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OPTIMIZATION OF LOGISTICS DISTRIBUTION NETWORK BASED ON ANT COLONY OPTIMIZATION NEURAL NETWORK ALGORITHM

JING YANG*

Abstract. In order to improve the timeliness of logistics distribution, based on the theory of road network smoothness and reliability, the author conducted a study on the optimization of urban logistics distribution and transportation networks based on smoothness and reliability. The concept of logistics distribution and transportation network smoothness and reliability was proposed, and a logistics distribution and transportation network optimization model was established. The solving process of ant colony algorithm was given, and finally, a comparative analysis of a case was conducted. The results showed that: With a 6% increase in total delivery distance, the reliability of the delivery network has increased by 30%. This indicates that when using the model built by the author for distribution network optimization, effective optimization of network smoothness and reliability can be achieved, while only increasing the distance by a small amount. The optimal reliability of a smooth distribution network means that the probability of delivery delays is minimized, which is the most powerful guarantee for the effective accessibility of delivery. Verified the practicality of the constructed model. The proposed logistics distribution network optimization model has practical significance in guiding decision-making for optimizing urban logistics distribution transportation networks and reducing uncertainty in the process of urban logistics distribution.

Key words: Logistics distribution, Network optimization, Smooth reliability, Ant colony

1. Introduction. In the process of globalization, the level of modernization of logistics has become an important indicator of a country's modernization and strength. It is the fundamental driving force for the sustained development of the national economy at a high starting point and an effective way for enterprises to seize competitive advantages in fierce market competition [1]. China is increasingly valuing the development and application of logistics technology to reduce logistics costs and bring considerable economic benefits to enterprises and society. The logistics distribution path optimization problem is a typical combinatorial optimization problem that involves multiple disciplines. Many practical problems can be classified into this category, with broad application prospects. Therefore, it has always been a hot research topic in the fields of operations research and combinatorial optimization. In recent years, significant achievements have been made in the research of vehicle optimization scheduling problems, which have been widely used in various aspects of production and life, such as newspaper or cargo delivery, taxi scheduling, and parcel express delivery.

The logistics network is specifically composed of various logistics nodes and routes connecting each point. Among them, nodes include distribution centers, warehouses, etc., while routes refer to the routes and routes for logistics distribution operations in accordance with regulations. The purpose of optimizing the distribution network path is to optimize the movement (transportation) path of goods during the spatial transfer process from the production area to the consumption area. The purpose of studying it is to find the most reasonable vehicle transportation path, overcome spatial barriers, and achieve cost savings. Due to the fact that solving the distribution path problem is an NP hard problem with high complexity. The traditional methods for solving such problems include precise algorithms and heuristic algorithms. The optimal solution to a problem can be obtained using precise algorithms, but its solving time often increases exponentially with the size of the problem. When there are a large number of nodes to be processed, it takes a considerable amount of time to solve, so its practical application scope is limited. Heuristic methods usually simplify problems into several small problems or modules based on their characteristics, and solve them in a more intuitive way. Therefore, most researchers are committed to the development and improvement of heuristic algorithms. Research on previous research has found that although heuristic algorithms can obtain satisfactory solutions to VRP problems, it is difficult to

* School of Finance and Economics, Hainan Vocational University of Science and Technology, Haikou, Hainan, 570000, China (yjkytg2023@126.com)

obtain the optimal solution within a reasonable computational time using existing algorithms as the problem size increases.

