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Cooperative Distribution Path Optimization Study of Electric Unmanned Vehicle End based on Multiple Distribution Entities

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Abstract

Since the planning of China's urban logistics system does not include end-of-line distribution in the unified planning, and less consideration is given to the cooperative distribution of multiple subjects, resulting in the overall low efficiency of the transportation link; at the same time, considering the impact of the epidemic on logistics distribution, "electric unmanned vehicles" with high efficiency, low cost and no contact characteristics become an important tool for end-of-line distribution. In summary, this paper takes the urban end distribution scenario as the research object, builds a cooperative distribution model among multiple subjects with electric unmanned vehicles as the carrier, and designs an improved algorithm to solve the model; finally, the optimization model proposed in this paper is verified through an example that it can give full play to the advantages of energy saving and emission reduction of electric unmanned vehicles and capital reduction compared with the traditional single distribution and single journey vehicle distribution model, thus promoting urban The model can be used to promote the green, low-carbon and sustainable development of the city.

Keywords

Electric Unmanned Vehicle Logistics; Multi-Distribution Body; Collaborative Distribution; End-Distribution; Path Optimization.

1. Introduction

As the existing urban logistics system does not include end distribution in the unified planning, resulting in a single distribution body and duplicated distribution paths, reducing the overall efficiency of logistics activities; most urban logistics transport vehicles are mainly gasoline vehicles, highly dependent on fossil energy, which seriously affects the green, low-carbon and sustainable development capacity of the logistics and distribution system. For this reason, on the one hand, there is a need for joint distribution path optimization for multiple distribution entities [1] On the other hand, it is necessary to actively promote electric unmanned vehicle distribution to reduce the reliance on fossil energy for urban end distribution [2] On the other hand, we need to actively promote electric unmanned vehicle distribution, reduce the reliance on fossil energy in urban end distribution, and reduce the energy loss in distribution process.

Co-distribution is the process of collaborative distribution among multiple distribution entities in order to improve distribution efficiency and reduce duplication of distribution routes. At present, the research on collaborative distribution is mainly about the definition of the concept of collaborative distribution, which is defined by the Japan Logistics System Association as a logistics system jointly established by multiple logistics and distribution entities(In 1977, the Ministry of Transportation and Communications issued the "Outline for the Promotion of Cooperative Transportation Systems" with the aim of promoting the development of cooperative transportation.); [Japanese] Taniguchi, Eiichi [3] After analyzing the urban logistics system, [Japanese] Taniguchi Eiichi et al. concluded that the logistics activities at the end of the city, whether production or transportation, should be optimized collaboratively; secondly, innovative attempts on innovative distribution models, Thompson RG and Zhang LL [4] et al. established a two-layer optimized express delivery model that optimizes both the route from the distribution center to each distribution center and the route from the distribution center to each end distribution point, and used an improved genetic algorithm to solve , both of which proved the superiority of the collaborative delivery model. The VRP problem derived from pure electric unmanned vehicles used as logistics transportation vehicles for distributing goods is called the pure electric logistics vehicle vehicle path problem. In recent years, research on such problems has mainly focused on the innovation of path planning under different constraints. In the problem of studying the impact of different charging modes of electric vehicles on path planning, Keskin and Catay[5] explored the problem of allowing EVs to be only partially charged according to the driving range required for the remaining tasks, and built an EVRP path planning model with a time window under this premise, which was solved using an adaptive large-scale neighborhood search algorithm ; secondly, an extended study on the VRP-derived problem, Desaulniers[6] In the study of this problem, Desaulniers et al. have extended the study to four scenarios, which are allowing each EV to be fully charged only once, not requiring a full charge once, charging each vehicle multiple times, and not requiring a full charge each time; domestic scholar Yang Jun[7] In contrast, domestic scholar Jun Yang researched the problem of siting EV switching stations, establishing a dual-objective planning model that integrates siting and path planning, and designing a two-stage heuristic algorithm for solving the problem by combining the improved Clarke-Wright saving algorithm and the forbidden search algorithm .

