Logistics Distribution Path Optimization Based on Real-Time Road Conditions

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Abstract. With the rapid development of online shopping platform, the traditional logistics distribution system is facing great challenges, which aggravates the operation pressure of urban traffic and makes the planning of logistics distribution route more complicated. However, the existing distribution route selection mainly depends on manual experience, which is difficult to achieve efficient and accurate distribution requirements. The traditional vehicle path planning model regards the road traffic status between nodes as fixed, which is difficult to make effective guidance for logistics distribution. Therefore, this paper selects a certain area of Zhengzhou City as the research object, introduces the road congestion index and the model conversion distance, and proposes a dynamic logistics distribution path optimization model considering real-time road conditions, which can quickly find the optimal distribution plan in a complex road operating environment. Firstly, the road network of the study area is drawn, and ArcGIS is used to obtain the latitude and longitude coordinates of each node of the selected road network. Secondly, Python language is used in Visual Studio Code to crawl real-time data of road traffic, including congestion degree, length of congested road section, driving speed and so on. Then, the congestion index database and the optimal distance matrix of each road section in each day from 07: 00 to 20: 00 in a week are established in hours, so as to calculate the initial distribution scheme. When the vehicle reaches a new node, the road data is re-acquired to update the distance matrix, so as to reduce the impact of emergencies on the distribution scheme. Finally, the ant colony algorithm is improved, and the algorithm is optimized in MATLAB with the goal of minimizing the distribution cost. The feasibility of the model and algorithm is verified by case analysis, which can provide new ideas and methods for the improvement of urban logistics distribution system.

Keywords: urban logistics distribution, dynamic road conditions, road congestion index, path optimization

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1 INTRODUCTION

According to the data released by the National Post Office, in 2018, China 's express delivery orders were about 50 billion; in 2021, it will exceed 100 billion; by 2023, the cumulative volume of China 's express delivery business will reach 132.07 billion pieces, which fully demonstrates the rapid development momentum of the express logistics industry. At the same time, it also brings severe challenges to the urban traffic environment. According to the data of China 's " Statistical Yearbook, " from the end of 2015 to the end of 2022, the number of private cars increased by 101.47 %, while the growth of highway mileage was only 16.99 %. The growth rate of highway mileage is much lower than the growth rate of car ownership, which will inevitably bring a series of traffic problems. The rapid development of the logistics industry and the severe urban traffic environment coexist. Under this background, it is particularly urgent to carry out unified regulation and optimization of urban logistics distribution. Scientific and reasonable distribution plan can not only improve distribution efficiency and reduce distribution costs, but also help to alleviate urban traffic congestion and improve urban operating environment. Therefore, it is of great theoretical value and practical significance to study the optimization method of urban logistics distribution path. In recent years, the rapid development of the express delivery industry has made the path optimization problem highly concerned, and the emerging intelligent algorithms have also been widely used in the research of logistics distribution problems. Gao Yingteng et al. used the hybrid algorithm combined with the positive feedback characteristics of the ant colony algorithm and the global search ability of the Dijkstra algorithm to shorten the time required to adapt to changes in road conditions [1]. Wang Jianing et al. proposed an algorithm combining marine predators and ant colony algorithm. Under the constraints of charging strategy, vehicle load and service time window, the path optimization problem of electric vehicles in cold chain logistics distribution [2]. Jiang Guangtian et al. divided the multi-vehicle dynamic vehicle routing optimization into two stages: pre-optimization and dynamic adjustment. In the pre-optimization stage, the improved adaptive genetic algorithm (IAGA) was selected to obtain the initial distribution plan, and then combined with the road conditions, vehicle volume, vehicle location and other conditions for dynamic adjustment [3]. Tan Xiaowei et al. established a cold chain logistics distribution model with the lowest total cost and the best customer satisfaction under the condition of considering multi-distribution centers, dynamic changes in customer demand, and replenishment strategies along the way. They proposed three damage and repair operators respectively. The calculation results of three examples of small, medium and large scales show that the obtained distribution scheme can significantly save the distribution resources of enterprises and reduce the cost [4].

