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Study on Distribution Path Planning of Electric Logistics Vehicles Under Partial Charging Strategy

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Abstract: The current situation of energy consumption and environmental pollution is becoming more and more serious, electric vehicles have gradually become an important distribution tool for logistics companies due to their advantages of low energy consumption and low pollution, however, the problems of limited battery capacity and long charging time are still the main obstacles to their effective promotion in the field of logistics and distribution. In order to improve the utilization rate of electric logistics vehicles, the charging method of the vehicle is studied in detail, and it is proposed to use partial charging strategy to optimize the distribution path scheme of electric logistics vehicles with soft time window, and to establish an optimization model with the goal of minimizing the total cost of distribution, and at the same time, consider the constraints of the vehicle's loading, the customer's soft time window, and the battery endurance; the genetic algorithm is improved by using the idea of destruction and repair in the large neighborhood search algorithm, and the problem is solving, and verify the effectiveness of the model and algorithm using the Solomon arithmetic set; and conduct a sensitivity analysis of the distribution cost by adjusting 2 parameters, the battery capacity and charging price of the electric vehicle. The results show that the partial charging strategy can effectively reduce the cost compared with the full charging strategy in the distribution activities of electric logistics vehicles. In the example, the total cost is reduced by 7.69%, the electricity cost is reduced by 8.85%, and the total distance is shortened by 7.4%. In this case, the total cost, electricity cost and time window cost increased by 6.22%, 19.83% and 6.83% respectively. At the same time, some charging strategies can also significantly improve the power utilization rate of the vehicle battery, and reduce the idle and waste of vehicle resources and power resources. This paper proposes a distribution route optimization model of electric logistics vehicles under the partial charging strategy, which can provide beneficial enlightenment for logistics enterprises in the scheme scheduling and distribution model selection in urban distribution, and is of great significance for reducing the distribution cost of logistics enterprises.

Keywords: Distribution path planning; partial charging strategy; electric logistics vehicle; soft time window; urban distribution.

1. Introduction

Along with the rapid development of e-commerce, the logistics industry in the field of urban distribution demand is growing, the use of traditional fuel vehicle distribution has been unable to meet and adapt to the social requirements of green low-carbon, energy-saving and environmental protection, electric vehicles as a new type of distribution tool came into being, because of its high efficiency, convenience, and the advantages of clean pollution and other advantages, by the fields of wide attention and application. 2023 June, the General Office of the State Council issued the Guiding Opinions on Further Constructing a High-Quality Charging Infrastructure System", which clearly puts forward that by 2030, a high-quality charging infrastructure system with wide coverage, moderate scale, reasonable structure and perfect function will be basically built, vigorously developing new energy vehicles and strongly supporting the development of the industry; the application of electric vehicles in the urban distribution system has also won the attention of more and more e-commerce and logistic enterprises, such as the "Qingliu Plan" put forward by Jingdong. Proposed "green flow plan", Cainiao network launched the future of green intelligent logistics program, many companies have turned to new energy logistics vehicles.