Based on the above background, constructs an EVRPDD (Electric Vehicle Routing Problem with Dynamic Demands) model for cooperative distribution of multiple entities, and builds the target models for the deployment and distribution phases respectively.

2. Model Building

2.1. Problem Description

In this paper, the end distribution problem is divided into two phases: the process of mutual adjustment of goods belonging to distribution subjects is called the deployment process, and the end distribution process of distribution subjects is called the distribution process; the electric unmanned vehicle is used as the carrier, and the distribution path is semi-open, i.e., the unmanned vehicle in the distribution phase can return to any nearest distribution subject, and the path optimization of the whole end pickup and distribution is carried out. The objective is to minimize the sum of the cost of the vehicle, charging cost and mileage cost in the case of considering both the deployment and distribution phases.

Assume the following for the above.

1. Vehicles may not be returned to the original center during the distribution and redeployment phase.
2. Assume that the remaining battery charge is proportional to the distance that can be driven.
3. Each end demand point is served by one and only one logistics vehicle.
4. The load capacity of the distribution vehicle from the distribution center shall not exceed its maximum load capacity.
5. Each distribution body acts as a distribution center at the same time and is responsible for loading and unloading goods from the delivery vehicles. Initially, each distribution center has 5 unmanned vehicles for distribution and accommodates up to 10 delivery vehicles.

2.2. Mathematical Model

According to the problem description, the whole distribution process is modeled separately into two phases: distribution and provisioning.

(1) Distribution phase model.

$$MinC_0 = C_1 + C_2 + C_3 \tag{1}$$

$$C_1 = f_1 \sum_{k \in K} \sum_{i \in M'} \sum_{j \in N_m^{m'}} x_{ijk} + u_1 \sum_{k \in K} \sum_{i \in M' \cup N_m^{m'}} \sum_{j \in N_m^{m'}} x_{ijk} d_{ij} \tag{2}$$

$$C_3 = u_3 \sum_{j \in F} y_{jk} \tag{3}$$

$$\sum_{i \in M' \cup N_m^{m'}} x_{ijk} = 1 \quad \forall j \in N_m^{m'} \quad \forall k \in K \tag{4}$$

$$\sum_{\forall i \in M' \cup N_m^{m'}} x_{ijk} = \sum_{\forall p \in M' \cup N_m^{m'}} x_{jpk} \quad \forall j \in N_m^{m'} \quad \forall k \in K \tag{5}$$

$$x_{m'jk} = 1 \quad \forall j \in N_m^{m'} \cup m'' \quad \forall k \in K \tag{6}$$

$$x_{im''k} = 1 \quad \forall j \in N_m^{m'} \cup m' \quad \forall k \in K \tag{7}$$

$$D_{jk} = [D_{ik}(1 - y_{ik}) + y_{ik} D_{\max} - D_{ij}] x_{ijk}$$
$$\forall j \in \sum_{m \in M} N_m \cup F \cup M'' \quad \forall i \in \sum_{m \in M} N_m \cup F \cup M' \quad \forall k \in K \tag{8}$$

$$D_{jk} \geq 0 \quad \forall j \in \sum_{m \in M} N_m \cup F \cup M'' \quad \forall k \in K \tag{9}$$

$$Dm'k = D\max \quad \forall k \in K \tag{10}$$

$$\sum_{i \in M' \cup N_m^{m'}} \sum_{j \in N_m^{m'}} x_{ijk} q_j \leq W_{\max} \quad \forall k \in K \tag{11}$$

$$y_{jk} \leq z_j \quad \forall j \in \sum_{m \in M} N_m \cup F \cup M'' \quad \forall k \in K \tag{12}$$

$$x_{ijk} = \{0,1\} \quad \forall j \in N_m^{m'} \cup m'' \quad i \in M' \cup N_m^{m'} \quad \forall k \in K \tag{13}$$

$$y_{jk} = \{0,1\} \quad \forall j \in \sum_{m \in M} N_m \cup F \cup M'' \quad \forall k \in K \tag{14}$$