Foreign countries have also done a lot of research on path optimization. Adelzadeh Mehdi et al. proposed a new mathematical model and heuristic algorithm for multi-depot vehicle routing problem with time windows and different vehicle types. A multi-warehouse routing mathematical model was developed for service time windows, different capacities and speeds of vehicles, and the effectiveness of the method was demonstrated by the case of SACO [5]. Zhang Huizhen et al. proposed a solution strategy based on ant colony optimization and three mutation operators for multi-objective vehicle routing problems with flexible time windows, and evaluated the performance of the proposed method using the benchmark Solomon problem [6]. Mohse Abdulqader M proposes a hybrid algorithm which combines the advantages of ant colony algorithm, simulated annealing, mutation operator and local search process in view of the characteristics of ant colony algorithm, which is easy to fall into local minimum and low convergence rate. Simulated annealing and mutation operator are used to increase the diversity of ant population, and local search is used to search the current region efficiently, so as to solve the traveling salesman problem [7]. Pan Binbin et al. proposed a hybrid algorithm based on adaptive large neighborhood search and tabu search for the vehicle routing problem with time windows, and used the automatic configuration tool to adjust the relevant parameters to determine the optimal configuration set [8]. In order to break through the limitations of traditional logistics path optimization, Almazroi Abdulwahab Ali et al. proposed the Hybrid Firefly -Spotted Hyena Optimization (HFSHO) algorithm by combining the fast exploration and global search ability of the Firefly Algorithm with the local search and regional development skills of the Spotted Hyena Optimization Algorithm. The superiority of HFSHO is verified by comparing with the traditional algorithm and the benchmark test method using the standardized function set [9]. Zheng Hongyu et al. proposed an enhanced artificial electric field algorithm (SC-AEFA) based on sine and cosine mechanism for the vehicle scheduling problem of logistics distribution. They simulated the vehicle scheduling and established a motion law model to solve the vehicle scheduling problem. The effectiveness of the method is verified by an example [10].

At present, there have been more in-depth studies on the optimization of logistics distribution routes. However, when calculating the distance, most scholars directly calculate the linear distance between points by obtaining the coordinates of each point; when doing path optimization, most scholars regard the road traffic operation status as fixed. This is obviously different from the actual situation. Therefore, this paper proposes a path optimization method based on the real route, which takes into account the dynamic traffic operation state and the waiting time of the intersection traffic lights, to explore a more realistic and more reasonable and efficient logistics distribution scheme.

2 CONSTRUCTION MONDEL

2.1 Problem Description

Dynamic vehicle routing problem (DVRP) is an extension of the traditional vehicle routing problem (VRP). It aims to solve the real-time change of orders and traffic conditions in the distribution process, adjust the distribution plan in time to adapt to the dynamic environment, and improve the distribution efficiency and service quality. This paper studies the problem of logistics distribution path optimization considering real-time road conditions, and sets up a fixed distribution center, which is responsible for dispatching vehicles of the same type to multiple community stations in the region for logistics distribution. The vehicles are driven at the same fixed speed and are not affected by other vehicles, facilities and activities on the road. After completing the distribution task, they need to return to the distribution center; each community can only accept one vehicle service; there are multiple paths to choose from the distribution center to each community and between each community. Each path is composed of several sections with real-time changes in traffic status. The goal is to calculate a distribution plan with the shortest total driving distance, the least required vehicles and the lowest total cost under the premise of meeting the vehicle load limit and road speed constraints, and to complete the distribution tasks of each district.

2.2 Mathematical Model

Range Model. Based on Baidu map development platform, Python language is used to obtain real-time road traffic data in Visual Studio Code environment. The road state is divided into four categories: smooth, slight congestion, congestion and severe congestion. Except for smooth, the other three traffic states can obtain the average driving speed, traffic direction and congestion distance of non-smooth road sections. In order to reduce the high-frequency line adjustment caused by frequent and regular congestion, relying on the Baidu map development platform, the road traffic data of each period from 07 :00 to 20 :00 from Monday to Sunday in 12 weeks are obtained on a weekly basis, and the road congestion index database is established to predict the traffic congestion of each road segment in each day of a week [11]. The optimal distance matrix between each node in the day is constructed, and the initial logistics distribution scheme is obtained. In order to be more in line with the actual driving situation, this paper introduces the waiting time of intersection signal lights, not every intersection needs to wait, so this paper will pass each intersection straight red light waiting straight for 40 s, left turn red light waiting time is set to 45 s. The calculation of traffic time, congestion index and model distance between nodes of each section are shown as follows: (1), (2), (3).

$$T_{ij,m,n}^{\alpha,\beta} = \frac{d_{n-d_{ny}}}{v_z} + \frac{d_{ny}}{v_{ny}} \tag{1}$$

$$\theta_{ij,m,n}^{\alpha,\beta} = T_{ij,m,n}^{\alpha,\beta} \times \eta_{ij,m,n}^{\alpha,\beta} + \left(\frac{d_n}{v_z}\right) \times \left(1 - \eta_{ij,m,n}^{\alpha,\beta}\right) \tag{2}$$

$$L_{ij,m,n}^{\alpha,\beta} = \left(\sum_{n=1}^{\mu} T_{ij,m,n}^{\alpha,\beta} + p_{ij,m} \times t_s + q_{ij,m} \times t_l\right) v_z \tag{3}$$