At present, logistics distribution logistics in a general sense refers to the establishment of distribution centers according to the frequency and size of goods order the needs of different customers, as well as the use of 7R (for products, quality, time, time, location, conditions, customers, and costs). Because of the complexity of the transportation system in distribution, especially in urban distribution system, not only the multi-points transportation system, multi-products, and the traffic network, but the distribution of the transportation content in the transportation service area is also incompatible. Therefore, reasonable and efficient road design to reduce the number of vehicles and transportation costs has become an important and practical problem. The goal of logistics distribution center will be how to make good use of the vehicles, determine the cheapest driving way, to deliver the products to the customers in the shortest possible time.Specifically, it means using multiple vehicles from the distribution center to deliver goods to multiple demand points (users), with a fixed location and demand volume for each demand point, a fixed load capacity for each vehicle, and a reasonable arrangement of vehicle routes to achieve predetermined goals (such as shortest distance, least cost, least time, and least number of vehicles used). The interesting situation during this process is that the total number of points needed on each delivery path is within the carriage; The length of each road shall not exceed the maximum distance that a car can deliver at one time; All requests must and only be sent by one vehicle. This is a special topic of vehicle problem detection (VRP).

According to statistics, the annual logistics costs in the US industry reach $400 billion. As long as it is reduced by 10%, it can save 40 billion US dollars in a year, so the logistics industry is vividly likened to "a gold mine worth 40 billion US dollars yet to be mined." In 2004, the demand for logistics in society continued to grow rapidly, with a total logistics volume of 3.84 billion yuan, a year-on-year increase of 29.9%, an increase of 2.9 percentage points compared to the same period last year. The logistics industry showed a rapid development trend. However, as a rapidly developing industry, the logistics industry has become a bottleneck that must be effectively managed in the process of national economic development. The proportion of logistics costs to GDP continues to be high, far higher than that of developed countries. At present, the logistics cost in developed countries accounts for about 10% of GDP, while in moderately developed countries (such as South Korea) it accounts for about 16%, while in China it is as high as around 20%. Transportation is the key to logistics decision-making, and in general, transportation costs account for a higher proportion than other logistics costs, except for procurement costs. Therefore, optimizing transportation logistics and reducing transportation costs is one of the effective ways to enhance the core competitiveness of logistics enterprises and reduce logistics costs.

Meanwhile, with the accelerated development of urban economy in recent years, various problems in cities have become increasingly prominent. Transportation and distribution have not only become important factors affecting the cost of goods, but also the level of urban development. The problems caused by distribution transportation, such as traffic congestion, traffic accidents, and exhaust pollution from transportation vehicles, have become major problems that hinder urban economic development and affect the normal life of residents. The traditional delivery method of goods involves retailers receiving goods directly from factories, forming a spider web cross transportation route, resulting in chaotic transportation and low efficiency; With the rapid increase of private vehicles in cities, especially in large cities, although cities have built three-dimensional transportation networks on the ground, above ground, and underground, they still cannot meet the transportation needs of population and vehicles, and urban traffic is becoming increasingly congested; In addition, due to the severe reduction of petroleum energy, fuel prices have risen rapidly, posing challenges to improving vehicle operating efficiency and reducing transportation costs. Therefore, as the volume of logistics and distribution business in cities gradually increases, if the previous logistics methods are still used to organize distribution, a series of problems will arise, such as a decline in service quality and inability to meet customer requirements; The emergence of a large number of unreasonable distribution plans will make it difficult to control logistics costs; Unreasonable vehicle path planning can increase the number of trips and routes for logistics delivery vehicles, leading to an increase in urban transportation burden. In order to solve the above problems, the urban logistics distribution network should be optimized to achieve goals such as on-time delivery, lowest total cost, and shortest total driving path. The advantage of distribution is that it eliminates cross transportation, saves transportation costs, increases the loading rate of transportation vehicles, reduces empty driving rates, timely delivery, improves service quality, and eliminates the need for users to place orders everywhere, while also reducing consumer inventory. With the development of urban transportation and economy, the demand in the market is gradually diversifying, and in such an environment, a new distribution center - a distribution center - has emerged. In this logistics distribution and transportation method, the distribution center organizes delivery according to the high-frequency and small batch ordering requirements of different customers, generating activities such as physical distribution, commercial flow, information flow, and capital flow. Physical distribution refers to the process of delivering products to customers during the production and sales process. In this process, transportation costs often account for the majority of the total transportation and sales costs. Therefore, in recent years, many enterprises have been committed to reducing transportation costs to improve their core competitiveness. In terms of transportation costs, the cost of moving goods in the sales channel is the highest. Therefore, it is of great practical significance to study how to allocate vehicles and generate distribution routes based on the determined amount of goods, in order to reduce the total transportation cost.