Eq. (1) indicates that the total cost consists of distribution cost, deployment cost and charging cost; Eq. (2) indicates that the distribution cost is determined by the number of vehicles dispatched and the total mileage traveled; Eq. (3) indicates the charging cost; Eq. (4) ensures that a vehicle is available for service at each demand point; Eq. (5) indicates that the flow at the service point is conserved to ensure that the vehicle leaves at the end of the dispatch; Eq. (6), (7) guarantee that the vehicle departs from the distribution center and eventually turns back to the distribution center; equations (8) and (9) represent the mileage constraint to ensure that the remaining range of the electric unmanned vehicle to reach any node is not 0 and the vehicle always proceeds along the shortest path; equation (10) indicates that the delivery vehicle is fully charged when it departs from the distribution center; equation (11) indicates that the loading of the delivery vehicle at any node does not exceed the vehicle load capacity; equation (12) indicates that the delivery vehicle is fully charged at the fixed charging station only; equation (13) of x_{ijk} is a 0-1 variable that indicates the initial route; equation (14) of y_{jk} is a 0-1 variable that indicates the initial charging schedule.

(2) Dispatch phase model.

$$C_2 = f_2 \sum_{k' \in K'} \sum_{i \in M'} \sum_{j \in N_m^{m'}} x_{ijk'} + u_2 \sum_{k' \in K'} \sum_{i \in M' \cup N_m^{m'}} \sum_{j \in N_m^{m'}} x_{ijk'} d_{ij} \tag{15}$$

$$\sum_{i \in M' \cup N_m^{m'}} x_{ijk'} = 1 \quad \forall j \in N_m^{m'} \quad \forall k' \in K' \tag{16}$$

$$\sum_{\forall i \in M' \cup N_m^{m'}} x_{ijk'} = \sum_{\forall p \in M' \cup N_m^{m'}} x_{jpk'} \quad \forall j \in N_m^{m'} \quad \forall k' \in K' \tag{17}$$

$$x_{m'jk'} = 1 \quad \forall j \in N_m^{m'} \cup m'' \quad \forall k' \in K' \tag{18}$$

$$x_{im''k'} = 1 \quad \forall j \in N_m^{m'} \cup m' \quad \forall k' \in K' \tag{19}$$

$$\sum_{i \in M' \cup N_m^{m'}} \sum_{j \in N_m^{m'}} x_{ijk'} q_j \le W'_{\max} \quad \forall k' \in K' \tag{20}$$

$$x_{ijk'} = \{0,1\} \quad \forall j \in N_m^{m'} \cup m'' \quad i \in M' \cup N_m^{m'} \quad \forall k' \in K' \tag{21}$$

Eq. (15) is expressed as the cost of redeployment consists of the fixed trip cost of the redeployment vehicle and the travel cost of the redeployment vehicle; Eqs. (16) and (17) indicate that all shipments are detected and each shipment is served by one and only one vehicle; Eqs. (18) and (19) guarantee that each redeployment vehicle departs from and returns to the distribution center; Eq. (20) indicates that distribution vehicles are guaranteed to be loaded with no more than the vehicle capacity at any node; equation (21) is a 0-1 variable, which indicates the virtual goods transfer route.

(3) Variable and parameter definition

C_0 Total cost

C_1 : Distribution costs

C_2 : Redeployment costs

C_3 : Charging cost

u_1 : Distribution center distribution unit distance cost (yuan/km)

u_2 : Unit distance cost of deployment between distribution centers (Yuan/km)

u_3 : Single charge cost (yuan/time)

f_1 : Single dispatch cost of distribution vehicles in distribution centers (yuan)

f_2 : Cost of single dispatch of vehicles deployed by the distribution center (yuan)

M : Collection of distribution centers attributed from the end demand point

M' : The set of distribution centers to which the end demand points are assigned (starting point)

M'' : Set of distribution centers to which end demand points are assigned (end point)

F : Charging Station Collection

N_m : Collection of end demand points attributed to distribution center m

$N_m^{m'}$: the set of end demand points attributed to distribution center m, but assigned to distribution center m′

