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Last-mile delivery optimization considering the demand of market distribution methods: A case studies using Adaptive Large Neighborhood Search algorithm

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A B S T R A C T

Based on the current situation and problems of transportation "last mile" transportation distribution, this paper establishes a path optimization model based on user distribution methods from the perspective of market preference for transportation distribution methods, designs an Adaptive Large Neighborhood Search (ALNS) algorithm, and builds a user portrait based on the solution algorithm and the construction method. Based on the solution algorithm and the user portrait construction method, the solution scenario is established, and the distribution route and transportation distribution method are planned based on five real location data. Through the analysis of the solution scenarios, it can be obtained that after the optimization of the model, the transportation distribution cost of enterprises can be reduced, and the satisfaction of the transportation distribution service quality can be improved. The higher the complaint cost, the lower the total transportation and distribution cost, and the higher the satisfaction rate; the higher the time window penalty cost, the higher the total distribution cost, and the lower the satisfaction rate. Through several model comparisons, it is found that the optimized model has obvious advantages in transportation cost and good performance in transportation service satisfaction. To further strengthen the promotion and application of the distribution path optimization model, countermeasures are proposed in three aspects: establishing a unified end transportation information service platform, increasing the investment in end transportation path optimization, and strengthening the formulation of supporting policies to realize the optimization of end distribution services.

A R T I C L E I N F O

Keywords:
Transportation;
Last mile;
Adaptive Large Neighborhood Search (ALNS);
Market demand;
Logistics;
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Optimization;
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1. Introduction

In recent years, with the gradual acceleration of China's economic development, people's living standards greatly improved, the demand for all kinds of commodities also gradually increased. With the popularity of the Internet, online shopping, live shopping and other business models have gradually emerged, which has brought new growth points to China's economy and put forward new requirements for the development of China's transportation. With the issuance of the Outline for The Construction of a Transport Power, the development of transport has gradually changed from high-speed development to high-quality development, putting forward higher requirements for the distribution path at the end of the transport logistics supply chain [1]. The distribution path at the end of transportation is the "last mile" link of the development of logistics supply chain in China. It is a direct link between the transportation operator and the harvester, and also an important embodiment of the development level of transportation system in cities and regions. It has high requirements for transportation efficiency and service quality. For the development of the transportation industry, optimizing the distribution path of the city transportation terminal and getting through the "last mile" of logistics can further meet the needs of the people. It is an important starting point for the transportation industry to grasp the new development stage, implement the new development concept and construct the new development pattern. For the development of transportation enterprises, scientific and accurate calculation of the optimal distribution path at the end of city transportation can further do a good job in cost control, improve distribution efficiency, enhance the competitiveness of enterprises, and achieve development of enterprises. Pointed in this paper, the proposed path, not just the actual path and distance, but to the goods which are transported to the user in the city or regional distribution site, which is transported from the distribution site to the user to specify locations after submitting orders by the users, and contained in the process of route optimization, cost control, customer satisfaction, etc., by optimizing the path, so as to further meet the needs of user diversity [2].

1.1 Problem definition

In China's city end transportation distribution field, the user's high difficulty in matching the time window has been one of the difficulties of end transportation distribution. User demand is scattered, and the average daily transportation distribution volume of many communities is more than 150 pieces, and there are no less than 500 such communities in each city in China. As China's transportation and distribution platform is gradually bigger, the implementation of city transportation and distribution of goods and cargo types gradually increased, so the diversity of user demand for the end of the goods transportation methods further increased. At present, users for the end distribution mainly includes door-to-door transportation distribution and self-pickup, due to different user needs, the enterprises also need to consider their own costs, so there are often poor communication and coordination between the transporters and users, affecting the consumer experience and satisfaction. The main problems include the following aspects.

Firstly, the distribution path selection and demand mismatch. Due to the diversity of users' demands for transportation distribution modes, sometimes the transportation distribution personnel cannot fully match users' demands when both parties communicate and coordinate, such as the need to wait, etc. Moreover, since the agreed time with the transportation distribution personnel cannot be precise to the minute, and even if users agree to face-to-face transportation distribution, they may be out of the office or in other situations, so they cannot complete the handover and inspection of goods at the first time when the goods arrive. Affecting the efficiency of transportation distribution, sometimes also due to poor communication and coordination between the two sides, resulting in complaints. In the promotion of the use of unmanned intelligent cabinets, as some communities are lack of regular maintenance of some intelligent cabinets leads to a high rate of damage, so it may further lead to transportation distribution personnel and users need to increase the additional transportation distribution distance to complete the transportation distribution.

Secondly, the transportation path selection randomness is strong. From the viewpoint of the implementation status of China's transport enterprises, the implementation path of the "last mile" of urban transportation and distribution is often determined by the subjective experience and awareness of the distribution personnel. In different scenarios, facing different cargo conditions and external environment, the distribution personnel make judgments based on their own subjective experience and determine the final transportation distribution method on their own, even without communicating with users. In addition, influenced by the environment and income treatment, distribution personnel generally have lower education in China, so most of them are "empirical" when choosing the transportation distribution route, which leads to a large randomness of transportation distribution methods and affects the service experience of users is affected.

Thirdly, the depth of the transportation enterprises' awareness of the distribution cost is insufficient. The enterprises' cognition of cost mainly focuses on the cost accounting of labor and vehicles, ignoring the attention to intangible costs. Since the selection of end distribution mode mainly relies on the experience judgment of distribution personnel, which leads to the distribution personnel always being under pressure in the process of distribution, and when there is a change of distribution time, it may have an impact on the overall distribution time of the distribution personnel on that day. It is difficult for the relevant personnel to choose the best way to deliver through their own decision, and the resulting poor communication and coordination will lead to dissatisfaction and complaints from both sides, which will also affect the experience and satisfaction of the parties concerned with the transportation service.