The focus of current academic research on path planning for electric logistics vehicles can be broadly divided into three areas, the first being the path optimization problem for electric vehicles and hybrid fleets. Zhuang Helin et al.[1] describe the EV path and mainstream variants of the problem from a holistic perspective, categorize the solution methods and techniques of EVRPs, and give the baseline dataset information and part of the node distribution map; Li Ying et al.[2] Propose a hybrid fleet configuration and path optimization model for the status quo, and obtain its optimal configuration and path results; Dongyao Kim et al.[3] Focus on the electric vehicle path problem with load constraints, backtracking-based charging strategy to satisfy the power constraints, and use hybrid genetic search algorithm to solve; Keskin, M et al.[4] Proposing electric vehicle path problems with time windows and random waiting times at charging stations, and proposing a new adaptive mechanism to adjust the constant waiting time used to find the first stage solution; Wu, F. L. et al.[5] focused on how to reduce the energy consumption of electric vehicles by optimizing the path, and established an energy-optimal path planning model with time constraints. The second is the electric vehicle path problem based on the siting of charging and switching facilities. Zhao Peng[6] proposed a comprehensive charging and switching station siting, and split the problem into two types of charging station siting and switching station siting to study them separately; Ma Yanfang et al.[7] constructed a mobile charging pile siting and electric vehicle path planning model with the goal of minimizing the total distribution distance to achieve the goal of planning the initial distribution path, charging pile siting and path adjustment; Ma Qiao[8] proposed a multi-objective optimization method for electric vehicle charging station layout that considers the balance of interests among electric vehicle users, charging station investors and grid operators, and planning paths based on V2G dynamic space-time tariff-guided orderly charging and discharging strategies for electric vehicles. Third, the electric vehicle path planning problem considering charging strategy. Lam, E et al.[9] studied the electric vehicle path problem with time windows, segmented linear charging and capacitor charging stations, modeled the vehicle charging process as a segmented linear function of charging time, proposed a branch-and-cut pricing algorithm, used Dantzig-Wolfe decomposition to specified integer planning paths, and used logic-based Benders decomposition to dispatch to constrained planning; Mao, HT et al.[10] Investigated a new variant of the electric vehicle path problem with time windows by integrating the decisions of multiple charging options, designed an improved ant colony optimization algorithm, and compared the results of all instances under the multiple charging strategy with those under the partial charging and switching strategies; Huang, J. et al.[11] Aiming at the characteristics of electric vehicle distribution process where the power consumption rate is affected by the load size, the problem of electric vehicle power consumption rate and incomplete charging strategy under dynamic load is explored, and a vehicle path optimization model with soft time window is constructed with the objective of optimal comprehensive cost, and an improved hybrid genetic annealing solution algorithm is designed; Ge Xianlong et al.[12]proposed the electric vehicle logistics and distribution path optimization problem with time window, introduced the partial charging strategy, and designed the hybrid simulated annealing algorithm to solve the integer planning model. Analysis shows that domestic and international research on the relationship between charging strategy and path planning for electric logistics vehicles is relatively weak.

In this paper, when studying the problem of urban distribution path optimization for electric logistics vehicles, the focus is on how to choose a charging strategy that can better play the advantages of the vehicle and circumvent the negative impacts of the key shortage, and proposes the use of a partial charging strategy as an optimization method to better reduce the distribution cost of logistics enterprises, improve the utilization of electric energy of distribution vehicles, and reduce the probability of violating the soft time window that leads to customer dissatisfaction.

2. Problem Description and Mathematical Model

2.1. Description of the problem

The Electric Vehicle Routing Problem (EVRP) is an extension of the traditional Vehicle Routing Problem (VRP), and the EVRP problem, compared to the VRP problem, needs to additionally consider the electric vehicles' Compared with the VRP problem, the EVRP problem also needs to consider the issues of battery range and charging in the distribution process. In order to overcome the shortcomings of the current study, this paper adopts a partial charging strategy for charging electric logistics vehicles, i.e., when the delivery vehicle arrives at the charging station for power replenishment, it determines the amount of power that the vehicle will replenish at the current charging station according to the status of the remaining to-be-served customers, and the required mileage to return to the distribution center. The research problem of this paper can be demonstrated in Fig. 1-1, with the full charging strategy shown in the left dashed box and the partial charging strategy in the right dashed box.

