ISSN: 2688-9323

Research on Vehicle Path Optimization Problem for Urban Express Terminal Delivery

Yiwei Yu, Gengjun Gao

School of Institute of Logistics Science and Engineering, Shanghai Maritime University, Shanghai 201306, China

Abstract

The express delivery industry, as a barometer of our economy, directly reflects the degree of activity of our economy. However, the end of the courier industry is frequently short of people, so it is crucial to optimize the end of the courier delivery path within the limited manpower. This study aims to reduce the fixed cost of cars, distribution and transportation expenses, time penalty charges, etc. due to the high total cost and time restrictions faced by the express terminal distribution link in the urban context, and with the needs of each customer's express delivery time window, the maximum distance traveled by the vehicle, the vehicle's rated load capacity and volume as the constraints, the establishment of the city's express terminal distribution vehicle path planning model. In order to solve this model this paper designs an improved particle swarm algorithm, which introduces particle search optimization, convergence performance improvement, and elite retention optimization strategies for the disadvantages of particle swarm algorithm such as prematurely falling into the local optimum. It has been established, using Shanghai Pudong New Area as an example, that using the upgraded particle swarm optimization algorithm to solve the model results in a cost savings of 11.79% as compared to using the basic particle swarm optimization algorithm. A better urban express terminal distribution path may be found using the upgraded particle swarm optimization algorithm, and a less expensive vehicle path scheme can be obtained.

Keywords

City Express Terminal Distribution; Vehicle Routing Optimization; Particle Swarm Algorithm.

1. Introduction

In recent years, e-commerce gradually tends to market granularity, online shopping demand also tends to be more high-frequency sinking. Express industry as the wind vane of e-commerce, business volume and business income growth year after year at the same time face many challenges, which close to the client end of the city courier distribution highlights a number of problems, such as low distribution efficiency, high cost, delivery delays, etc.. Therefore, how to quickly and timely delivery of express delivery to the hands of customers at a low distribution cost, is the city express end distribution vehicle path optimization needs to solve the problem. Planning the distribution route of the end of the courier in advance can not only cut the distribution cost of enterprises, but also increase the service level of the end of the distribution.

At present, there have been a certain number of studies on the optimization problem of urban express terminal delivery path at home and abroad. Qiu Hanguang et al.(2018) studied to meet the personalized needs of customers for terminal delivery mode and service time window in urban distribution, considering two terminal delivery modes: door-to-door delivery and self-pickup cabinet, and established a multi-objective joint optimization problem model of self-pickup cabinet siting-time window allocation-path planning, which portrayed the impacts of

ISSN: 2688-9323

distance to the self-pickup cabinet, delivery time window, and the customer's demand for delivery services[1]. Li Wei et al.(2019) for the current problems in the process of urban terminal logistics and distribution, using the mileage saving algorithm to solve the path planning model, and concluded that the lowest congestion cost as the premise of choosing the path can make the lowest distribution cost[2]. Tan(2019) stood in the perspective of new retail industry, analyzed the current situation of distribution mode and successful cases, and used genetic algorithm to derive the multi-objective path planning scheme under the new retail industry with the objectives of minimum distribution cost, minimum distribution distance and maximum customer satisfaction[3]. Pan Binbin(2012) defined a VRP problem of "multiple delivery sites and multiple customers" with a time window, and took time, low carbon and traffic congestion restrictions as the main constraints to study the optimization model of the delivery route of the end of the courier[4]. Aized T et al.(2014) believed that the "last mile" delivery system is the key to the delivery problem, in the paper using Petri network method to construct hierarchical optimization model, to provide a solution to the distribution routes in the case of road congestion[5]. Yang Haoxiong et al.(2014) optimized the courier vehicle path problem in commercial area and proposed a mobile warehouse distribution model[6]. Lin C et al.(2014) introduced fuzzy time window to quantify the courier service level under the dynamic situation of courier service and optimized the distribution path with the goal of the highest service efficiency[7]. Sonu et al.(2020) proposed a multi-vehicle terminal delivery vehicle path problem based on customer satisfaction, using a two-stage ant colony optimization technique, the issue is resolved by taking into account the quickest turnaround time and lowest cost to suit the client's expectations.[8]. Qin et al.(2019) analyzed the distribution cost, customer satisfaction, and carbon emission cost, and took customer satisfaction and end distribution cost as the optimization objectives, and the results of the improved genetic algorithm solution showed that the cost increased by a small portion while the customer satisfaction increased to a large extent, so as to obtain an economically efficient distribution scheme[9]. Based on the simulated annealing algorithm, Li et al.(2020) considered the terminal delivery vehicle routing optimization problem of customer satisfaction, and verified the effectiveness of the model[10].

