end{bmatrix} \quad T_i^p = \begin{bmatrix} 0 & 4 & 3 & 7 \\ 4 & 0 & 5 & 3 \\ 3 & 5 & 0 & 7 \\ 7 & 3 & 7 & 0 \end{bmatrix}
\]

Using the back tracking method, we can get the optimal distribution path between each node of the logistics distribution in flat peak period and peak periods of the urban road network in the following table.
### Table 1. Optimal distribution path between logistics distribution nodes during flat peak period and peak periods of urban road network

| Urban Logistics Node | Flat peak period optimal distribution route | Best distribution route during peak period | Shortest Distribution Time in Flat Peak period (Unit: Time) | Shortest Distribution Time in Peak period (Unit: Time) |
|----------------------|---------------------------------------------|------------------------------------------|------------------------------------------------------------|------------------------------------------------------|
| V1-V1                | -                                           | a13-a32-a24                              | 6                                                         | 7                                                    |
| V1-V2                | a13-a32-a42-a24                            | a12-a24-a42                              | 6                                                         | 7                                                    |
| V1-V3                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V1-V4                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V2-V1                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V2-V2                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V2-V3                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V2-V4                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V3-V1                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V3-V2                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V3-V3                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V3-V4                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V4-V1                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V4-V2                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V4-V3                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |
| V4-V4                | a13-a32-a24                                | a12-a24-a42                              | 6                                                         | 7                                                    |

#### 5. Conclusion

Based on the traffic stability constraint of urban road network, this paper takes the shortest logistics distribution time as the objective to construct the optimal logistics distribution path model. The model also considers the time variability of urban road network traffic conditions, and designs different optimal logistics distribution paths in different time periods. In the process of solving the model, the time impedance of each section of urban logistics distribution network is abstracted into time impedance matrix, and the time impedance matrix algorithm is designed to solve the model. Finally, the validity of the model and the algorithm is verified by a concrete example.

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