1.2 Literature review

The end distribution methods include home transportation distribution and goods pickup. The first one is door-to-door distribution, which refers to the transportation distribution method of delivering goods to users on time and at the agreed time and place. Han *et al*. [3] proposed that door-to-door distribution is the transportation distribution of goods to users by short-distance vehicle transportation, and it is one of the most important methods of end transportation. Howe [4] was the first to propose crowdsourcing service, which is the use of "rush order" mode to provide transportation distribution services for users, and this approach has been widely used in end transportation distribution. Bühler *et al*. [5] argued that logistics providers aim at the lowest cost for end transportation distribution, and constructed four new linear mixed integer programming models to portray the service situation of door-to-door transportation distribution. Chen *et al*. [6] constructed the M/D/1 queuing system to portray the specific utility of door-to-door transportation distribution to users, and argued that although door-to-door distribution can bring greater convenience, there are disadvantages such as high cost and low timeliness.

The second one is goods self-pickup, which refers to the transportation distribution method in which goods no longer continue to be delivered door-to-door but are delivered to the user's surrounding logistics terminals and the user picks up the goods by himself, is also the most common way of end logistic supply chain. Guo [7] focused on the end transportation time mismatch problem to alleviate the problem of time conflict between users and distribution personnel. Song *et al.* [8] used the collected end transportation information to study cargo self-pickup, which effectively solved the time mismatch of cargo distribution, and at the same time greatly improved the efficiency of cargo distribution. Zhou *et al*. [9], Li *et al*. [10], and Xu *et al.* [11] analyzed the impact of self-pickup courier services on users' usage, the spatial distribution pattern of cargo self-pickup terminals, and users' willingness to choose self-pickup parcels through example verification. Guo [12] and others summarized cargo font points into different modes, such as: retail stores, subway stations, communities, and 24-hour public smart parcel stations for collection and transportation distribution; cargo self-pickup also includes Jing Dong pickup cabinets, Feng Chao Express provided by SF, CaiNiao post, and ShouHuobao.

In terms of research methods, there are three main algorithms: exact algorithm, traditional metaheuristic algorithm, and ALNS algorithm. Lee *et al*. [13] analyzed the route optimization problem of multiple vehicles and optimized the exact algorithm based on the shortest path search algorithm using the minimum number of vehicles as the optimization goal. Ozbaygin and Savelsberg [14] proposed an iterative branch pricing method based on the solution based on the branch pricing method and used the algorithm to solve the optimization problem of distribution routes. Zhao *et al*. [15] assembled genetic algorithm and forbidden search algorithm to solve a joint optimization scheme for end distribution, taking urban distribution in the core area of Su Ning in Chongqing as an example. Zhou *et al*. [16] portrayed the scenario of multiple users picking up at the same intermediate pickup facility, with the objective of minimizing the total distribution cost. Goeke *et al*. [17] conducted a comparative analysis of the cross-sectional and longitudinal computing performance between the large neighborhood search algorithm and other algorithms through a comparative analysis, and concluded that the large neighborhood search algorithm has higher and better computing efficiency and computing performance. Rohmer *et al*. [18] aimed at cost optimization, and on the basis of fully considering the costs incurred by distribution improved the adaptive large-neighborhood search metaheuristic algorithm with the goal of cost optimization, and verified the effectiveness of the algorithm. Jin *et al*. [19] used heuristic approach to optimize the trucks transportation route to reduce travel cost. In the application of other methods, Ocampo *et al.* [20] constructed an integrated multiple criteria decision-making approach to locate the locations of last-mile delivery facilities. Wang *et al*. [21] discussed optimization model of joint distribution system including warehousing, transportation and logistics business to optimize logistic solution.

2. Model construction and validation

Focusing on the problems faced by "last mile" path of transportation, the fundamental solution lies in understanding the needs of different users and providing exclusive transportation distribution services for users on the basis of good enterprise cost control. Combining the current situation of research and the application of related methods, this paper intends to use the ALNS algorithm to establish a model design to optimize the end transportation path considering users' preferences for transportation distribution methods and users' tendency to complain, and to determine the appropriate strategy to reduce transportation distribution costs and improve users' satisfaction.

2.1 Model construction

Consider the following transportation distribution situation. There is an end distribution terminal which offers service for m users. Every user i has a request q_i and the earliest time window and latest time window E_i, L_i. each user has a preferred transportation distribution method which is represented by p_i. $p_i = 1$ represents user preferred door-to-door transportation distribution, $p_i = 0$ respresents user preferred self-pickup transportation distribution. If the vehicle does not deliver according to the user's preference, there may be two results, the user who is easy to complain will complain to the relevant departments, and thus the transportation distribution company has to accept a certain penalty; while another part of the users are more talkative and suffer this result silently, without taking any complaint behavior. Users can be divided into four categories, based on their preferences and complaint behavior, and each category is represented by n ($n = 1, 2, 3, 4$), including preferring door-to-door transportation distribution and easier to complain ($n = 1$), preferring self-pickup transportation distribution and easier to complain ($n = 2$), preferring door-to-door transportation distribution with no complain($n = 3$), preferring self-pickup transportation distribution with no complain ($n = 4$). The cost of complaint for category n users is p_n^1. Each user point can be accessed once and only once. The number of vehicles available at the distribution station is k. Each vehicle departs from the distribution station to serve the user point and returns to the station. The capacity of the vehicle is Q_k. The running distance d_{ij} between user points i and j, the running time is t_{ij}, and the running cost is c_{ij}. Vehicles can arrive earlier than the earliest time window of user i or later than the latest time window, but incur a corresponding penalty cost, the size of which is related to the user type and is denoted by p_n^2. The distribution starts immediately after the vehicle arrives at the user's point i. The service time is s_i (the case of self-pickup applies to loading and unloading time, door-to-door applies to waiting + transportation distribution time) and leaves immediately after serving the point. The vehicles are homogeneous. The model symbols are shown in Table 1.

Constraint Eq. 1 is an objective function with three components: transportation distribution cost, complaint cost, and time window penalty cost. Constraint Eq. 2 limits the number of vehicles used. Constraint Eq. 3 expresses the relationship between and. Constraint Eq. 4 guarantees that each user can be served only once. Constraint Eq. 5 expresses the flow balance. Constraint Eq. 6 expresses that the total demand of user points delivered by a transportation distribution vehicle cannot exceed the capacity of that vehicle. Constraint Eq. 7 expresses the relationship between the starting service moments of two neighboring user points visited by the vehicle. Constraints Eq. 8 to Eq. 9 are the initial values of the vehicle when it stops at the distribution station. Constraints Eq. 10 to Eq. 12 are the decision variable definition fields.