In summary, urban express delivery is a large-scale combinatorial optimization problem with more distribution points than logistics distribution. Finding the global best solution fast and precisely is challenging. An effective solution approach is an intelligent algorithm. Due to the features of the urban express delivery route optimization problem, this research will develop a mathematical model with the lowest overall cost and propose an enhanced particle swarm optimization technique to solve the model.

2. Model Construction

2.1. Problem Description and Assumptions

2.1.1. Problem Description

The express delivery is placed at the end of the city. According to the demand category and demand of each customer, the vehicle delivers the express delivery accurately within the time window. From a global perspective, the rapid decision-making of vehicle loading and distribution route schemes is a difficult problem that urban express terminal distribution should pay special attention to. Known as one of the city 's end outlets and customer coordinates, latitude and longitude or distance matrices, vehicles with the same indicators are driven from the end outlets to express delivery to customers in their respective paths, and all customer services on the path are returned to the distribution center. In this study, minimizing transportation costs, time costs, early/late penalty costs, and fixed vehicle distribution costs is the main target. The vehicle routing optimization model for the urban express terminal delivery is established, and the objective condition constraints are set, including the soft time window of each customer's express delivery, the longest distance of the vehicle's one-time delivery, and the maximum load of the vehicle.

2.1.2. Assumptions

(1)This paper examines the problem of a single endpoint outlet with an endpoint customer;

(2)Customer location, number, demand, and time window for requested deliveries determined;

(3)The end distribution outlets have enough vehicles, the vehicles have a certain load capacity, the distribution vehicles are all of the same type, and all the vehicles have a certain speed;

(4)All vehicles start at the end point, serve their assigned customers, and ultimately return to the end point;

(5)If the vehicle departs, the sequence of customers served is determined and no new customers will enter the planned route;

(6) Each customer 's courier can only be delivered by one vehicle, and a single delivery will be made.

2.2. Description of Symbols

i: courier number, i=1,2,3,…,I;

j: vehicle number, j=1,2,3,…,J;

p,q: all customer numbers, p,q=0,1,2,…,K, where 0 represents the end point;

dpq: denotes the distance from client p to q;

k: customer point number, k=1,2,…,K;

Vi: denotes the volume of express i, unit: m3;

VVj: rated volume of the j th vehicle, unit: m3;

CWpi: weight of customer p's ith courier, unit: kg;

VWj: rated capacity of the jth vehicle, unit: kg;

Sj: maximum number of miles per trip for the jth vehicle, unit: km;

VCj: unit transportation cost for the jth vehicle, unit: RMB;

TCj: unit time cost of the jth vehicle;

Tmax: maximum time spent on a single delivery;

Ajk: time of arrival of vehicle j at customer point k;

ETk , LTk: earliest and latest time to receive delivery at the customer's location;

Uz, Uc: costs associated with early and late arrival penalties calculated per unit of time;

C: unit fixed cost.

