Research on Optimizing the Route of New Energy Vehicles in Commercial Districts Considering Environmental Costs

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Abstract. Aiming at the problem of ignoring the environmental cost and the high total cost of distribution for each merchant in a logistics park, a new energy vehicle is adopted as the distribution tool, and multiple factors are taken into consideration, including the distribution demand, the limitation of the power of the new energy vehicle, the constraints of the time window and the transportation capacity, etc. Referring to the culture of the business circle adopted by the takeaway distribution center, the whole logistics park is regarded as a center, and a same-city distribution path optimization model, which considers environmental costs in addition to direct costs and is solved using a genetic algorithm. A specific chromosome coding method as well as a method of fusion with the objective function were designed to adapt this model. The results show that although the environmental cost accounts for a small proportion of the total distribution cost, its indirect impact on the total distribution cost is as high as 9%, which shows that the environmental cost is a non-negligible factor in the path optimization problem.

Keywords: business district, environmental cost, time window, path optimization

1 INTRODUCTION

With the progress of the economy, people's expectations of the logistics industry have changed in a new way. In the takeaway industry, people put forward higher requirements for the convenience and timeliness of vehicle delivery, so the takeaway delivery path optimization problem centered on the business circle emerges [1]. There are many scattered merchants in the logistics park, and in order to facilitate a simple and effective analysis of them, this paper proposes the concept of business circle logistics park. The business circle logistics park has certain advantages in the optimization of the overall analysis, but there are still some problems, such as low-carbon issues. Cui Wang et al. from the personnel, land, equipment and investment in terms of sustainable evaluation and analysis, in addition to economic and social benefits in addition to

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the consideration of the environmental benefits, put forward the targeted decision-making for sustainable development [2]. Logistics parks in low-carbon construction involves a wide range of aspects, in addition to supply, economy, layout and other aspects of optimization, the optimization of its transportation system can not be ignored. As an important part of transportation capacity, reducing carbon emissions in the distribution process can effectively reduce the transportation cost of logistics parks. The use of new energy vehicles in logistics has played a crucial role in solving the problem of carbon emissions in transportation. Compared with traditional fuel vehicles, electric vehicles are expected to reduce transportation costs and pollution impact. However, limited distribution mileage and long charging time as well as limited charging facilities are still key issues in EV distribution compared to traditional fuel vehicles [3-5]. The electric vehicle routing problem (EVRP) is an extension of the traditional fuel vehicle routing problem (VRP) by specifically finding the optimal path for EVs under the consideration of battery constraints and charging operating conditions [6-7].Nolz P C et al. considered the case of EV charging at fixed time slots, assuming that the vehicle can only be charged in the morning between deliveries and pickups and drop-offs in the afternoon, and used this as a constraint to build a more realistic modeling [8] Bekta's, Ehmke, Psaraftis and Puchinger, in a survey of green freight operations research, examined the main differences between the vehicle routing problem for electric vehicles and the vehicle routing problem for conventional fuel vehicles, namely their limited range, long charging time and limited availability of charging stations [9]. Koç, Jabali, Mendoza and Laporte introduced the electric vehicle route planning problem with shared charging stations, considering a nonlinear charging function with the objective of minimizing the sum of the fixed opening cost of the charging station and the driver cost [10]. Edward Lama, Guy Desaulniersb, Peter J. Stuckeya proposed the electric vehicle routing problem with time windows, segmented linear charging, and capacitor charging stations with a branch-and-burn algorithm [11]. Yan Miao, Chou Liangyong constructed a new energy vehicle distribution path optimization model for cold chain with time window, considering different charging needs of different models, and finally used a new algorithm that fused the ocean predator algorithm and ant colony algorithm to provide a new idea for the charging station layout and vehicle distribution [12]. vincenzo De Rosa a,n, Marina Gebhard a, Evi Hartmann a, Jens Wollenweber Considering the impact of logistics on the whole supply chain, the facility siting problem with bidirectional product flow is proposed to integrate the reverse logistics as a whole into the existing forward supply chain, providing ideas for sustainable development of enterprises [13].