Table 1 End distribution mode model symbol description

Symbol	Instruction
0	Distribution terminal
C	User collection, $C = \{1,2,\ldots,m\}$
V	Terminal collection, $V = C \cup \{0\}$
K	Cars collection, $K = \{1,2,\ldots,k\}$
a_i^n	If the user point i belongs to category n, if so, $a_i^n = 1$; or 0
p_n^1	Cost of complaints for category n users
p_n^2	Cost per unit penalty for violating the time window of n class a user
d_{ij}	Distance between arcs (i,j)
t_{ij}	Operating time between arcs (i,j)
c_{ij}	Operating cost between arcs (i,j)
s_i	Service time of user i
q_i	Demand quantity of user i
e_i, l_i	Time window of user i
Q	Capacity of the vehicle
x_{ijk}	If the car k go through arcs (i,j), and it is 1; or 0
y_{ik}	If the car k service user i, and it is 1； or 0
z_i	If the distribution method is same with preference of user i, it is 0; or 1
r_{ik}	The starting time of service of the car k to user point i

$$min \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} c_{ij}x_{ijk} + \sum_{n\in\{1,2\}}\sum_{i\in C} p_n^1 a_i^n z_i + \sum_{n\in\{1,2\}}\sum_{k\in K}\sum_{i\in C} p_n^2 a_i^n (1-z_i) y_{ik}[(E_i - r_{ik})^+ + (r_{ik} - L_i)^+] \tag{1}$$

$$\textstyle\sum_{k\in K}\sum_{j\in C} x_{0jk} \le K \tag{2}$$

$$\textstyle\sum_{i\in V} x_{ijk} = y_{jk} \forall j \in C, k \in K \tag{3}$$

$$\textstyle\sum_{k\in K}\sum_{j\in C} x_{ijk} = 1 \forall i \in C \tag{4}$$

$$\textstyle\sum_{i\in V} x_{ijk} = \sum_{i\in V} x_{jik} \ \forall j \in C, k \in K \tag{5}$$

$$\textstyle\sum_{i\in C} y_{ik} q_i \le Q_k \forall k \in K \tag{6}$$

$$r_{ik} + s_i + t_{ij} - r_{jk} \le M(1 - x_{ijk}) \quad \forall i \in V, j \in V, k \in K \tag{7}$$

$$r_{0k} = 0 \tag{8}$$

$$s_0 = 0 \tag{9}$$

$$x_{ijk} = \{_{0,1}\} \forall i \in V, j \in V, k \in K \tag{10}$$

$$y_{ik} = \{_{0,1}\} \quad \forall i \in C, k \in K \tag{11}$$

$$z_i \in \{0,1\} \qquad \forall i \in C \tag{12}$$

To verify the effectiveness of the model proposed in this paper for large-scale cases, we also use this algorithm to solve the Vehicle Routing Problems with Time Windows (VRPTW) problem. Based on numerical examples from Solomon and Desrosiers [22] (100 consumers) and Homberger and Gehring [23] (200 and 400 consumers), the applicability of the proposed algorithm is obtained. Tables 2, 3 and 4 show the 100, 200 and 400 consumer scenarios, respectively. According to the results, the algorithm proposed in this paper has strong adaptability and can solve other similar problems well.

In addition, we also verified the efficiency of the proposed algorithm compared with the genetic algorithm based on the calculation example in this paper, the algorithm effect is shown in Table 5. Compared with the Genetic Algorithm, the proposed algorithm is more efficient, so it can better find the optimal solution, and when the data is larger, the efficiency of the proposed algorithm is higher.

Table 2 Solomon 100 consumers numerical example

Numerical example	HGA (best 6 result)	LNS (best 6 result)
1	828.38	828.38
2	589.86	589.86
3	1210.69	1209.2
4	951.51	956
5	1384.17	1384.17
6	1119.24	1123.17
Total	57196	57259

Table 3 200 consumers numerical example

Numerical example	HGA (best 6 result)	LNS (best 6 result)
1	2718.41	2720.12
2	1831.59	1831.65
3	3613.16	3605.09
4	2929.41	2921.85
5	3180.48	3204.41
6	2536.2	2547.84
Total	168092	168809

Table 4 400 consumers numerical example

Numerical example	HGA (best 6 result)	LNS (best 6 result)
1	7170.47	7188.35
2	3952.95	3877.18
3	8402.57	8538.45
4	6152.92	6238.56
5	7907.14	8145.91
6	5215.21	5233
Total	388013	392214

Table 5 Comparison of algorithm efficiency

Numerical example	Genetic algorithm	LNS	Comparison
100	256.22	254.38	0.7 %
200	292.49	287.66	1.6 %
436	313.57	303.23	3.2 %

2.2 Example adoption and algorithm analysis

Combining the model calculation results, the model of user transportation distribution method preference is further validated and analyzed by using examples.

Example adoption

As shown in Fig. 1, this paper uses five neighborhoods in Haidian District of Beijing as the basis for calculation example analysis, including Gangyan neighborhood, Jiaodajiayuan neighborhood, Mingguangcun neighborhood, Tianzhaojiayuan neighborhood, and Changhewan neighborhood as the community transportation distribution area, and the number of transportation distribution users in each neighborhood is 89, 87, 99, 85, and 75. In order to simplify the analysis and better display the results, the transportation distribution points of users in each district are simplified to 5. According to the actual research of the relevant company, the distribution center is selected at the bottom of Yixi Business Hotel, No. 33, Xueyuannan Road, Haidian District. To get the data of the users in the district, this paper designed questionnaires around basic information, preference of transportation distribution methods and complaint behavior, and the questionnaires were mainly obtained by posting the questionnaire links in the property groups, and 436 valid data were finally collected. Other model calculation parameters are set as follows: $k = 8$, $Q_k = 350$, E_i and L_i are obtained from the questionnaires filled out by users, d_{ij} is calculated from latitude and longitude, $c_{ij} = 10$, s_i and q_i are randomly generated, $p_n^1 = 1$, $p_n^2 = 8$.