With the rapid development of the economy and the continuous acceleration of urbanization, urban spatial structure, transportation layout, and infrastructure construction are constantly undergoing changes [2]. However, it is not optimistic that the problems that may arise during the urbanization process are increasingly exposed, among which urban traffic congestion is particularly prominent, which directly affects the efficiency of logistics distribution based on urban road networks. Therefore, in order to meet market needs, the logistics distribution and transportation network system should be optimized in a timely and reasonable manner [3,4]. From the perspective of traffic flow, the smoothness of logistics distribution networks is closely related to the random changes in road network traffic status. Therefore, while improving the operational efficiency of logistics distribution systems themselves, we must consider the impact of road network traffic status on logistics distribution networks. In reality, there are many random factors that affect the effectiveness of road network traffic, such as natural disasters, traffic accidents, or frequent traffic congestion. The reliability index is an important indicator for measuring the performance of road networks under the influence of random factors. The existing research results on road network traffic reliability can be divided into two categories: One focuses on the physical stability of the road network, only studying its reliability from the perspective of network topology structure, and basically not considering traffic flow; Another type focuses on the comprehensive performance of network functions, rather than just the evaluation of the road network structure itself [5]. In practical situations, the road network often maintains connectivity, but due to random changes in traffic flow, it may not always be smooth, which may cause logistics delivery vehicles to be unable to arrive at customer points in a timely manner. Based on the characteristics of urban logistics delivery itself, the author analyzes from the perspective of smoothness and reliability, and makes reasonable choices for distribution routes to improve logistics delivery efficiency and achieve the goal of optimizing the logistics distribution transportation network [6].

2. Methods.

2.1. Logistics Network Optimization Issues.

(1) Logistics Network Definition. From the micro perspective of enterprises, the definition of logistics network can be summarized as: the circulation channels through which goods move from the place of supply to the place of sale. By abstracting the social logistics system, a network consisting of logistics nodes and transportation routes has been formed, as shown in Figure 2.1 [7]. The transportation routes in the network represent the movement routes of goods between different inventory storage points, while logistics nodes refer to the storage or demand points of goods, such as warehouses, distribution centers, logistics centers, factories, suppliers, etc. There may be multiple transportation routes connected between any pair of logistics nodes, representing different transportation modes, routes, or products. Logistics nodes also represent temporary stopping points during the inventory flow process, such as logistics centers.

(2) Mathematical model of logistics distribution. The general distribution vehicle routing problem can be described as follows: Linear programming can effectively solve balanced transportation problems, as it can be summarized into the following linear programming model. Assuming the unit freight rate from place of origin i to place of sale j is cij, i=1, 2.., m; J=1, 2, n. X is the optimal shipping volume from origin i to destination j,