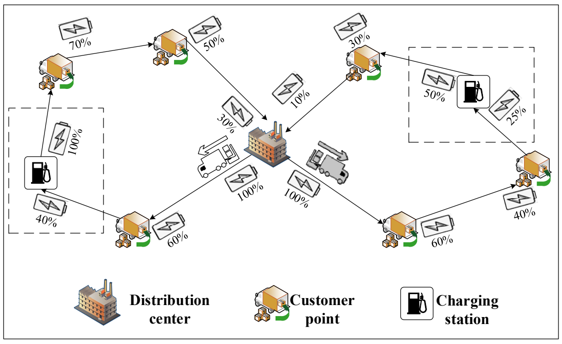

Fig. 1-1. Electric vehicle cargo distribution diagram of partial charging strategy

2.2. Formulation of hypotheses

Since the EV logistics and distribution problem considering partial charging strategy is more complex than the traditional VRP problem[14] , therefore, the following assumptions are made before the model construction in this paper out of the need to simplify the problem and simulate the real situation:

1) Assume that in each loop, the vehicle departs from the distribution center and returns to the distribution center after completing the task;

2) Assume that the geographic locations of the distribution centers, customer sites and charging stations and the demand at each customer site are known;

3) Assume that the distribution activity is subject to a soft time window, i.e., the vehicle can arrive earlier or later than the required time, but must pay a certain opportunity or penalty fee;

(4) Assume that each vehicle only serves one path, each customer point is served once and only once, and the logistics is one-way flow, and the distribution vehicle is only responsible for delivering goods to the customer point, not for picking up goods from the customer point;

5) It is assumed that the carrying capacity of the vehicle is greater than the sum of the customer point demands on each circuit;

(6) Assuming that the cost of electricity used by the electric logistics vehicle is linearly related to the driving distance, the energy consumption coefficient is constant, and the city road is flat and has no gradient, i.e., ignoring the acceleration resistance and the gradient resistance in the driving process;

7) It is assumed that distribution centers are equipped with slow charging facilities to facilitate low-cost charging of vehicles at night, and that vehicles leave the distribution centers in a fully charged state and do not consume power while serving at the customer's point;

8) Assume that the cost of battery depletion from the number of charges is not considered;

9) Assume that the environmental costs incurred in distributing goods are linearly related to the distribution path length.

2.3. Symbolic description of variables and parameters

In order to clearly and accurately describe the model, the symbols of the sets, variables, and parameters used in the model are first defined, and the symbols used in this paper are summarized in Table 1-1.

Table 1-1. Table of symbolic definitions of sets, variables, and parameters

categorization	notation	hidden meaning	unit (of measure)
set (mathematics)	B	The set of client points，B={1,2,3,…,m}	-
	S	The set of candidate points for the charging station，S={1,2,3,…,s}	-
	{0}	distribution center	-
	E	The set of electric logistics vehicles，E={1,2,3,…,e}	-
	G	the set of all nodes，$G = B \cup S \cup \{0\} = \{0,1,2,3,...,i\}$	-
Decision variables	X_{ije}	0-1 variable, 1 if the electric logistics vehicle e goes directly from node i to node j, 0 otherwise	-
non-decision-making variable	C	Total operating costs	yuan
	N	Total number of vehicles utilized	num
	Q	Battery capacity of electric logistics vehicle e	kWh
	U_e	Loading capacity of electric logistics vehicle e	t
	d_{ij}	Euclidean distance between nodes i and j	km
	q_i	Demand at customer point i	t
	t_{ei}	Service time of electric logistics vehicle e at customer point i	min
	v	Average travel speed of electric logistics vehicle e	km/h
	a	Charging power of electric logistics vehicle e	kW
	Q_{es}	Electric logistics vehicle e charging at charging station s	kWh
	P_{ie}	Remaining power of e-logistics vehicle e arriving at node i	kWh
	$[e_i, l_i]$	Soft time window for client point i, where and represent the earliest and latest arrival times, respectively	-
	τ_{ie}^{A}	Actual arrival time of e-logistics vehicle e at customer point i	-
	τ_{ie}^{L}	Time of actual departure of e-logistics vehicle e from customer point i	-
parameters	α_1	Opportunity cost per unit of time when a vehicle arrives early and waits	yuan/min
	α_2	Penalty cost per unit of time when a vehicle arrives late	yuan/min
	c_1	Fixed travel costs per vehicle	yuan
	c_2	Charging cost per unit of power	yuan
	c_3	Cost per unit of carbon emissions	yuan
	γ	Electricity consumption factor, i.e., the amount of electricity consumed per unit distance traveled	kWh/km
	θ	Electricity emission factor, i.e., carbon emissions per unit of electricity	kg/kWh
	ω	Share of thermal power generation	-