2 Problem description and assumptions

In this paper, from the thinking of business district type logistics park, the whole logistics park is regarded as a distribution center, and the distance between is ignored due to the proximity of each merchant. In order to save the cost of same-city distribution, new energy vehicles are used as distribution tools. Consumers in the same city place orders for goods through the App, and the merchants provide vehicles to deliver the goods to each self-pickup point, and return to the logistics park after completing the delivery task. Each pick-up point has a delivery time limit. New energy vehicles have capacity and mileage limitations, and the delivery process may require charging at a charging station. Thus the problem can be viewed as a single distribution center performing distribution tasks to multiple nodes, aiming to minimize its total cost including environmental cost. The assumptions are as follows:

(1) New energy vehicles leave the charging station with a full charge.

(2) New energy vehicles are of a single type and are not overloaded.

(3) No power consumption during the self-preparation service process.

(4) Each delivery task is less than the maximum load of the new energy vehicle.

(5) The speed of the new energy vehicle distribution process is constant.

(6) The coordinates of the distribution center, charging station and self-pickup point are known, the charging time of the vehicle is known, and the order and service time window of the self-pickup point are known for a certain period of time.

(7) Each new energy vehicle can serve more than one self-pickup point, but each self-pickup point can only be served by one vehicle.

(8) Assuming that the new energy vehicles from the distribution center when the departure of 0 moment

(9) All new energy vehicles start from the distribution center and return to the distribution center after completing their tasks.

(10) The range of the new energy vehicles is known.

(11) Each new energy vehicle can access each charging station at most once during the delivery.

3 MODEL

3.1 Description of symbols

In order to understand the model more clearly, the symbols used in the model are defined as shown in Table 1.

Table 1. Explanation of formula symbols in the model

Notation	Meaning
$A = \{O\} \cup N \cup P$	A denotes the set of all nodes, subscripted by a. O denotes the distribution center. N denotes the set of pickup points. P denotes the set of charging station points.
K	K denotes the set of all new energy vehicles, k is any new energy vehicle of K. $k \in K$
c	Unit distance transportation cost of new energy vehicles.
d_{ij}	Euclidean distance from point i to point j. $i, j \in A$
m_i	Dot i's allotment. $i \in A$
Q	Maximum load capacity of new energy vehicles.
r_{ak}^1	Remaining power of new energy vehicle k when it reaches point a.
r_{ak}^2	Remaining charge when new energy vehicle k leaves point a.
M	Maximum battery capacity for new energy vehicles.
e_i	The earliest service time requested by point i. $i \in N$
l_i	The latest service time requested by self-pickup point i. $i \in N$
eop	Opportunity cost per unit of waiting time incurred by a new energy vehicle arriving early at the customer's point of entry.
lop	Penalty value for the unit of time in which the new energy vehicle arrives at The

	customer's point later than the time window.
t_i^1	The time at which the new energy vehicle reaches point i. $i \in A$
t_i^2	The time at which a new energy vehicle leaves point i. $i \in A$
tw_i	Waiting time for new energy vehicles at dot i. $i \in N$
ts_i	If i is a self-pickup point, ts_i is the service time of the new energy vehicle at point i. if i is a charging station point, ts_i is the charging time. $i \in N \cup P$
t_{ij}	Time from i to j for new energy vehicles. $i, j \in A$
v	Average speed during delivery of new energy vehicles.
e_c	carbon tax
γ	Co2 emission factor for thermal power generation.
α	New energy vehicle battery consumption factor.
$x_{ijk} = \begin{cases} 1 \\ 0 \end{cases}$	New energy vehicle from point i to point j. $i, j \in A; k \in K$ If not
$y_{ki} = \begin{cases} 1 \\ 0 \end{cases}$	New energy Vehicle k for Dot i Services. $i \in A, k \in K$ If not

3.2 Distribution Cost Analysis

(1)Transportation Costs

Vehicle transportation cost increases with the increase of traveling distance, mainly in its electric energy consumption, so it can be considered that the transportation cost of the vehicle is directly proportional to the traveling distance. The expression is shown in equation (1):

$$C_1 = c \sum_{k \in K} \sum_{i \in A} \sum_{j \in A, i \neq j} x_{ijk} d_{ij} \tag{1}$$