Among them: $T_{ij,m,n}^{\alpha,\beta}$ is during the$(\beta, \beta + 1)$ period of the α day of a week, the driving time of the vehicle on the nth section of the mth path from the community i to the community j ; d_n is the actual length of the nth section of the route from community i to the community j ; d_{ny} is the congestion distance of the nth section of the route from community i to the community j ; v_z is the normal driving speed of the vehicle under smooth conditions ; v_{ny} is the speed of the congested road section in the nth section of the route from community i to the community j ; $\theta_{ij,m,n}^{\alpha,\beta}$ is the congestion index of nth section of the mth path from the community i to the community j in the $(\beta, \beta + 1)$ period of day α of a week ; $\eta_{ij,m,n}^{\alpha,\beta}$ is during the $(\beta, \beta + 1)$ period of the α day of a week, the probability of congestion on the nth section of the mth path from community i to the community j, includes mild congestion, congestion and severe congestion ; $L_{ij,m}^{\alpha,\beta}$ is the model distance of the mth path from community i to the community j in the $(\beta, \beta+1)$ period of day a of a week ; $p_{ij,m}$ is the number of straight through the intersection with signal lights in the mth path of the route from community i to the community j ; $q_{ij,m}$is the number of left-turning intersections with signal lights in the mth path from community i to the community j ; t_s is the average waiting time for straight through the intersection ; t_l is the average waiting time for left turn through the intersection .

Taking the minimum distribution cost as the goal, the driver cost and vehicle use cost are introduced to construct the objective function, as shown in formula (4).

$$MinZ = \sum_{k=1}^{K} S_k \times (c_s + c_y) \tag{4}$$

Among them: S_k is the model distance of the total driving of the kth vehicle in the final scheme; c_s is the wage of the unit distance driver; c_y is the use cost of vehicles per unit distance.

In order to facilitate the later calculation, it is stipulated that there are no more than five traffic paths between nodes. Based on the principle of shortest traffic time, the optimal traffic paths between nodes in different periods are selected, and the initial optimal distance matrix is established, which can reduce the calculation difficulty and does not affect the applicability of the model. The road traffic situation predicted based on historical data will inevitably be different from the actual road traffic situation. Therefore, when the vehicle reaches a new community, it begins to update the optimal distance matrix, which can reduce the impact of accidental traffic accidents on logistics distribution.

Algorithm Design. Ant colony algorithm can deal with multi-objective problems, has better global search ability, and is suitable for solving complex path optimization problems. Therefore, this paper chooses ant colony algorithm to optimize logistics distribution under dynamic road conditions.

$\xi_{ij}(t)$ represents the expected degree of ants from node i to node j at time t. Combined with the research content of this paper, the improvement is made on the original basis. The calculation formula is shown in Equation (5).

$$\xi_{ij}(t) = \frac{1}{w_j \times L_{ij}(t) \times (c_s + c_y)} \tag{5}$$

Among them, w_j is the proportion of the number of express deliveries at node j to the total; $L_{ij}(t)$ is the shortest travel distance from node i to node j at time t.

When an ant passes through a path, it will release a certain amount of pheromone to communicate with other ants. The pheromone will gradually disappear over time. After a search is completed, the concentration of the pheromone needs to be updated to guide the subsequent ants to select the path. The calculation formula is shown in Equation (6).

$$\tau_{ij}(t+1) = (1-\phi)\tau_{ij}(t) + \sum_{e=1}^{m} \Delta\tau_{ij}^{e}\ \Delta\tau_{ij}^{e} = \begin{cases} \frac{Q}{L_e}, & the\ e-ant\ contains\ the\ path\ from\ i\ to\ j\ in\ this\ cycle \\ 0, & otherwise \end{cases} \tag{6}$$

Among them, $\tau_{ij}(t)$ is the pheromone residue on the path from node i to node j at time t ; ϕ is the pheromone dissipation; $\Delta\tau_{ij}^{e}$ is the pheromone concentration released by the e-th ant on the path from node i to node j ; L_e is the total walking distance of the e-ant in this cycle.