K : Collection of vehicles in the distribution phase

K' : Vehicle pooling in the redeployment phase

d_{ij} : Travel distance between point i and point j

q_j : Weight of goods at demand point j

$W_{\max}$: Loading capacity of distribution vehicles

$W'_{\max}$: Deployment of vehicle loading capacity

x_{ijk} : 0-1 decision variable, when the vehicle travels from point i to point j is 1, otherwise is 0

y_{jk} : 0-1 decision variable, 1 when vehicle k is charging at point j, 0 otherwise

$d_{mm'}$: Distance between distribution center m and m′

3. Algorithm Design

3.1. Attribution

Because the result of the final solution of the forbidden search algorithm and the speed of the solution depend largely on the quality of the initial solution[8] , so this paper generates the initial solution of this stage according to the heuristic rule of ordering the ratio size of the end demand point demand and the distribution distance from the distribution center, i.e., the closer to the distribution center and the larger the distribution volume the earlier the demand point is satisfied.

Step1: Calculate the Euclidean distance between each distribution body and each end distribution pointd_{ij} ;

Step2: Generateq_j /d_{ij} The matrix Q = $\begin{matrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{matrix}$ with rows representing m distribution centers and columns representing all n end distribution points;

Step3: Take the demand/distance matrix Qr_{ij} the maximum value of$r_{i'j'}$ and check whether the load capacity of distribution vehicles in distribution center i′ can complete the distribution task of end distribution pointj' and if so, assign the distribution pointj' If it can, then assign the distribution point to the distribution bodyi' and delete the distribution pointj' If it can, the distribution point will be assigned to the distribution body for distribution, and the column where the distribution point is located will be deleted.$r_{i'j'}$ If the distribution point cannot be completed, the distribution point is set to zero;

Step4: Repeat Step3 until all distribution points are assigned to each distribution center, then the initial distribution point attribution scheme is obtained.

3.2. Distribution Route Planning

(1) Coding

The delivery vehicle used in this study is an electric vehicle, and it is necessary to consider not only the distribution problem, but also the problem of going to the charging station to recharge when the remaining mileage is insufficient due to the distance constraint of the electric vehicle. Therefore, the problem needs to be able to show the order of the vehicles visiting the stations, which can be coded in the order of natural numbers, with m distribution centers coded as 1, ..., m, and a total of n distribution points with distribution point numbers m+1, ..., m+n. Each distribution center is assigned to each distribution point in the vesting allocation stage in Rehearse in order, and then insert the corresponding distribution center according to the load constraint of the distribution unmanned vehicle and the distribution volume of each distribution point to ensure that the total amount of delivery and pickup between distribution centers does not exceed the load constraint of the unmanned vehicle. For example, there are 2 distribution centers with 20 end demands, which are divided into (3 5 7 9 11 13 15 17 19 21) and (4 6 8 10 12 14 16 18 20 22) after attribution allocation Using the load constraint to insert the corresponding distribution centers to get (1 3 5 7 9 11 13 1 1 15 17 19 21 1) and (2 4 6 8 10 12 2 2 14 16 18 20 22 2) means there are 2 distribution centers with 4 distribution unmanned vehicles serving 20 distribution points.

(2) Decoding

Decoding is the inverse operation of encoding. The end carrier used in this paper is an unmanned delivery vehicle, so for the above encoding, we need to judge the remaining mileage on the sub-path, and once the remaining mileage is not enough to reach the charging station nearest to the next node from the next node, then go to the charging station nearest to the current node to charge. For example, in the above example, there are r end charging stations with numbers m+n+1,m+n+2,...,m+n+r. If 2 distribution centers send 4 vehicles to serve 20 distribution points and need to visit 2 charging stations midway, the codes are (1 3 5 7 9 25 11 13 1 1 15 17 19 21 1) and (2 4 6 8 10 28 12 2 2 14 16 18 20 22 2) , then the vehicle path after decoding is

Path 1: 1-3-5-7-9-25 (charging station) - 11-13-1

Path 2: 1-15-17-19-21-1

Path 3: 2-4-6-8-10-28 (charging station) - 12-2

Path 4: 2-14-16-18-20-22-2

The initial feasible solution is obtained by encoding and decoding.