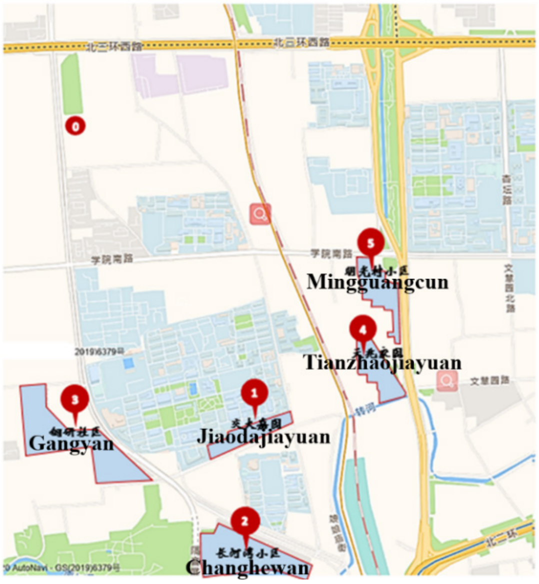

Fig. 1 Community distribution district selection figure

Algorithm analysis

Initial setting

Since the objective function is profit maximization, we need to deal with the objective function first. Since $max\ f_{netp} = min\ (-f_{netp})$, we let the cost of any feasible solution $O(S) = -f_{netp}$. So the initial solution S^0 corresponds to the expression of the temperature function as:

$$T = O(S^0) \times P_{init} \tag{13}$$

Neighborhood structure

Since the distribution method of users who have checked the value-added service will no longer change, we add new removal and insertion policies to improve the feasibility of the path based on the original removal and insertion policies. For the convenience of description, we refer to the users who have checked the value-added service as value users. The basic idea of these two strategies is that the higher the proportion of value users included in a path, the lower the number of solutions generated by adjusting the user distribution method for that path, and the less favorable it is to generate feasible solutions in the early stage of the algorithm. Therefore, our two strategies operate mainly on such paths to ensure the convergence speed of the algorithm.

Path removal strategy

Step1: Count the proportion of each path containing value users in a certain solution S, and then sort them in descending order.
Step2: Remove the paths until the number of removed is n_r.

Distribution method factor insertion strategy

The distribution mode factor insertion strategy is to determine whether the user point is allowed to be inserted based on the distribution mode.

Step1: Calculate the distribution mode correlation between the arc and the user point to be inserted.

Since it is assumed that arc (i, j) is an arc on path p, k is the target insertion point, and $E_i \leq E_k \leq E_j$. Arc (i, j) is associated with the distribution method of the user point$k$, the calculation method is as follows:

$$\sigma_{ik} = \begin{cases} max\{L_i - E_k, 0\} & E_i \leq E_k \\ min\{L_i, L_k\} - E_i & E_k < E_i \leq L_k \\ max\{L_k - E_i, 0\} & E_i > L_k \end{cases} \tag{14}$$

$$\sigma_{kj} = \begin{cases} max\{L_k - E_j, 0\} & E_k \leq E_j \\ min\{L_k, L_j\} - E_k & E_j < E_k \leq L_j \\ max\{L_j - E_k, 0\} & E_k > L_j \end{cases} \tag{15}$$

$$\sigma_{ij} = \sigma_{ik} + \sigma_{kj} \tag{16}$$

Step2: According to the distribution mode association degree, user point k is inserted into the arc (i, j) with the largest association degree.

By analyzing the distribution mode correlation here, due to the existence of value users in the later stage of the algorithm, the basic constraints such as vehicle capacity can be easily satisfied, but it is more difficult to satisfy the distribution mode constraint, and the penalty cost incurred is larger, which needs to be handled specifically for the distribution method. The increased cost of considering the insertion of arc (i, j) into user point k does not need much consideration. Therefore, we need to recalculate the correlation degree.

3. Case studies: Results and discussion

Combining the model results and the arithmetic results, the optimal path is further analyzed, including the selection of routes and transportation distribution methods, etc., and its sensitivity is further analyzed.

3.1 Optimal path and transportation distribution method

Optimal route

Because of the large number of points in the example, each path is shown separately in this paper to clearly demonstrate the path of the vehicle driving, and the specific vehicle route scheme is shown in Table 6. As can be seen from the Table 6, due to the time window constraints, the transportation distribution paths are not based on the distance to choose aggregated transportation distribution. Most of the vehicles will deliver to 4 or 5 neighborhoods. But in reality, the transportation distribution companies often distribute the cargo to a neighborhood by a special transporter, but after taking into account the cost of time window, user preferences for transportation distribution services and the cost of complaints, the distribution of vehicles will show a more decentralized form.