(2) Penalty Costs

Distribution centers cannot guarantee that a distribution task will be completed within a specified time, and for practical reasons, distribution tasks are often constrained by soft time windows. The expression is shown in equation (3):

$$pu_i(t_i) = \begin{cases} eop(e_i - t_i) & e_i > t_i \\ 0 & e_i < t_i < l_i \\ lop(t_i - l_i) & t_i > l_i \end{cases} \tag{2}$$

$$C_2 = \sum_{k \in K} \sum_{i \in N} pu_i(t_i) \tag{3}$$

(3) Environmental Costs

This paper focuses on environmental costs and uses the form of carbon emissions as its measure. Carbon emissions in general are represented through carbon emissions, with 77% of the country's electricity generation coming from thermal power. Therefore, this paper introduces a carbon tax policy, i.e., a tax on carbon dioxide emissions, and calculates the cost of carbon emissions based on the amount of electricity consumed by vehicles on their way to distribution. Assuming that thermal power generation accounts for 75% of power generation, e_c is the carbon tax, γ is the carbon dioxide emission coefficient of thermal power generation, and α is the power consumption coefficient of vehicle battery, the expression is as in equation (3):

$$C_3 = 0.75 \times e_c \times \gamma \sum_{k \in K} \sum_{i \in A} \sum_{j \in A, i \neq j} x_{ijk} d_{ij} \alpha \tag{4}$$

3.3 Mathematical Model

Based on the constraints and assumptions in the previous section, this paper constructs the path optimization model with the objective function of minimizing the total cost of distribution including environmental cost, which is formulated as follows:

$$minC{=}C_1 + C_2 + C_3 \tag{5}$$

$$\sum_{k\in K}\sum_{i\in N} x_{oik} - \sum_{k\in K}\sum_{j\in N} x_{ojk} = 0 \tag{6}$$

$$\sum_{i\in N, i\neq j} x_{ijk} = \sum_{j\in N, i\neq j} x_{ijk} = y_{ki} \qquad \forall k \in K \tag{7}$$

$$\sum_{i\in N} y_{ki} m_i \leq Q \quad \forall k \in K \tag{8}$$

$$\sum_{k\in K}\sum_{i\in A, i\neq 0} x_{oik} \leq |K| \tag{9}$$

$$\sum_{i\in N}\sum_{j\in N, i\neq j} x_{ijk} \leq |N| \quad \forall k \in K \tag{10}$$

$$t_0^2 = 0 \tag{11}$$

$$t_{ij} = \frac{d_{ij}}{v} \qquad \forall i,j \in A \tag{12}$$

$$t_i^2 = t_i^1 + tw_i + ts_i \quad i \in N \cup P \tag{13}$$

$$t_j^1 = \sum_{i\in A}\sum_{j\in A, i\neq j} x_{ijk}(t_i^2 + t_{ij}) \qquad \forall k \in K \tag{14}$$

$$tw_i = \max[0, (e_i - t_i^1)] \quad \forall i \in N \tag{15}$$

$$r_{ik}^1 = r_{ik}^2 \qquad \forall i \in N, \forall k \in K \tag{16}$$

$$r_{ik}^2 = M \qquad \forall i \in O \cup P, \forall k \in K \tag{17}$$

$$r_{ak}^1 \geq 0 \qquad\qquad \forall a \in A, \forall k \in K \tag{18}$$

$$x_{ijk}, y_{ijk} \in \{0,1\} \quad \forall i,j \in A, \forall k \in K \tag{19}$$

$$pu_i(t_i^1) = eop \times \max(e_i - t_i^1, 0) + lop \times \max(t_i - l_i, 0) \tag{20}$$