$$x_{jpq} = \begin{cases} 1, \text{the } j\text{th vehicle goes from node } p \text{ to node } q \\ 0, \quad \text{others} \end{cases}$$

$$y_{jk} = \begin{cases} 1, \text{delivery of the } j\text{th vehicle to the } k\text{th customer} \\ 0, \quad \text{others} \end{cases}$$

$$z_{ijk} = \begin{cases} 1, \text{the } j\text{th vehicle delivers the } i\text{th courier for the } k\text{th customer} \\ 0, \quad \text{others} \end{cases}$$

2.3. Model Building

$$\min f = \sum_{j=1}^{J}\sum_{p=0}^{K}\sum_{q=0}^{K} x_{jqp} d_{pq} VC_j + \sum_{j=1}^{J} TC_j * T_{\max} + \sum_{j=1}^{J}\sum_{k=1}^{K} P(p) + \sum_{p=1}^{K}\sum_{j=1}^{J} y_{ik} C \quad (1)$$

s.t.

ISSN: 2688-9323

$$\sum_{p=0}^{K}\sum_{q=0}^{K} x_{jqp} d_{pq} \leq S_j, \forall j = 1,2,3,\cdots,J \tag{2}$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} z_{ijk} y_{ik} CW_{pi} \leq VW_j, \forall j = 1,2,3,\cdots,J \tag{3}$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} z_{ijk} V_i \leq V\,V_j, \forall j = 1,2,3,\cdots,J \tag{4}$$

$$\sum_{j=1}^{J} y_{ik} = 1\,, \forall k = 1,2,3,\cdots,K \tag{5}$$

$$\sum_{p=1}^{K} x_{j0p} = \sum_{q=1}^{K} x_{jp0}\,, \forall j = 1,2,3,\cdots,J \tag{6}$$

$$P(p) = \begin{cases} U_z\left(ET_k - A_{jk}\right) & A_{jk} < ET_k \\ 0 & ET_k \leq A_{jk} \leq LT_k \\ U_c\left(A_{jk} - LT_k\right) & A_{jk} > LT_k \end{cases} \tag{7}$$

$$x_{jpq} \in \{0,1\} \quad p,q = 0,1,2,\cdots,K; J = 1,2,3,\cdots,J \tag{8}$$

$$y_{jk} \in \{0,1\} \quad k = 0,1,2,\cdots,K; J = 1,2,3,\cdots,J \tag{9}$$

$$z_{ijk} \in \{0,1\} \quad i = 0,1,2,\cdots,I; J = 1,2,3,\cdots,J; k = 0,1,2,\cdots,K \tag{10}$$

Formula(1) represents the optimization objective function and is made up of the fixed cost, time cost, early/late penalty cost, and transportation cost for vehicles used in distribution. Formula (2) ~ (10) is the constraint condition: equation(2)indicates that the combined mileage of each vehicle is less than or equal to the maximum value; equation(3)shows that the total weight of a single delivery of each vehicle is less than or equal to the rated load of the vehicle; equation(4) shows that the total volume of a single delivery of each vehicle is less than or equal to the vehicle capacity; equation(5) indicates that a customer 's express delivery is delivered by a vehicle and cannot be repeated; equation(6) indicates that each vehicle returns to the terminal distribution network after serving the last customer; equation (7) shows the penalty value when the express delivery time is outside of the time window given by the customer; equation(8), equation(9) and equation (10) are the values of decision variables. If the value is 1, it means that the task is completed. If the value is 0, it is not completed.