The formula for calculating the transition probability p of ant e from node i to node j at time t is shown in Equation (7).

$$p_{ij}^{e}(t) = \begin{cases} \frac{[\tau_{ij}(t)]^{\gamma}[\eta_{ij}(t)]^{\delta}}{\sum_{s\epsilon allowed_e}[\tau_{is}(t)]^{\gamma}[\eta_{is}(t)]^{\delta}}, & s\epsilon allowed_e \\ 0, & otherwise \end{cases} \tag{7}$$

Among them, $allowed_e$ is the set of unreached demand points of the ant e; γ is the importance weight of pheromone; δ is the importance weight of heuristic information.

2.3 Case Study

In this paper, a certain area of Zhengzhou City is selected to draw a complete road network including main roads, secondary roads and branches in the area at a ratio of 1:1to ensure that all potential distribution routes are covered. In addition, 10 communities in the area are selected as the target points of logistics distribution (as shown Figure1), and the average daily express delivery volume and service time of the community are obtained through investigation. Create a plane coordinate system in AutoCAD to determine the location information of each cell, as shown in Table 1. It is convenient to visualize the distribution path, and the logistics distribution is selected from 07：00 to 10 ：00 on Monday morning.

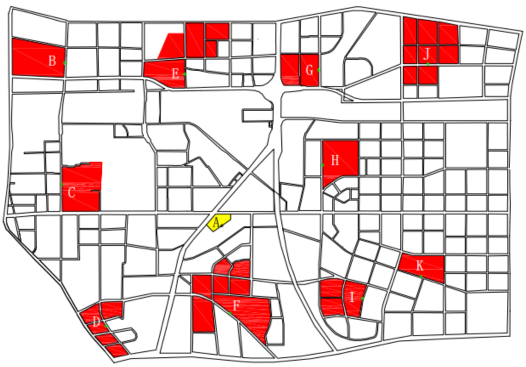

Fig. 1. The road network map of the study area.

Table 1. Residential location and courier information.

Community code	X	Y	The number of express delivery (pieces)	Service time (min)
A	2896	2110		
B	459	4572	420	7.6
C	428	2668	560	10.2
D	1116	437	840	15.3
E	2349	4389	1680	30.5
F	2977	1025	1575	28.6
G	4457	4451	507	9.2
H	4519	2968	1207	21.9
I	5140	881	805	14.6
J	6181	4550	647	11.8
K	6056	1218	350	6.4

The improved ant colony algorithm is used to optimize the distribution path. As a result, the number of distribution vehicles is reduced from four to three, the total driving distance is reduced from 48831 m to 46,897 m, and the distribution cost is reduced from 131.84 yuan to 126.62 yuan, which reduces the distribution cost and improves the efficiency of express transportation. The data are shown in Table 2.

Table 2. Data comparison before and after optimization.

Item	Total cost (yuan)	Total model distance (m)	Vehicle number	Delivery path for the first car	Delivery path for the second car	Delivery path for the third car	Delivery path for the fourth car
Manual decision	131.84	48831	4	A→F→I→K→A	A→H→J→G→A	A→C→D→A	A→E→B→A
Improved ant colony algorithm	126.62	46897	3	A→J→H→I→K→A	A→B→E→G→A	A→C→D→F→A	

3 CONCLUSION

In this paper, through the comprehensive application of AutoCAD, ArcGIS, Python and Matlab and other tools and technologies, the real-time optimization of distribution path is realized, and the real-time road state data is integrated into the traditional dynamic vehicle path planning, which greatly improves the adaptability and accuracy of path planning. Especially in the urban environment, the rapidly changing traffic conditions often make the pre-planned path need to be temporarily adjusted. The proposed model makes the logistics distribution more flexible and efficient by updating the road congestion information in real time. The case analysis shows that after optimizing the distribution path through the improved ant colony algorithm, the number of distribution vehicles is reduced, the total driving distance is shortened, and the distribution cost is reduced, thus verifying the validity of the model. It not only improves the distribution efficiency, but also has a positive impact on reducing the burden of urban traffic and reducing environmental pollution. Future research can be further deepened in the following directions: first, more types of real-time data, such as weather changes and emergencies, can be explored to integrate into the model to further improve the ability of the model to cope with emergencies; secondly, a variety of algorithms can be selected to run comprehensively to improve the computational efficiency and universality of the algorithm. This paper provides an effective methodological framework and practical tools, which will better meet the needs of customers, promote the development of the express delivery industry, provide a new idea for the optimization of urban logistics distribution system, better meet the needs of customers, and promote the development of the express delivery industry. It has certain theoretical value and application prospects.

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