(3) Neighborhood shift

When performing the neighborhood move in the case of this paper, the charging station in the current optimal solution is first removed from the route, and the new charging station is inserted according to the load and mileage constraints when generating a feasible solution for the neighborhood, and the total distribution cost is calculated. In this paper, to increase the randomness of the algorithm in the path finding phase, nine neighborhood moves are proposed for generating the neighborhood of the current solution. At each iteration, one of these nine neighborhood moving methods is randomly selected to generate the neighborhood in combination with the current solution.

(4) Determination of candidate set

A certain number of feasible solutions are selected from the neighborhood as the candidate set.

(5) Evaluation of solutions

Solution evaluation is performed to update the current solution and to find the optimal solution from the neighborhood of the current operation to move the iteration towards a better solution. The evaluation criterion used in this phase is the lowest total distribution cost, i.e., the sum of driving cost, trip cost and charging cost.

(6) Taboo rules

The taboo length is a fixed constant that determines how many iterations the taboo object does not recur; the taboo object is the route solution corresponding to the optimal solution of the non-taboo object in the candidate set in each iteration.

(7) Stopping guidelines

That is, the upper limit of the number of iterations, which is taken as a fixed value in this paper.

4. Case Simulation

4.1. Overview of the Algorithm

Four courier companies exist in a region with coordinates [5,5], [20,10], [20,25] , [5,20], and [5,20] respectively. On a certain day, all four courier companies have 10 delivery tasks in the morning, and all these delivery points are distributed in an urban area of 30kmx30km, and the distance between delivery points is assumed to be Euclidean distance in this paper. At present, the four delivery companies adopt joint delivery mode, each delivery company has 5 delivery unmanned vehicles and 1 deployment vehicle at the site before the start of this day's task, the cost of the delivery unmanned vehicle is 50 RMB/vehicle, the maximum driving distance is 60km, the driving cost is 1 RMB/km, the maximum load capacity is 100kg, and the average driving speed is 30km/h; the cost of the deployment vehicle is 100 RMB/vehicle, the maximum driving distance is 200km, and the average driving speed is 30km/h. The maximum driving distance is 200km, the driving cost is 2 yuan/km, the maximum capacity is 200kg, and the average driving speed is 40km/h.

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There are 20 charging stations within the city area, and the locations of the charging stations are shown in Figure 1. The charging time for each unmanned vehicle is 30 minutes, and the charging cost is 15 RMB/time, and the coordinates of the charging stations are shown in the attached table; to prevent the vehicles from being too concentrated at a certain distribution site, a virtual parking space system is set up, and the maximum number of unmanned vehicles for each distribution center is no more than 10, and the average waiting time for the distribution goods to reach the distribution point is 5min.