3. Improved Particle Swarm Optimization Algorithm for Solving

3.1. Particle Swarm Optimization Algorithm

Particle swarm optimization algorithm, also known as bird swarm algorithm, is an algorithm designed from the inspiration of bird predation behavior. Each particle is the epitome of the birds. Particles have two characteristics : velocity and position. Position denotes movement direction, while velocity denotes how fast one moves. TThe algorithm's fundamental premise is that each particle independently looks for the best solution within a certain range, stores the best answer as an individual extreme value, and informs other particles of its individual extreme value. Each particle not only ' learns ' according to its own extreme value, but also learns from the current extreme value in the entire population to determine the speed and direction of the next iteration. The optimal individual extreme value searched by a particle is iteratively iterated as the global optimal value of the entire particle swarm. The basic particle swarm optimization algorithm has the following disadvantages in solving the vehicle routing problem : the convergence speed is high enough, the solution region is too tiny, and the particle motion is too erratic. For the vehicle path of urban express delivery, shortening the path length is only a basic requirement. How to reduce the consumption of meaningless time in a complex environment, make it reach the customer point on time, and avoid the emergence of local optimal solution is the key.

3.2. Improved Particle Swarm Optimization Algorithm

For the aforementioned issues, an enhanced particle swarm optimization algorithm is created in this research. To optimize the individual (single particle) and the collective (particle swarm), the particle search optimization strategy, convergence performance improvement strategy, and elite retention optimization strategy are presented. This enables the particles to quickly and actively search for the location of the optimal solution throughout the entire space. The improved particle swarm completes the update of particle velocity position and so on through formula(11) to formula(18). The premise is that there are n particles and m particle swarms in the dimensional space.

$$X_i = (x_{i1}, x_{i2}, \cdots, x_{id}), i = 1,2,3, \cdots, m \tag{11}$$

$$V_i = (v_{i1}, v_{i2}, \cdots, v_{id}), i = 1,2,3, \cdots, m \tag{12}$$

$$P_i = (p_{i1}, p_{i2}, \cdots, p_{id}), i = 1,2,3, \cdots, m \tag{13}$$

$$G_i = (g_{i1}, g_{i2}, \cdots, g_{id}), i = 1,2,3, \cdots, m \tag{14}$$

$$v_{id}^{n+1} = w * v_{id}^n + c_1 r_1 (p_{id}^n - x_{id}^n) + c_2 r_2 \left(p_{gd}^n - x_{id}^n\right) \tag{15}$$

$$x_{id}^{n+1} = x_{id}^n + v_{id}^n \tag{16}$$

$$x_{id}^{n+1} = c_3 x_{id}^n + c_4 v_{id}^n \tag{17}$$

ISSN: 2688-9323

$$X_i \in [X_{min,}X_{max}], \qquad V_i \in [V_{min,}V_{max}] \tag{18}$$

Among them: w is the weight of inertia, and the existence of w can maintain the inertia of particles; c1 and c2 are cognitive factors, where c1 represents individual learning ability and c2 represents population learning ability. Generally, c1 and c2 are arbitrary values on the interval [0,4], and they are not 0 at the same time; c3 and c4 are particle improvement factors. Assuming that the set value of particle improvement factor is high, the particle motion ability will be enhanced, and the information sharing between particles and between particles and groups will be more frequent, so the range of solutions will be wider. r1 and r2 are random numbers on two intervals [0,1].

Eq.(11) denotes the position of particle i ; eq.(12) represents the velocity of particle i ; eq.(13) represents the optimal position of the particle i search; eq.(14) represents the optimal position of the group search; eq.(15) represents the velocity update formula of particle i in dimensional space; eq.(16) represents the update of the position of the particle i in the dimensional space; eq.(17) represents the improved optimization of particle i position in dimensional space; eq.(18) represents the velocity and range boundary of the particle.

3.3. Improved Particle Swarm Optimization Algorithm Implementation

The improvement of the particle swarm optimization algorithm is mainly optimized by three aspects : particle search optimization, convergence performance improvement and elite retention optimization.

(1)Particle search optimization strategy. The improved particle position formula is inserted, so that the particles search for the target value through their own variation and the cross-variation of the particle swarm.

(2)Convergence performance enhancement strategy. The main work of this strategy is to adjust the basic parameters of the algorithm. For example, the improvement of the inertia weight w can adopt the linear decreasing weight strategy or other strategies, which will significantly improve the full range search ability of the algorithm.