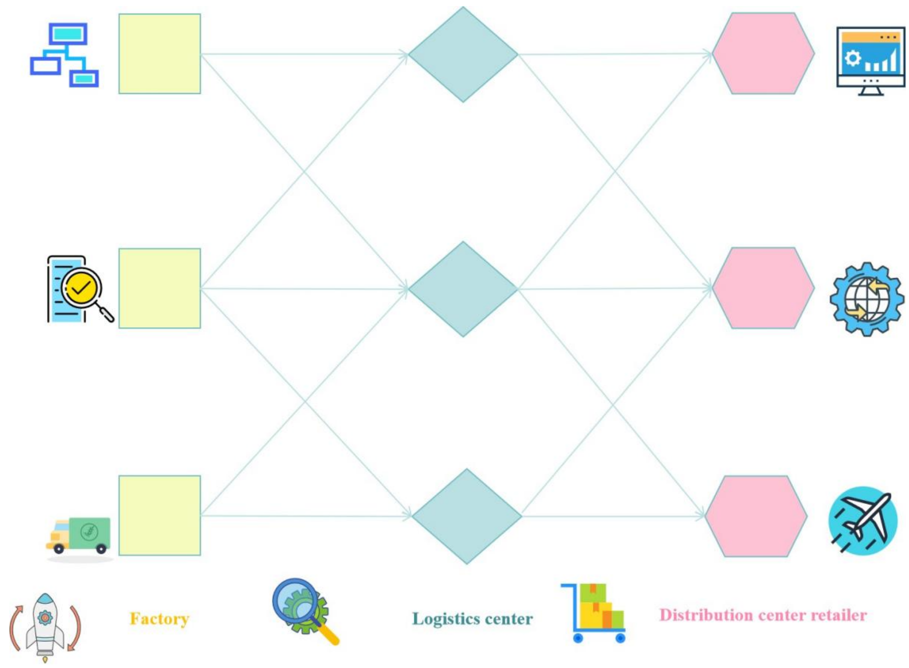

Fig. 2.1: Logistics Network Structure

and z is the optimal total shipping cost, the mathematical model is:

$$minz = \sum_{i=1}^{m}\sum_{j=1}^{m} c_{ij}, x_{ij} \tag{2.1}$$

Constraints:

$$\begin{aligned} \sum_{i=1}^{m} x_{i,j} = b_j, j = 1, \cdots, n \\ \sum_{i=1}^{n} x_{i,j} = a_j, i = 1, \cdots, n, x_{i,j \geqslant 0} \end{aligned} \tag{2.2}$$

Therefore, equation 2.1 and its constraints precisely constitute the mathematical model of the linear programming problem. By using the linear programming method to solve it, the optimal solution can be obtained, which is to minimize the total freight cost while satisfying the possible supply and demand of the place of origin [8].

2.2. Optimization modeling of logistics distribution and transportation network based on smooth reliability. The main purpose of optimizing logistics distribution and transportation network is to improve the efficiency of reliability and accessibility of distribution network. Therefore, the purpose of the modeling is to achieve the reliability and reliability of shipping and transportation systems. According to the characteristics of multi- city, multi- variety, small -scale, multi- package, and short cycle logistics distribution, the following parameters are mainly determined:

1. The total amount of goods on each distribution route shall not exceed the limits of vehicle capacity and load capacity [9,10];
2. Within the allowable range of existing transportation capacity in the logistics center;
3. During the delivery process, each delivery point can only be accessed once and must be accessed once;

4. Each vehicle can only serve one route, and each delivery vehicle must depart from the distribution center and finally return to the distribution center;
5. Delivery costs should be controlled at a certain level.

Following the above constraints, establish an optimization model as follows:

$$maxZ = max\Psi = \sum_{n=1}^{N} \xi_n \Psi_n$$

$$s.t \begin{cases} \Psi_n = \prod \Psi_{ij} \\ q_n \leqslant Q_n \\ N \leqslant M \\ \sum_{i=0}^{n} x_{ij} = 1(j = 1, 2, ..., n) \\ \sum_{i=0}^{n} x_{ij} = 1(i = 1, 2, ..., n) \\ \sum_{i=0}^{n} x0i = \sum_{i=0}^{n} xi0 = N \\ \sum_{i=0}^{n} \sum_{j=0}^{n} C_{ij} X_{ij} \leqslant A \end{cases} \tag{2.3}$$

In the formula, Ψ_n represents the smoothness and reliability of the nth distribution line in the network; Qn is the load capacity of the vehicles arranged on the nth route; Qn is the total amount of goods at all distribution points on the nth route [11]; N is the overall number of distribution routes; M is the number of delivery vehicles in the logistics center; Cij is the cost from node i to node j, $x_{ij} = \begin{cases} 1, \text{The vehicle line passes the arc(i,j)} \\ 0, \text{The vehicle line does not pass through the arc(i,j)} \end{cases}$ A is the cost quota at a certain level of certainty, which is a constant and can be determined based on empirical values.