The objective function (5) denotes the total cost of distribution. Constraint (6) denotes that the distribution center serves as the starting point of the distribution task as well as the end point. Eq. (7) denotes that each self-pickup point is served only once. Eq. (8) denotes that the total weight of the goods for the distribution task of the new energy vehicle does not exceed the rated capacity. and Eq. (9) denotes that the total number of vehicles owned by the distribution center satisfies the distribution task. Equation (10) indicates that the number of self-pickup points served by each new energy vehicle is less than or equal to the total number of self-pickup points. Equation (11) indicates that the new energy vehicle departs from the distribution center at the moment of 0. Equation (12) indicates that the time required by the new energy vehicle to travel from point i to point j is equal to the Euclidean distance between the two points divided by the vehicle traveling speed. Equation (13) indicates that the time for the new energy vehicle to leave point i is equal to the time for the vehicle to arrive at point i. The new energy vehicle's waiting time as well as service time are summed up, vehicle's waiting time at point i, and the sum of the service time. equation (14) indicates that the time for a new energy vehicle to arrive at point j is equal to the sum of the time for the new energy vehicle to leave point i and the time for the vehicle to travel from point i to point j. equation (15) indicates that when a new energy vehicle arrives at the self-pickup point i earlier than its required earliest service time e_i, it needs to wait until the service time e_i, and the waiting time is $e_i - t_i^1$, on the contrary, there is no need to wait and tw_i is 0. Eq. (16) indicates that the power of the new energy vehicle when it arrives at the pick-up point is equal to its power when it leaves, i.e., it does not consume the power when it is in service. Eq. (17) indicates that the new energy vehicle is full of power when it leaves from the distribution center or the charging station after charging. Eq. (18) indicates that the new energy vehicle has enough power to arrive at the arbitrary point of its planning. Eq. (19) represents the decision variable. Eq.) represents the decision variable. Eq. (20) is the expression of the function of penalty cost.

4 Algorithm Design

4.1 Coding

Due to the complexity of binary coding and floating-point type coding, we adopt the method of natural number coding for the single distribution center, many distribution customer points and fewer vehicles in this paper. The length of the chromosome is $m + n + k + 1$,n is the number of self-pickup points, m is the number of switching stations, and k is the number of new energy distribution vehicles. The code of the distribution center is 0; code 1, 2, 3, ..., n is the natural number serial number of the assigned self-pickup point; $n + 1, n + 2, n + 3, \ldots, n + m$ is the natural number serial number of the assigned charging station.

4.2 Population Initialization

First all the self-pickup points and charging station codes are randomly arranged in a column, and m_i^1 is the delivery volume of the ith self-pickup point in the chromosome. If $\sum_{i=1}^{z} m_i^1 \leq Q$ and $\sum_{i=1}^{z} m_i^1 > Q$, then 0 is inserted after the zth position of the chromosome; and then start to repeat the calculation until inserting $n - 1$ zeros, and then the first chromosome and the last chromosome are inserted into a 0 respectively, and finally an initial chromosome is formed, and this process is repeated to produce N individuals constituting the initial population.

4.3 Fitness Functions and Constraint Handling

This paper adopts the method of penalty function to deal with the constraints, i.e., the form of penalty function is used to deal with the range and rated load of new energy vehicles, and the objective function is obtained by fusing the penalty function with the objective function:

$$minC = c\sum_{k\in K}\sum_{i\in A}\sum_{j\in A,i\neq j} x_{ijk}d_{ij} + \sum_{k\in K}\sum_{i\in N} pu_i(t_i) + L_1\max\left(\sum_{i\in N} m_i^1 - Q, 0\right) + L_2\max\left(-r_{ak}^1, 0\right)$$

Both constraints must be satisfied, so very large positive numbers for L_1、L_2 result in extremely large values of the chromosome objective function that do not satisfy the constraints.

The larger the fitness function, the better, so we take its inverse as the fitness function here, i.e.$fit(i) = 1/minC$

4.4 Algorithmic Step

1. Select Copy

Step1: Calculate the current per-chromosome fitness $fit(i)$.

Step2: Calculate the sum of chromosome fitness $sumfit = \sum_{i\in N} fit(i), i = 1,2,3, \ldots, n$.