(3)Elite retention optimization strategy. To assist the particles in the local search to exit the loop, there is a chance to accept the operator that does not adhere to the particle crossing operation's requirements.

4. Simulation Analysis of Examples

4.1. Data Reduction

Taking Shanghai Pudong New Area as an example, the vehicle routing of urban express terminal distribution is studied. In this paper, some communities in Gaoqiao Town and Gaohang Town of Pudong New Area are selected as demand points, and a shopping center warehouse is used as the terminal distribution network. The specific geographical location diagram is shown in Figure 1. The number of the terminal distribution network is 0, and the location number of each customer is from 1 to 10.

Figure 1. Location distribution map

According to the distribution of each customer point and the end point, the distance matrix between the end point and each customer point is calculated according to the position coordinates provided by the map. The position coordinates of each customer point and the end point are shown in Table 1.

Table 1. Coordinates of each information point

Serial Number	X	Y
0	7.0	7.0
1	2.2	12.0
2	3.0	12.5
3	5.4	13.5
4	4.0	8.1
5	4.6	6.2
6	5.0	3.0
7	10.0	2.2
8	7.3	5.8
9	8.1	8.4
10	9.2	6.7

The city 's terminal distribution network has a number of distribution vehicles of the same type. The rated load of the vehicle is 1000 kg, the rated volume of the vehicle is 25 m3, the maximum mileage of the vehicle is 20 km, the fixed cost of each vehicle is 600 RMB/vehicle, the transportation cost per unit distance is 5 RMB/km, the cost per unit time is 12 RMB/min, and the average speed is 40 km/h. According to the results of the seventh census and the official announcements and documents of the selected community, the population of each customer point is obtained, and the number of express delivery of selected customer points is calculated based on the population of the community and the average demand. The arrival time window is set according to the urgency of demand to ensure fairness. The sorted data is shown in Table 2.

Table 2. Delivery information

Customer Point Number	Number of couriers	Express Weight(kg)	Express Volume(m^3)	Time Window
1	720	60	1.80	10:00~11:00
2	540	45	1.35	8:30~10:00
3	1620	135	4.05	8:00~9:00
4	900	75	2.25	10:30~12:00
5	1080	90	2.7	17:00~18:30
6	1440	120	3.60	15:00~16:00
7	800	67	2.00	14:00~15:30
8	1080	90	2.70	13:00~15:00
9	540	45	1.35	9:00~10:00
10	850	72	2.20	7:00~8:30

4.2. Simulation Analysis

Firstly, the basic parameters of the algorithm are set. The particle swarm size is 200, the maximum number of iterations is 300, the unit early arrival penalty cost is 4 RMB/min, and the unit late arrival penalty cost is 6 RMB/min. The inertia weight w is dynamically adjusted by the linear decreasing weight strategy. The cognitive factors c1 and c2 are optimized by the synchronous learning factor method. The particle improvement factor c3=1, c4 =1.3.

In this paper, matlab2017b is used to program the algorithm. The hardware environment information is : CPU i5-6300HQ, 2.30GHz, 4G memory, Windows10 professional version, 64-bit operating system. The simulated community express vehicle delivery path is shown in Figure 2.