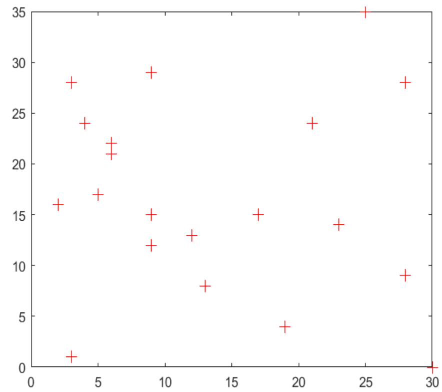

Figure 1. Coordinate map of the charging station

4.2. Contrast Analysis

(1) Traditional use of single-mileage vehicles for distribution

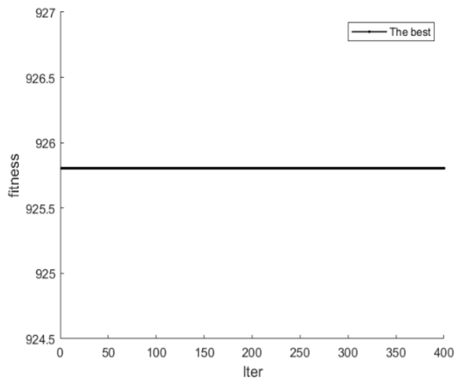

Figure 2. Iterative optimization diagram

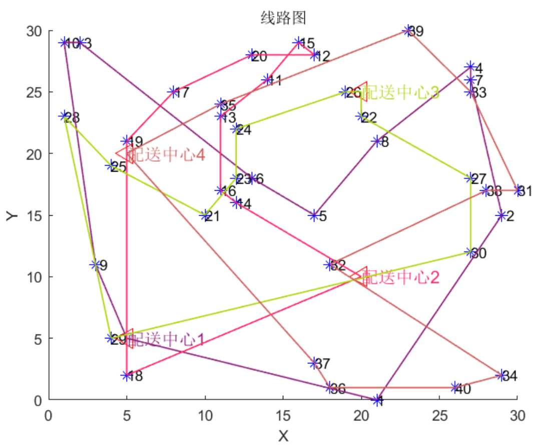

Figure 3. Single-mile vehicle route map

Firstly, we analyze the traditional distribution subject using single-mileage distribution vehicle for distribution alone, with a delivery vehicle capacity of 100 kg, a driving cost of 1 yuan/km, a maximum driving distance of 80 km, and a fixed trip cost of 50 yuan. The optimization search is performed using the mileage saving method with 400 iterations.

A total of four delivery routes are generated, and the total delivery cost is $925.5. The iterative optimization is shown in Figure 2, and the routes for single-mileage vehicle delivery are shown in Figure 3.

(2) The use of electric unmanned vehicles for collaborative distribution

This model is the distribution model studied in this paper, the cost of the delivery unmanned vehicle is 50 RMB/vehicle, the maximum distance traveled is 60km, the travel cost is 1 RMB/km, the maximum capacity is 100kg, and the average travel speed is 30km/h; the cost of the deployment vehicle is 100 RMB/vehicle, the maximum distance traveled is 200km, the travel cost is 2 RMB/km, the maximum capacity is 200kg, and the average travel speed is 40km/h. In this stage, we use the improved algorithm of the taboo search algorithm to find the best for the two stages of distribution and deployment respectively, and the number of neighborhood search is set to 100, the maximum number of iterations is 1000, and the length of taboo search is 80.

The simulation results generate a total of 5 distribution paths with a total distribution cost of $630. The iterative optimization is shown in Figure 4, and the roadmap is shown in Figure 5.

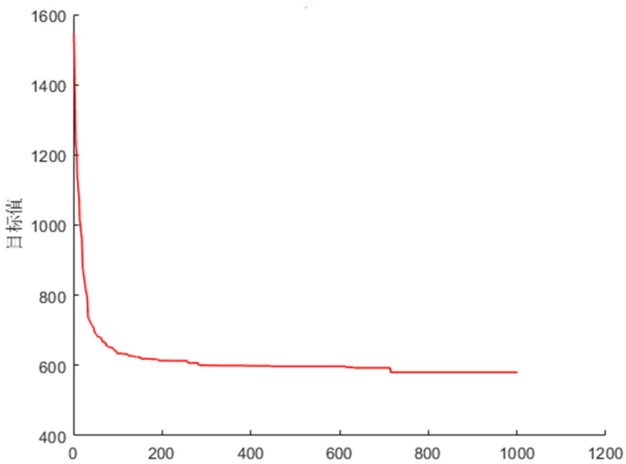

Figure 4. Collaborative iterative optimization diagram

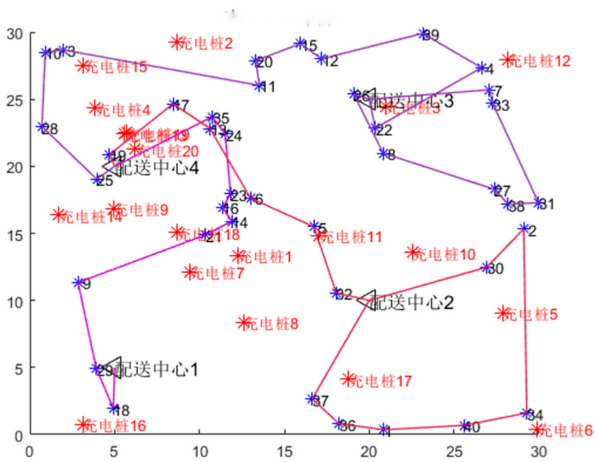

Figure 5. Collaborative path diagram

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In this example, the roadmap of the deployment phase is shown in Figure 6, and the table of deployment routes among distribution centers is shown in Table 1.