Table 6 Optimal route display

No.	Path
1	[0,50,115,259,293,309,424,427,436,21,30,142,152,246,264,287,315,347,349,402,8,9,44,71,87,102,110,114,120,136,141,166,169,178,207,209,247,255,279,283,308,321,325,350,385,421,93,155,223,379,387,98,122,180,183,314,274,0]
2	[0,337,390,403,82,83,224,228,268,304,2,15,124,129,131,149,162,168,206,213,225,226,230,328,215,280,281,243,417,46,150,194,273,307,327,352,368,391,404,20,37,184,195,201,222,244,305,330,432,109,116,143,164,277,284,326,419,153,361,19,63,130,170,0]
3	[0,270,285,289,316,324,331,338,346,397,400,426,428,429,431,27,42,57,74,75,112,172,396,58,154,182,62,92,199,359,411,23,101,145,176,250,251,290,317,334,358,383,103,237,261,265,345,348,353,167,375,137,146,212,332,344,418,11,18,81,156,187,231,256,303,398,125,235,16,29,86,105,119,135,138,147,245,249,340,73,0]
4	[0,173,272,298,393,10,77,84,186,288,370,197,39,48,61,89,96,128,157,258,271,323,372,1,41,51,132,214,282,399,433,4,181,216,266,292,364,435,3,36,165,335,177,218,275,286,320,384,388,76,106,161,210,310,378,185,196,200,236,241,252,254,291,311,322,336,339,357,416,99,0]
5	[0,14,204,229,232,28,72,160,260,371,140,238,253,354,413,423,425,5,7,17,22,24,26,31,47,60,64,90,111,123,179,188,198,203,217,221,234,239,257,269,278,297,301,333,366,367,94,97,107,267,318,356,362,373,374,394,409,25,45,49,70,329,377,0]
6	[0,32,38,43,52,56,65,69,78,88,95,104,133,139,190,211,220,242,342,351,360,363,380,386,392,401,406,414,434,53,233,422,34,55,66,68,80,91,117,118,174,208,227,248,276,295,355,365,382,405,67,296,300,306,319,13,144,148,158,313,381,408,59,151,171,412,299,369,0]
7	[0,12,33,35,54,191,193,240,263,40,126,134,189,192,202,205,341,343,395,415,430,302,407,312,100,219,0]
8	[0,79,85,121,127,159,163,175,262,389,6,108,113,294,376,410,420,0]

This section first checks the distribution of users in the different routes and the characteristics of user types.

- Distribution of users in Route 1 and characteristics of user types.

  Fig. 2 shows the distribution of users as well as the path. Each point represents the number of users delivered at that point. The users in Route 1 are mainly distributed in Mingguangcun and Tianzhaojiayuan neighborhoods, and a small number of Jiaodajiayuan users. The distance between Mingguangcunand Tianzhaojiayuan neighborhoods is relatively close to each other, so they will deliver together to gain the advantage of distance. In Route 1, the transportation distribution method for Mingguangcun users is mostly door-to-door method, while the transportation distribution method for Tianzhaojiayuan and Jiaodajiayuan users is mostly self-pickup. To satisfy more users within a certain time, the transportation company can intersperse a certain number of self-pickup users among the door-to-door users, so as not to waste waiting time but also to satisfy the needs of self-pickup users.

  According to the time window data in Route 1, in order to reduce the waiting time, the distribution company should first transport to users with similar time window together. The time window of users who deliver to Mingguangcun neighborhood in Route 1 are mostly concentrated in the afternoon, and some of them are self-pickup users. Since the time window of self-pickup users are very flexible, they can be satisfied together.

Fig. 2 The user distribution and the route of Route 1

- Distribution of users in Route 2 and characteristics of user types.

  Fig. 3 shows the distribution of users in Route 2 and the relevant situation. The distribution of users in Route 2 is similar to Route 1, distributed in Mingguangcun and Tianzhaojiayuan neighborhoods, with the difference that there are also users in Changhewan neighborhood in Route 2. However, the number of users in Changhewan neighborhood is very small, and they are basically self-pickup users, which means that the self-pickup users in Changhewan neighborhood are dispatched by the way because there is still spare capacity in the second vehicle. In route 2, the transportation distribution method of users in Mingguangcun and Tianzhaojiayuan neighborhoods is mostly door-to-door transportation distribution method, while the transportation distribution method of users in Jiaodajiayuan and Changhewan is mostly self-pickup.

Fig. 3 The user distribution and the route of Route 2

- The distribution of users in Route 3 and the characteristics of user types.

  Fig. 4 shows the transportation and distribution of users in Route 3 and the paths. The distribution of users in Route 3 is relatively wide, within all five neighborhoods. However, the number of users in Changhewan and Gangyan neighborhoods are small, and they are basically users of self-pickup method. In Route 3, the transportation distribution methods of users in Mingguangcun, Tianzhaojiayuan, and Jiaodajiayuan neighborhoods are mostly door-to-door method, but the time window of users in Mingguangcun and Tianzhaojiayuan neighborhoods are concentrated in the morning, while the time window of users in Jiaodajiayuan are concentrated in the afternoon. The transportation distribution method for users in Changhewan and Gangyan neighborhoods are mostly self-pickup.

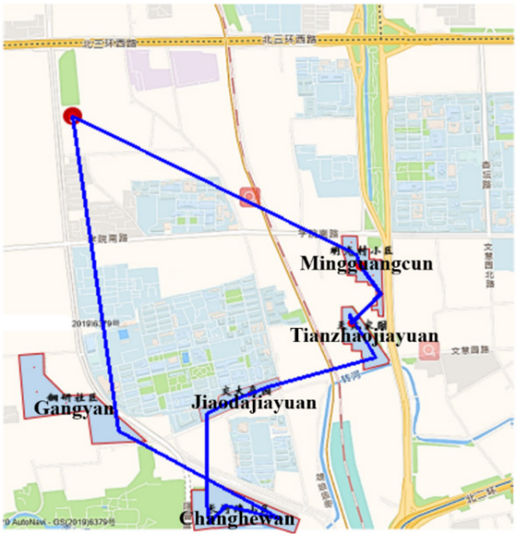

Fig. 4 The user distribution and the route of Route 3

- The distribution of users in Route 4 and the characteristics of user types.

  As shown in Fig. 5, in Route 4, the transportation distribution paths are spread across every neighborhood, but users are more concentrated in Tianzhaojiayuan, Jiaodajiayuan, and Changhewan neighborhoods. In route 4, the transportation distribution method of users is door-to-door transportation distribution method. However, the users are more concentrated in Tianzhaojiayuan, Jiaodajiayuan, and Changhewan neighborhoods. The time window of the users in Mingguangcun and Tianzhaojiayuan neighborhoods are concentrated in the morning, while the users in Jiaodajiayuan and Changhewan neighborhoods are concentrated in the afternoon.

Fig. 5 The user distribution and the route of Route 4

- Distribution of users and the characteristics of user types in Route 5

  As shown in Fig. 6, in Route 5, the users are distributed in Tianzhaojiayuan, Jiaodajiayuan, Changhewan, and Gangyan neighborhoods. Among them, the number of users in Changhewan and Gangyan neighborhoods are the largest. In Route 5, the most users' transportation distribution method is door-to-door method. However, there are some self-pickup method users in Changhewan neighborhood. The time window of users in Tianzhaojiayuan and Jiaodajiayuan neighborhoods are concentrated in the morning, while the users in Jiaodajiayuan and Changhewan neighborhoods are concentrated in the afternoon.