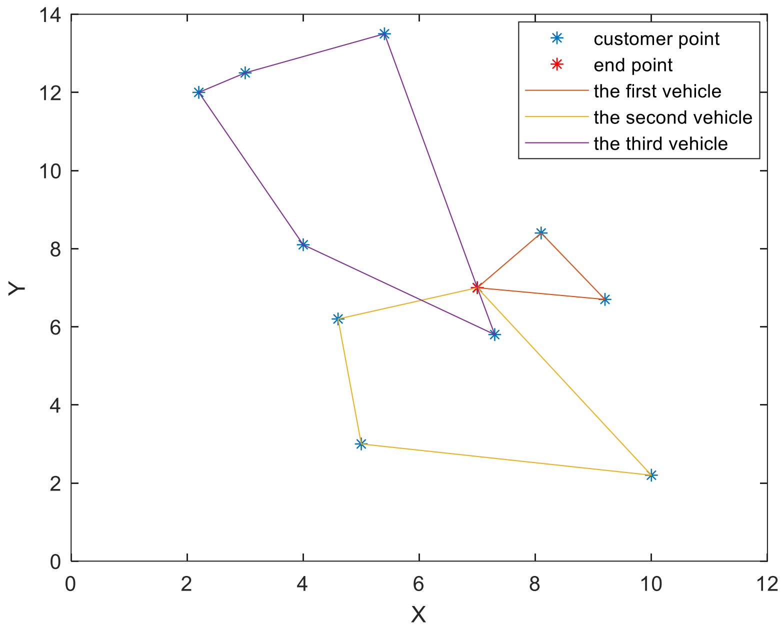

Figure 2. Terminal delivery vehicle routing

According to Figure 2 and the operation results, it is concluded that the distribution point order of the first vehicle distribution path is 0-10-9-0, and the material weight is 117 kg; the distribution point order of the second vehicle distribution path is 0-7-6-5-0, and the material weight is 277 kg ; the delivery point order of the third vehicle delivery path is 0-3-2-1-4-8-0, and the material weight is 405 kg. According to the results of the matlab command line window, the distribution cost is 201.55 RMB, the penalty cost is 10.27 RMB, the time cost is 707.56 RMB, the fixed cost is 600 RMB, and the overall cost is 1519.38 RMB. The vehicle arrives in each community almost within the time window, and the cost of early/late arrival is extremely low. The iteration process of the whole particle is shown in Fig.3. The abscissa is the number of iterations, and the ordinate is the optimal value.

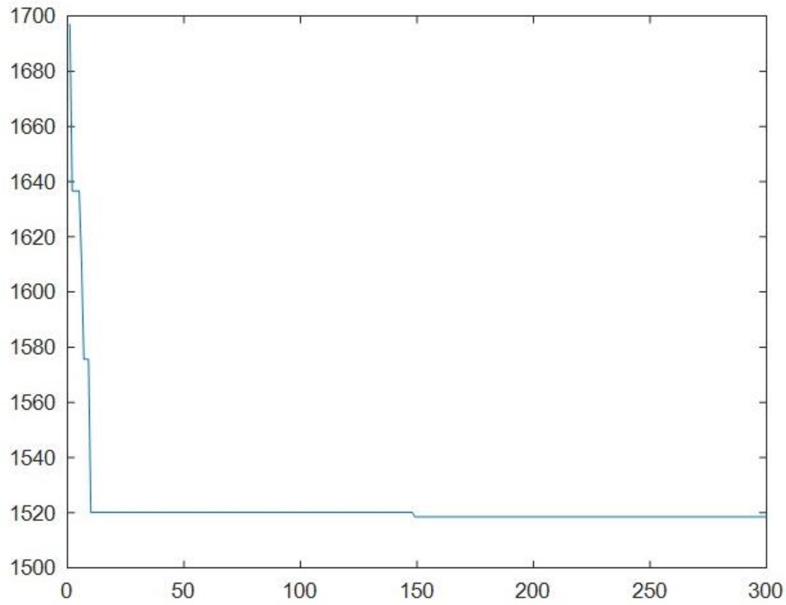

Figure 3. Iterative process

The basic particle swarm optimization algorithm is used to solve the model, and the parameters are unchanged. The results are compared with the improved particle swarm optimization algorithm, as shown in Table 3.