2.3. Implementation Algorithm of Logistics Distribution and Transportation Network Optimization Model Based on Smooth Reliability. Due to the large number of units in large-scale logistics distribution network systems, traditional algorithms for solving nonlinear programming may encounter "curse of dimensionality" or combinatorial explosion problems; Meanwhile, the design or improvement of the actual distribution network is often selected from several feasible solutions. Therefore, based on the specific situation of the logistics distribution network system, the author chooses ant colony algorithm for system optimization and solution.

(1) Introduction to Ant Colony Algorithm. The principle of the ant colony algorithm is to first create an ant colony with a certain number of ants, and let each ant create a solution or part of the solution [12]. Then, each ant starts from the first node of the problem and selects the next node to switch according to the concentration of pheromones along the path until the solution is reached. Each ant releases pheromones that are proportional to the quality of the solution in the state it passes through based on the quality of the solution found; Afterwards, each ant begins a new solving process until a satisfactory solution is found. Ant colony algorithm needs to follow the following rules in computing loops:

State transition rule: The probability calculation method for the h-th ant at location r to choose to transition to location s is:

$$P_{rs}^{k} = \begin{cases} \frac{[\tau(r,s)]\cdot[\eta(r,s)]^{\beta}}{\sum_{u\in J_k}[\tau(r,s)]\cdot[\eta(r,s)]^{\beta}} s \in J_k \\ 0, other \end{cases} \tag{2.4}$$

In the formula, P_{rs}^{k} represents the probability of ant k transferring from the current location r to the location, $\eta(r,s) = 1/d(r,s), d(r,s)$ represents the distance between location r and location s, the expected degree of $\eta(r,s)$ from location r to location s [13]. $\tau(r,s)$ represents the residual information between location r and location s, J_k represents a location that the k-th ant has not yet visited, parameter β is a parameter used to adjust the relationship between $\tau(r,s)$ and $\eta(r,s)$, it represents the different roles played by the information accumulated by ants during their movement and heuristic factors in ant path selection. Specifically, it represents the concentration of pheromones on a path and the reciprocal of its length, which person has the greater importance in probability calculation.

Ant's next path selection rule:

$$s = \begin{cases} arg \underset{u \in J_k(r)}{max} [\tau(r,s) \cdot \eta(r,s)]^{\beta} \\ S, q \leqslant q_0(exploitation), otherwise(exploitation) \end{cases} \tag{2.5}$$

In the formula, q is a random variable uniformly distributed on [Q1], q0 is a parameter on [Q1], and S is a probability distribution calculated based on the state transition rule for selection.

Local update rule: During the process of establishing a solution, each ant also undergoes a local update of pheromones. The information intensity of each arc on its path is adjusted according to the following formula:

$$\tau(r,s) = (1-p) \cdot \tau(r,s) + p \cdot \Delta\tau(r,s) \tag{2.6}$$

In the formula, p represents the volatility factor of local pheromones, and 1-p represents the retention rate of pheromones. In order to prevent infinite accumulation of information, the value range of p is limited to (0,1). $\Delta\tau(r,s)$ is the amount of information increase, which refers to the concentration of pheromones that Ant k increases along the path from City r to City s during the time period t to (t+n).

Global update rule: After all ants have completed one cycle, only the ants that have generated the global optimal solution (i.e. the ants that have constructed the shortest path from the beginning to the present) have the opportunity to perform global updates. The pheromones on all paths passed by the optimal ant are globally updated according to the following formula. The pheromones on paths that do not belong to the optimal ant are updated to 0.

$$\tau(r,s) = \begin{cases} (1-\alpha) \cdot \tau(r,s) + \alpha \cdot \Delta\tau \\ 0 \end{cases} \tag{2.7}$$

In the formula, α represents the volatility factor of global pheromones, 1-α represents the retention rate of global pheromones, and the value range of α is between (0,1). $\Delta\tau = 1/L_b, L_b$ is the shortest path length calculated by the algorithm (the shortest path here only refers to the shortest path obtained in this cycle).