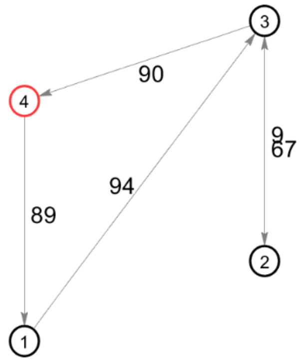

Figure 6. Distribution routes between distribution centers

Table 1. Dispatch route table

Deployment starting point	Number of tasks	Loading and unloading (1 for loading, 2 for unloading)	Loading and unloading volume
4	0	0	0
4	8	1	49
4	9	1	40
1	3	1	9
1	2	1	49
1	1	1	36
3	9	2	40
3	6	1	9
3	2	2	49
2	5	1	26
2	6	2	9
2	1	2	36
2	4	1	41
2	8	2	49
3	7	1	35
3	4	2	41
4	3	2	9
4	5	2	26
4	7	2	35
4	0	0	0

From Table 1, it can be seen that the deployment vehicle left from Distribution Center No. 4 to Distribution Center No. 1, loaded 40kg of goods that needed to be deployed to Distribution Center No. 3 and 49kg of goods that needed to be deployed to Distribution Center No. 2, respectively; arrived at Distribution Center No. 1, loaded 36kg of goods that needed to be deployed to Distribution Center No. 2, 49kg of goods from Distribution Center No. 3, and 4kg of goods from Distribution Center No. 4 9kg; then went to Distribution Center No. 3, unloaded 40kg of goods from Distribution Center No. 4, 49kg of goods from Distribution Center No. 1, and loaded 9kg of goods that needed to be transported to Distribution Center No. 2; then went to Distribution Center No. 2, unloaded 9kg of goods from Distribution Center No. 3, 36kg of goods from Distribution Center No. 1, 49kg of goods from Distribution Center No. 4, and loaded Then go to No.3 distribution center, unload 49kg of goods from No.2 distribution center and load 35kg of goods to be transported to No.4 distribution center; finally go back to No.4 distribution center and unload the goods from No.1, No.2 and No.3 distribution center to No.4 to complete the whole deployment process. process.

Table 2. Optimization results analysis table

	Driving Costs	Dispatch Costs	Charging Fees	Dispatch driving Cost	Dispatch Cost	Total cost
Distribution Center 1	133	100	0	~~0~~	~~0~~	233
Distribution Center 2	77	50	0	~~0~~	~~0~~	127
Distribution Center 3	98	50	30	~~0~~	~~0~~	178
Distribution Center 4	125	100	0			
Total cost before synergy	434	300	30	~~0~~	~~0~~	764
Total cost after synergy	194	250	30	86	100	660
Optimization range	55.3%	16.6%				15.8%

In this example, to verify the effectiveness of the algorithm, the collaborative and non-cooperative modes use the same load and mileage constrained vehicles, and the results are shown in Table 2. The collaborative distribution mode reduces the driving cost by 55.3%, and the total cost is optimized by 15.8% .

5. Conclusion

In this paper, with the lowest total transportation cost as the objective function, the objective models of the two stages of deployment and distribution in the end cooperative distribution process of multiple distribution entities are constructed based on the load as well as the mileage constraints, respectively. In the model solution, the initial solution is firstly produced based on the heuristic algorithm to produce the initial attribution allocation plan based on the principle of limited service at points with close proximity and high quality of goods, with vehicle load as the constraint; then the initial solution of the distribution scheme is obtained by coding and decoding, and the improved forbidden search algorithm is used to find the best. The results verify the universal applicability and superiority of the innovative distribution model, which can enable better planning and more efficient utilization of logistics resources, thus improving the overall efficiency of logistics distribution. Future research can take into account the complex situation of ground conditions to be more realistic.

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