Table 3. Algorithm comparison

Improved algorithm delivery route	Improved algorithm optimal value	Basic algorithm delivery route	Optimal value of basic algorithm
1st vehicle: 0-10-9-0	1519.38	1st vehicle: 0-8-0	1698.47
2nd vehicle: 0-7-6-5-0		2nd vehicle: 0-7-6-0	
3rd vehicle:0-3-2-1-4-8-0		3rdvehicle:0-10-9-3-2-1-4-5-0	

The penalty cost of the basic particle swarm optimization algorithm is 152.43 RMB, and the total cost is 1698.47 RMB. It can be seen that the improved particle swarm optimization algorithm proposed in this paper is compared with the basic particle swarm optimization algorithm. The total cost of the system is saved by 11.79%, and the distribution will not be affected by the limitation of time. Therefore, the vehicle routing optimization model and algorithm of urban express delivery terminal distribution proposed in this paper are effective.

5. Conclusion

Based on the problems faced by China's current express delivery industry, this paper constructs a vehicle routing optimization model for urban express delivery and designs a solution algorithm by analyzing urban express delivery. The example shows that the improved particle

ISSN: 2688-9323

swarm optimization algorithm designed in this study can effectively solve the optimization model of express terminal distribution path constructed in this paper. It can be used for express enterprises to reasonably arrange couriers and their distribution paths according to the express volume and formulate the service time of distribution points. It has practical significance and draws the following conclusions:

(1) The vehicle routing optimization model of urban express terminal delivery is constructed. This model basically covers the conditions that express vehicle delivery needs to include. A logistics vehicle routing optimization algorithm based on improved particle swarm optimization is designed to further enrich the VRP application scenario. At the same time, it can relieve customers ' urgent needs for express terminal delivery;

(2) In the improvement of particle swarm optimization, particle search optimization, convergence performance improvement and elite retention optimization strategy can obviously overcome the disadvantages of basic particle swarm optimization, and the global optimal value of the solution can better reflect the performance of the algorithm in the face of discrete problems;

(3) Through the example programming results, the optimization algorithm designed in this paper has higher solution accuracy and wider solution range, and the cost of the whole distribution is reduced by 11.79 %. At the same time, according to the processed express delivery, the optimal distribution path from the end point to the customer point is solved.

References

[1] Qiu Hanguang, Li Hainan, Song Han. Location-routing problem of urban distribution pick-up cabinets with demand dependent on terminal delivery and time window [J].Computer integrated manufacturing system, 2018, 24(10): 2613-2621.

[2] Li Wei, Yang Yanmei, Liu Hanying, et al. Research on the optimization of logistics distribution path at the end of the city [J].Railway freight, 2019, 37 (03): 9-14.

[3] Tan Jianwei.Research on the path of urban terminal distribution network under the new retail format [D].Beijing Jiaotong University, 2019.

[4] Pan Binbin.Research on distribution route optimization of B2C enterprises under low carbon constraints [D].Chongqing Jiaotong University, 2012.

[5] Aized T, Srai J S. Hierarchical modelling of Last Mile logistic distribution system[J]. International Journal of Advanced Manufacturing Technology, 2014, 70(5-8): 1053-1061.

[6] YANG Haoxiong, LIU Tong. Path optimization and simulation of express vehicles in commercial areas[J]. Computer Simulation, 2014, 31(08): 443-446.

[7] Lin C, Choy K L, Ho G, et al. A decision support system for optimizing dynamic courier routing operations[J]. Expert Systems with Applications, 2014, 41(15): 6917-6933.

[8] Sonu Rajak,P. Parthiban,R. Dhanalakshmi. Multi-depot vehicle routing problem based on customer satisfaction [J]. International Journal of Services Technology and Management, 2020, 26(2-3).

[9] Qin G, Tao F, Li L.A. vehicle routing optimization problem for cold chain logistics considering customer satisfaction add carbon emission [J].International journal of environmental research and publichealth, 2019, 16(4): 576.

[10] Li Changmin, Tao Ying, Peng Xian et al. Vehicle routing problem based on customer time satisfaction[J]. Journal of Shanghai University (Natural Science Edition), 2020, 26(03): 472-480.