Step3: Calculate the probability of selection $p(i) = \frac{fit(i)}{sumf}, i = 1,2,3, \ldots, n$.

Step4: Calculate the cumulative probability of each chromosome $ps(i) = \sum_{i\in N} p(i), i = 1, 2, 3, \ldots, n$.

Randomly select the resulting real number within [0,1] and choose the first chromosome if $ps(i)$ is greater than this real number, if not choose the ith chromosome such that $ps(i-1) < b < ps(i)$ holds.

2. Cross

In each of the two parent chromosomes, a section of the sub-path is randomly selected and fronted, and the part of the code that is not present in the other in one of them is added to the back of this one and the code 0 is added to its end; for this chromosome, the code 0 is added to one of the positions in the position after the sub-path, and the fitness is calculated separately for each of the multiple scenarios, with the largest fitness value being the child chromosome 1; similarly, the child chromosome 2 can be obtained.

3. Mutation

Three positions were randomly exchanged in the parent generation, their fitness in all cases was calculated, and the highest value was selected to go into the offspring population.

4. Termination

Determine the number of iterations to terminate on your own.

5 Example analysis

5.1 Presentation of examples

This paper selects a logistics park in line with the concept of business circle as the object of analysis through the research, a logistics park has a number of merchants for the distribution of 25 self-pickup points, the merchants are close to each other, so the distance between them is ignored, and the logistics park is regarded as a distribution center. Consumers place orders for vegetables through APP, and the distribution center provides three new energy vehicles of the same type for distribution. The range of the new energy vehicles is 220km, the rated load is 5t, and the fast charging time is 2h. Assuming that the vehicles start from the distribution center at 0h, the speed of the distribution is constant at 40km/h. The driving cost of the new energy vehicles is RMB2/h, the penalty cost coefficient eop is RMB10/h, and the lop is RMB20/h. Carbon tax is RMB0.03/kg [14], the emission factor γ is 0.9, and the CO_2 emission coefficient γ is 0.9. The carbon tax is RMB0.03/kg [14]. emission coefficient γ is 0.997 and power consumption coefficient α is 0.6kwh/km. Other data are shown in Table 2.

Table 2. Other data of the analyzed object

serial number	X coordinate	Y coordinate	Self-advance cargo requirements (t)	Earliest acceptable service time (h)	Latest acceptable service time (h)	Service time (h)
0	57	54	0	0	100	0
1	66	79	0.3	1	2	0.3
2	55	28	0.3	1	2	0.3
3	87	72	0.2	2	3	0.2
4	89	29	0.4	6	7	0.4
5	23	47	0.3	4	5	0.3
6	39	47	0.4	2	4	0.4
7	33	82	0.6	0	2	0.6
8	15	70	0.5	6	7	0.5
9	90	95	0.4	0	4	0.4
10	47	94	0.5	4	6	0.5
11	31	106	0.8	0	1	0.8
12	81	55	0.7	2	3	0.7
13	48	41	0.1	0	2	0.1
14	22	15	0.2	3	3	0.2
15	49	6	0.3	3	3	0.3
16	17	35	0.2	7	9	0.2
17	9	50	0.1	5	8	0.1
18	34	65	0.3	8	10	0.3
19	23	94	0.5	1	3	0.5
20	71	107	0.3	1	4	0.3
21	73	37	0.6	9	11	0.6
22	74	20	0.1	5	11	0.1
23	86	5	0.6	7	9	0.6
24	105	58	0.2	5	7	0.2
25	103	33	0.6	3	6	0.6
26	84	42	0.5	0	100	0.4
27	31	43	0.5	0	100	0.4

5.2 Example Results and Analysis

In this paper, python3.8.3 is used to prepare and solve the genetic algorithm. The population size in the genetic algorithm is set to be 1000, the maximum number of iterations is 500, the crossover probability is 0.9, and the mutation probability is 0.5. The running results show that when considering the environmental cost, the new energy vehicle delivery path data are [0, 7, 19, 11, 10, 6, 0, 13, 2, 15, 14, 5, 27, 16, 17, 8, 18, 0, 1, 20, 9, 3. 12, 24, 25, 4, 22, 23, 26, 21, 0] The roadmap is shown in Figure 1.