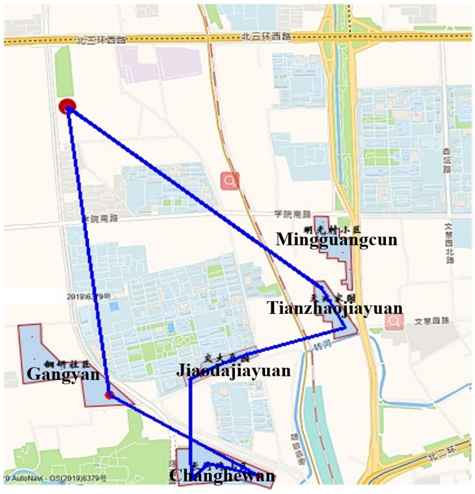

Fig. 6 The user distribution and the route of Route 5

- Distribution of users and the characteristics of user types in Route 6

  As shown in Fig. 7, in Route 6, the transportation distribution users are distributed in Jiaodajiayuan, Changhewan, and Gangyan neighborhoods, among which the number of users in Gangyan neighborhood is the largest. In Route 6, the transportation distribution method of users in Jiaodajiayuan and Changhewan neighborhoods are door-to-door distribution method. However, there are more self-pickup method users in Gangyan neighborhood. The time window of users in Jiaodajiayuan and Changhewan neighborhoods are concentrated in the morning, while the users in Gangyan neighborhood are concentrated in the afternoon.

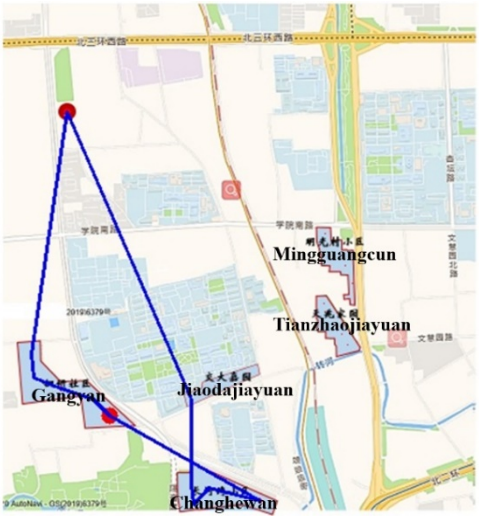

Fig. 7 The user distribution and the route of Route 6

- Distribution of users and the characteristics of user types in Route 7 and 8.

  As shown in Fig. 8, in both Route 7 and Route 8, the delivered users are distributed in Gangyan neighborhood. In both Route 7 and Route 8, the transportation distribution method of users is door-to-door transportation distribution method. Among them, the time window of users of Route 7 are all concentrated in the morning, while the time window of users of Route 8 are all concentrated in the afternoon. Therefore, although the Route 7 and 8 have spare capacity, they are not delivered together because the time window of the two paths are so different that it would take a long waiting time if they are delivered together, and it is better to deliver separately.

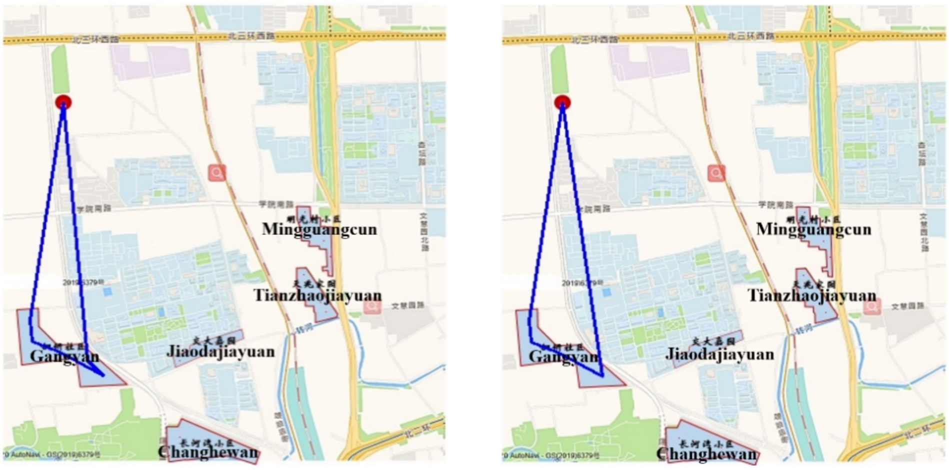

Fig. 8 The user distribution and the route of Route 7 and Route 8

By analyzing the characteristics of the users of each route, it can be found that the users in the same route show the following pattern:

Type 1: Each path has major distribution cells;
Type 2: Users in the same neighborhood have relatively close time window;
Type 3: Self-pickup users are interspersed with door-to-door method users, which can realize interpolated transportation distribution in the gaps of discontinuous time window of two users.

Transportation distribution method

According to the calculation results, the final decision of the transportation distribution method with different user preferences is:

Route 1: 337 390
Route 2: 225 321 250 192
Route 3: 150 58 435 275 47
Route 4: 428 359 157 251 317 395 298 182 28 253 55 300
Route 5: 181 320 235 12 59 85 193 217
Route 6: 267 360 407
Route 7: 117 365 306 219

This section examines the points where transportation distribution methods do not match user preferences, and finds that these user points are characterized by: a lower percentage of Type 1 users changing transportation distribution methods than Type 3 users; fewer users with a large earliest time window changing transportation distribution methods than those with a small earliest time window; a greater tendency for deliverers to concentrate on those users with the same transportation distribution methods; and priority for Type 1 and Type 3 users with smaller earliest time window transportation distribution. This is mainly determined by the complaint cost and time window violation cost, which are analyzed as follows:

- The complaint cost of Type 1 users is higher. Under the condition of the same time window violation cost, compared with Type 3 users, changing the transportation distribution method of Type 1 users will increase the higher complaint cost, while the reduced time window penalty cost is insignificant, therefore, the deliverers will tend to change the transportation distribution method of Type 3 users.
- Users with larger earliest time window are generally placed at the end of the path for transportation distribution, and the arrival time of the deliverer is more likely to be smaller than these users. If the transportation distribution method is changed, not only the complaint cost will increase, but also the arrival time of subsequent user points is advanced, and the time window penalty cost increases accordingly. Therefore, the transportation distribution person prefers not to change the transportation distribution method for this type of users.
- For users whose transportation distribution method is door-to-door method, the transportation distribution method of the dispatcher can choose door-to-door or self-pickup method, which has higher flexibility. The dispatcher can freely adjust the transportation distribution method according to the actual situation to achieve the purpose of reducing the time window penalty cost and thus reducing the total cost.
- If a transportation distribution path has both users who prefer door-to-door and self-pickup methods, the transportation distribution time window of self-pickup users is more relaxed and will not violate the time window of such users. Therefore, the transportation distribution agent will give priority to the door-to-door method users.

Users satisfaction

This section first conducts a comparative study of user satisfaction rates. To show the value of optimizing the user's transportation distribution method, the total cost C_{all} when the satisfaction rate is 100 % (i.e., the transportation distribution is made exactly according to the user's preference for self-pickup and door-to-door transportation distribution) is first calculated. Then, the optimal solution C_{opt} in the example problem of this paper and the number of user points $n_{opt} = 38$, which change the transportation distribution method can be obtained. In reality, the transporters also do not adopt the self-pickup method exactly for the users. Some users' packages are directly delivered to the pickup point, while some users' parcels are delivered to their homes. There is a certain degree of randomness in whether users are delivered by self-pickup or door-to-door transportation distribution, without considering the users' own preferences and complaint behavior. Therefore, 38 users are randomly selected to deliver according to the transportation distribution method opposite to their preferences and get the total cost $C_{opt}^{'}$. To analyse the effect of changing the number of users' transportation distribution method preferences by considering the cost, 142 users are also randomly selected to deliver according to the transportation distribution method opposite to their preferences and get the total cost C_{rand}. The cost corresponding to each satisfaction and the parameters are shown in Table 7. As can be seen in Table 7, the higher the satisfaction rate, the greater the transportation distribution cost, meaning that the transportation vehicle needs to drive longer distances to meet the user's transportation distribution method preference. When the satisfaction rate is 100 %, no complaint cost is incurred, but the time window penalty cost is high because one vehicle often has to transport to many users, so it is inevitable that users' time conflicts will occur, but at this time, the transportation distribution mode preference of door-to-door method users cannot be violated, thus the time window of many users will be violated, so the time window penalty cost of users is high.

The total cost $C_{all} = 329.09$, the optimal solution $C_{opt} = 303.23$ is obtained after optimizing the distribution method, which saves 25.86. The number of distribution methods changed after optimization, $n_{opt} = 38$, which has the optimal satisfaction rate which is 91.28 %. Keeping the satisfaction rate constant and randomly violating the user's transportation distribution method preference, the time window violation cost will increase at this time, and the complaint cost will also increase, and the path cost will instead have a small decrease, and the total cost will increase by 17.36. With a satisfaction rate of 67.43 %, the complaint cost is much higher than the complaint cost of the optimal solution, and the time window penalty cost is not much different.

From the overall trend, as the satisfaction rate decreases, the complaint cost increases and the time window penalty cost decreases. However, when the satisfaction rates are the same, the complaint costs will differ, which is mainly determined by the percentage of the first category of users among the user points that change the transportation distribution method. When the satisfaction rates are the same, the complaint cost will be higher for the paths with a high percentage of first category users, so the complaint cost in the optimal solution will be higher than the complaint cost in $C_{opt}^{'}$. On the other hand, the position of user points in the path that change the transportation distribution method affects the time window penalty cost. When increasing the number of user points that change the transportation distribution method in a small range, the change of the time window penalty cost is unpredictable. When the number of user points to be added to change the transportation distribution method is in a larger range, the time window penalty cost decreases, and the decrease changes according to the location of the user points.

Table 7 Impact of user satisfaction rate on cost

Satisfaction	100 %	91.28 %	91.28 %; $n_{opt} = 38$	67.43 %; $n_{rand} = 142$
Distribution Costs	219.55	184.75	181.37	166.94
Complaint Costs	0	82	94	386
Time window penalty cost	109.54	36.48	45.22	46.43
Total Cost	329.09	303.23	320.59	599.37

3.2 Sensitivity analysis

This section analyses the time window penalty cost. Holding the complaint cost constant, and change the unit time window penalty cost α gradually from 1 to 6 to observe the changes in total cost, complaint cost, transportation cost and time window penalty cost. As seen in Figs. 9 and 10, the total cost rises rapidly and remains constant when $\alpha = 5$, when the penalty factor increases. The complaint cost shows the same trend as the total cost, indicating that the increase in the total cost is mainly caused by the increase in the complaint cost, and the change of α has little effect on the transportation cost and the time window penalty cost.

As seen in Fig. 9, this is mainly because as the time window penalty cost α increases, the transportation distribution personnel choose to put the goods into the self-pickup counter, and the complaint cost increases but reduces the amount of time window violation (time window penalty cost = α* time window violation). At this point, the total cost still increases, but slows down the growth of the total cost. As α continues to increase, the time window violation volume gradually decreases to 0, and the time window penalty cost will also be 0. No matter how it increases, it has no effect on the time window penalty cost. If we continue to change the transportation distribution method of the first and third category of users, i.e., the goods are put into the self-pickup cabinet, it can only increase the complaint cost and make the total cost not optimal.

Fig. 10 gives the effect of the complaint cost coefficient on the total cost. It can be seen that the larger the complaint cost coefficient is, the lower the total complaint cost is instead, indicating that due to the larger complaint cost, the transport companies choose the way of preference for users to reduce the transportation distribution cost. The higher the complaint cost, instead, the higher the time window penalty cost, because changing the transportation distribution method will require a higher time window, thus increasing the time window penalty cost. In terms of total cost, the complaint cost coefficient can reduce the total cost of the company in general, but it causes a transient increase in total cost because in the first period, it may lead to an increase in time window penalty cost, and the increased penalty cost will be higher than the reduced complaint cost.