(2) Model Ant Colony Algorithm Solving. Using ants instead of vehicles, the next delivery point to be served will cause the total carrying capacity to exceed the vehicle's capacity, and then return to the distribution center, indicating that the vehicle has completed the transportation. Then change to another car and continue to serve the other delivery points until all delivery points receive a service, which represents the completion of an ant tour. When all ants patrol once, it is recorded as a cycle. After one cycle, calculate the pheromone increment and update the pheromones on the relevant paths based on the quality of each ant's patrol history (objective function value). The specific implementation steps are as follows:

Step 1: Initialize each basic parameter and set nc=Q;

Step 2: Calculate the transition probability;

Step 3: Based on the calculated transition probability and randomly generated q value, select the next path for each ant to move;

Step 4: When each ant passes through an edge and reaches the next delivery point, a local update of pheromones is performed on this edge according to local update rules;

Step 5: Repeat steps 2 to 4 for each ant in step 5 until all distribution points have ants passing by and the needs of the distribution points are met [14];

Step 6: Find the path that matches the optimal goal of the model among all generated paths, and the ant that passes through that path is the optimal ant;

Step 7: Perform a global pheromone update on each edge passed by the optimal ant according to the global update rule for this path;

Step 8: Repeat steps 2 to 7 until the nc reaches the specified maximum number of iterations or no better solution appears for several consecutive generations.

In this article, Matlab programming is used to implement the ant colony algorithm and solve practical problems.

Table 3.1: Customer demand at delivery points

Delivery point	Demand/t	Delivery point	Demand/t
P1	0.8	P6	1.4
P2	1.4	P7	1.5
P3	1.1	P8	0.7
P4	1.3	P9	0.4
P5	1.3		

Table 3.2: Distance between Distribution Centers and Distribution Points

distance	P0	P1	P2	P3	P4	P5	P6	P7	P8	P9
P0	1	11	9	8.5	10	8	8.5	5	14	10
P1	11	1	6	-	-	-	-	-	18	9
P2	9	6	1	7	-	-	-	-	-	-
P3	8.5	-	7	1	7	12	-	-	-	-
P4	9	-	-	7	1	8	-	-	-	-
P5	8	-	-	12	8	1	7	11	-	-
P6	8.5	-	-	-	9	1	6	-	-	-
P7	5	-	-	-	-	11	6	1	11	16
P8	14	18	-	-	-	-	-	11	1	8
P9	10	9	-	-	-	-	-	16	8	1

Table 3.3: Reliability of unobstructed road units between distribution center P0 and distribution point P_9

Road unit	Unblocked Reliability	Road unit	Unblocked Reliability
①	0.91	2	0.86
②	0.96	3	0.91
③	0.96	4	0.8
④	0.86	5	0.91
1	0.96		

3. Results and Analysis. A certain distribution center Po needs to deliver goods to 9 distribution points Pj (j=1, 2, 3,..., 9). The demand for each distribution point is qj, and the specific values are shown in Table 3.1. There are 2, 4, and 6 ton trucks available for allocation in the distribution center. The distances between distribution centers and distribution points, as well as between distribution points, are shown in Table 3.2. The unit distance cost is 2Q, and the cost quota A is 2000. Given the smoothness and reliability of the road sections and intersections between various distribution nodes, we will try to develop a reasonable distribution route.

3.1. Smooth reliability between distribution centers and distribution points, as well as between distribution points. Based on the smoothness and reliability of the road sections and intersections between various distribution nodes, the OD formula for calculating the smoothness and reliability of the inter transportation system is used to calculate the smoothness and reliability between distribution centers and distribution points, as well as between distribution points and distribution points. Taking the road network between distribution center P0 and distribution point P9 as an example for calculation, the smoothness reliability and road network of the road units between the nodes are shown in Table 3.3 [15,16].