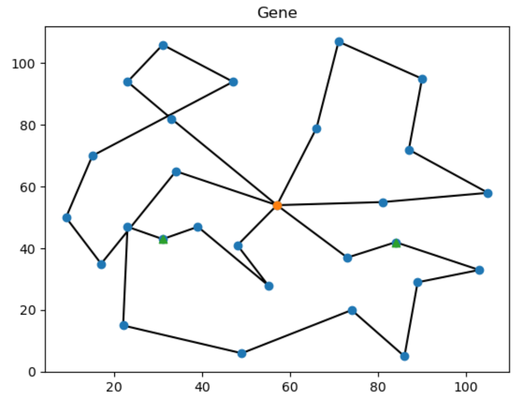

Fig. 1. Distribution roadmap when considering environmental costs

When the environmental cost is not considered, the new energy vehicle distribution path data are [0, 1, 3, 12, 26, 24, 25, 4, 23, 22, 21, 0, 7, 19, 11, 10, 20, 9, 0, 13, 2, 15, 14, 5, 6, 27, 16, 17, 8, 18, 0] The roadmap is shown in Figure 2.

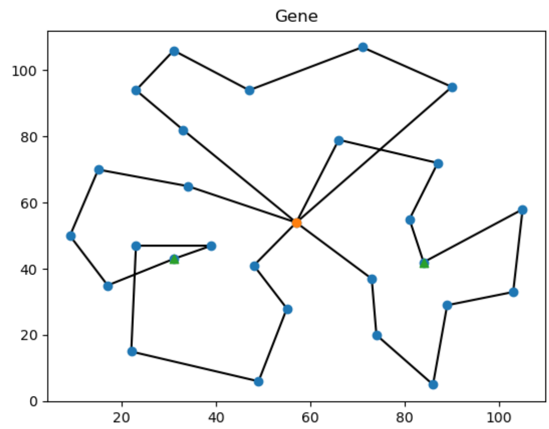

Fig. 2. Distribution roadmap without considering environmental costs

Comparison of distribution cost considering environmental cost and without considering environmental cost is shown in Table 3.

Table 3. Distribution Cost Comparison

	Vehicle matching routes	Traveling Costs	Time Window Penalty Costs	Environmental costs	Total cost
Consideration of environmental costs	vehicle1:0-7-19-11-10- 6-0 vehicle 2:0-13-2-15-14-5- 27-16-17-8-18-0 vehicle 3:0-1-20-9-3-12-24-25-4-22-23-26-21-0	￥1346.6	￥341.5	￥9.1	￥1697.2
No consideration of environmental costs	vehicle 1:0-1-3-12-26-24-25-4-23-22-21-0 vehicle 2:0-7-19-11-10-20-9-0 vehicle 3:0-13-2-15-14-5- 6-27-16-17-8-18- 0	￥1314.3	￥236.4	￥0	￥1550.7

The results show that, except for the difference in optimized routes, driving costs are 2.5% higher when environmental costs are considered than when they are not, time window penalty costs are 44.5% higher, and total costs are 9.5% higher. It can be seen that considering environmental cost or not has a direct impact on the optimal choice of distribution routes, and different choices of routes lead to differences in optimization costs, i.e., when ignoring environmental cost, 9.5% of the distribution cost is ignored, either directly or indirectly. Therefore, among the route planning problems, environmental cost is one of the factors that cannot be ignored.

6 Conclusion

The results show that, except for the different optimized routes, the driving cost is 2.5% higher when environmental costs are considered than when they are not, the time window penalty cost is 44.5% higher, and the total cost is 9.5% higher. It can be seen that although the environmental cost does not account for a high percentage of the total distribution cost, the total cost in the two cases differs by 9.5%, i.e., whether or not to consider the environmental cost indirectly affects the optimal choice of the path, which in turn has an impact on the total distribution cost. Here we can conclude that the environmental cost is one of the factors that cannot be ignored in the path planning problem.

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