The essence of this model lies in the trade-off between the cost of complaints and the cost of time window violation. For users, the unit time window violation cost is the same, but the complaint cost is different, and the heterogeneous and homogeneous costs of users can be transformed by vehicle route planning with the decision of user's transportation distribution method. In the transformation, the cost saving can then be achieved by the route change to form a favorable distribution method for users with high complaint cost.

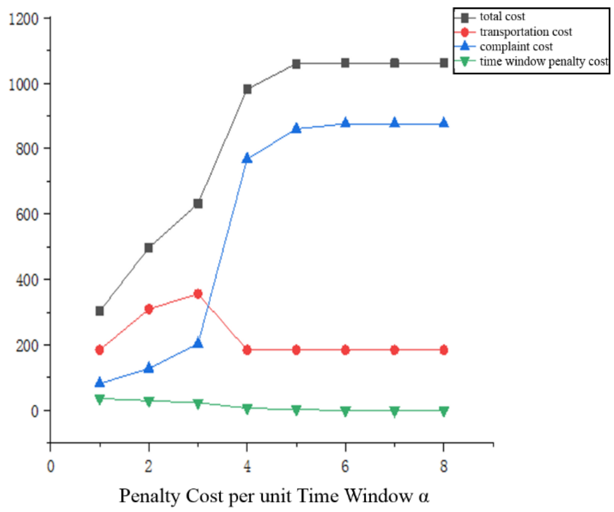

Fig. 9 The effect of penalty cost per unit time window on total cost

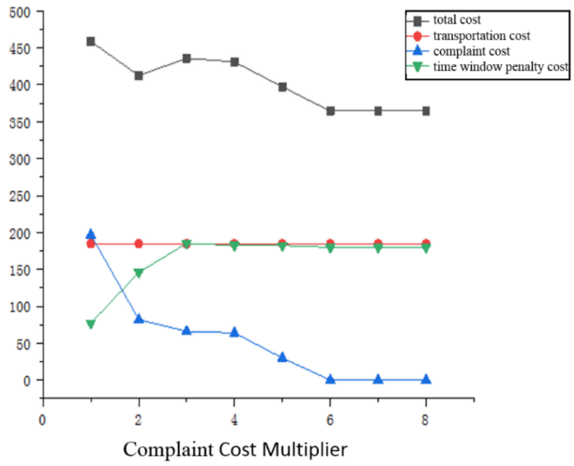

Fig. 10 The influence of complaint cost coefficient on total cost

4. Conclusion remarks and suggestions for policy and measures

In this paper, a path optimization model considering user's transportation distribution mode preference is established to optimize the driving path of end transportation vehicles as well as the transportation distribution methods, and the algorithm of ALNS is designed. Firstly, the initial solution is obtained by greedy algorithm and set as the optimal solution and the current solution, then the current solution is destroyed and repaired to obtain the neighborhood solution S^t. Based on the improved algorithm, the solution scenario is established, and the distribution paths and methods are planned based on the data of five neighborhoods, and the path optimization direction of the distribution methods is clarified. The analysis of the algorithm solution shows that the optimization of the model further satisfies the diversified needs of users for transportation distribution methods, and the satisfaction of the transportation distribution service can be improved while the cost of the terminal transportation distribution enterprises is reduced. The higher the complaint cost is, the total distribution cost first decreases slightly then increases and finally decreases again; the higher the time window penalty cost is, the higher the total distribution cost is. The calculation methods and results can provide some reference for the optimization of transportation end transportation routes based on users' preferences for transportation distribution methods.

In order to ensure the smooth implementation of relevant optimization methods and improve the quality of urban transportation and distribution services, it is necessary to provide policy guarantee and measure guarantee for urban transportation and distribution path optimization from multiple angles and aspects, and strengthen the promotion and application of relevant supporting policies, measures and methods from different levels and angles to achieve high-quality development of urban transportation and distribution market. First, establish a unified terminal transportation information service platform, strengthen the integration of data related to enterprise information, user information and industry information, establish a large database and realize the integration of data resources. Combined with the information on the service scale of distribution enterprises, user demand, and user service feedback, the industry management department further strengthens the research and judgment on the development of the transportation distribution market, forms industry development reports, and evaluates, analyzes and researches the market; enterprises collect information related to the distribution mode preference of users in the end distribution link through the platform, and constantly makes dynamic corrections to the end distribution habit preference characteristics of this user. Thus, the transportation and distribution paths can be further optimized dynamically. Second, increase the investment in the optimization of the end distribution path. Taking policy as a guide, from the height of the industry, guide all places to increase the policy and regulation guarantee for urban transportation and distribution path optimization, so as to realize the scientific and rationalization of end distribution path layout design. To industrial layout optimization, tax relief and other preferential means to guide the relevant enterprises to use scientific and efficient methods to optimize and adjust the path, and open up the transportation distribution "last mile". Enterprises to further increase the investment in path optimization program research, strengthen the science of transport and distribution route selection, control their own costs at the same time, to further meet the diversity of user needs. Third, strengthen the development of supporting policies. At present, urban transportation and distribution "last mile" vehicles are mainly tricycles, motorcycles, often crowding the motorway, sidewalk phenomenon, therefore, it is recommended that through policy guidance, in areas where conditions are ripe to pilot the opening of urban transportation and distribution of special channels, and motorway, non-motorized lanes, sidewalks to distinguish. Further ensure road traffic safety, while improving the efficiency of transportation distribution, and promote the opening of special parking spaces for distribution vehicles to solve the key problem of difficult parking for logistics and distribution vehicles. Establish a negative list in the field of urban transportation and distribution, promote the application of "double random a public" regulatory means, focus on the end of urban transportation and distribution of regulatory priorities, difficulties and weak links, the development of specific regulatory rules to reduce unnecessary costs for enterprises and promote a virtuous cycle of the market.

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