According to the OD formula for calculating the smoothness reliability of the transportation system, the smoothness reliability between distribution center P and distribution point P is 0.79. Similarly, calculate the smoothness reliability between other distribution nodes, as shown in Table 3.4 and Figure 3.1 [17].

3.2. Develop delivery routes. Apply optimization models and use ant colony algorithm for solving. When initializing the data, the maximum number of ants taken is 5Q, and the maximum number of executions

Table 3.4: Reliability of smoothness between distribution points

Delivery point pairs	Unblocked Reliability	Delivery point pairs	Unblocked Reliability
P01	0.76	P19	0.66
P02	0.62	P23	0.8
P03	0.72	P34	0.63
P04	0.7	P35	0.69
P05	0.66	P5	0.79
P06	0.7	P56	0.76
P07	0.77	P7	0.7
P08	0.72	P67	0.79
P09	0.8	P78	0.76
P12	0.73	P79	0.68
P18	0.76	P89	0.73

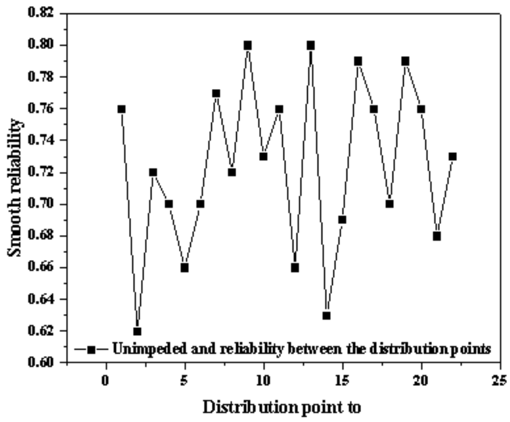

Fig. 3.1: Reliability of smooth delivery between different distribution points

is 200Q. After iterative calculation, the following three reasonable delivery routes are finally obtained.

Route I: P0-P3-P2-P1-P0. Using a 4-ton vehicle with a delivery distance of 28.5 [18]

Route II: P0-P4-P5-P6-P7-P0 uses a 6t vehicle with a delivery distance of 30;

Route III: P0-p8-P9-P0. Using a 2T vehicle with a delivery distance of 29, the optimal smoothness and reliability of the logistics distribution network under various constraints reached 0.297.

3.3. Comparative analysis. Using the mileage saving method, solve this example and obtain three delivery routes. Route i: P0-P2-P1-P9, P8-P0 uses a 4t vehicle with a delivery distance of 41; Route ii: P0-P3-P4-P0 uses a 2-ton vehicle with a delivery distance of 21.5; Route iii: P0-P5-P6-P7-P0 uses a 6t vehicle with a delivery distance of 20, and the reliability of the delivery network under this delivery plan is 0.229. Through calculation and analysis, it can be concluded that with a 6% increase in total delivery distance, the reliability of the delivery network has increased by 30%. This indicates that when using the model built by the author for distribution network optimization, effective optimization of network smoothness and reliability can be achieved, while only increasing the distance by a small amount. The optimal reliability of a smooth distribution network means that the probability of delivery delays is minimized, which is the most powerful guarantee for the effective accessibility of delivery. In today's fast-paced society, where the value of time is increasingly valued by people, the distribution model built by the author undoubtedly has certain practical significance [19,20].

4. Conclusion. Due to the fact that the optimization of logistics distribution and transportation networks only fully utilizes the existing road network and cannot transform it, further analysis of the reliability of logistics distribution and transportation networks can only be conducted based on the analysis of the existing road network's smoothness and reliability. The research conducted by the author aims to maximize the smoothness and reliability of logistics distribution networks at a certain cost level, thereby ensuring the effective accessibility of logistics distribution. However, in practical applications, if the improvement of the smoothness and reliability of logistics distribution networks requires a significant cost, it is necessary to consider whether the distribution center is in a reasonable transportation location or whether the division of distribution areas is reasonable. This is a direction that needs further research in the future.

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