2.4. Modeling

According to the problem of this paper and the application of electric logistics vehicles in the actual distribution process, the vehicles are subject to the constraints of on-board capacity, number of vehicles, battery range, node access and soft time window on the distribution route, and the minimization of the total operating cost consisting of four parts, namely, the fixed cost of the vehicle, the cost of electricity, the environmental cost of carbon emission and the penalty cost of the soft time window at is taken as the objective function, and the symbols of the variables and parameters compiled in the previous section are used to establish the A research model for delivery path optimization of electric logistics vehicle with soft time window under partial charging strategy.

$$\min C_{total} \tag{1}$$

$$\text{s.t.} \sum_{i,j\in G, i\neq j} \sum_{e\in E} X_{ije} = 1, \forall i,j \in B, \forall e \in E \tag{2}$$

$$\sum_{i\in B} \sum_{e\in E} x_{ie} \le n \tag{3}$$

$$\sum_{i\neq j, i, j\in G} X_{ije} - \sum_{j\neq i, i, j\in G} X_{jie} = 0, \forall e \in E, i, j \in G \tag{4}$$

$$0 \le \sum_{i\in B} \sum_{e\in E} q_i X_{ie} \le U_e, \forall i \in B, \forall e \in E \tag{5}$$

$$\tau_{ie}^{L} = \tau_{ie}^{A} + t_{ei} + t_{e}^{charge}, \forall i \in B, e \in E \tag{6}$$

$$\tau_{(i+1)e}^{A} = \tau_{ie}^{L} + \frac{d_{i(i+1)e}}{v} X_{i(i+1)e} + \frac{b_{es}}{a} Y_{es} \quad \forall i,(i+1) \in B, e \in E, s \in S \tag{7}$$

$$P_{0e} = Q_e, \forall e \in E \tag{8}$$

$$P_{ie} \geq 0.1Q_e, \forall i \in G, e \in E \tag{9}$$

$$0 \leq P_{(i+1)e} \leq P_{ie} - \gamma d_{i(i+1)} x_{i(i+1)e} + Q_e(1 - x_{i(i+1)e}) \\ \forall i, (i+1) \in G, \forall e \in E \tag{10}$$

$$P_{ie} \geq \min\{\gamma d_{is} x_{ise} + 0.1Q_e, \gamma d_{i0} x_{i0e} + 0.1Q_e\} \\ \forall i \in B, \forall s \in S, \forall e \in E \tag{11}$$

$$P_{ie} = P_{(i+1)e}, \forall i, (i+1) \in B, e \in E \tag{12}$$

$$0 \leq b_{es} = \gamma \sum_{i,j \in G} d_{ij} x_{ije} \leq Q_e - P_{se}, \forall i, j \in G, e \in E \tag{13}$$

$$X_{ije}, \ Y_{es} \in \{0,1\}, \forall i, j \in G, e \in E, s \in S \tag{14}$$

Constraint.(2) denotes that vehicle e starts from vertex m and passes through customer point n to provide service one and only once; constraints(3) denotes that the sum of the number of customers served by all electric vehicles is less than the total number of customers; constraints(4) denotes that vehicle *e* travels to any node *i* (including customer points and charging stations) and leaves any node *i* an equal number of times; constraints(5) denotes that the sum of the loads provided by vehicle e for each customer point does not exceed its maximum load; constraints(6) Table indicates the time for vehicle e to leave customer point *i*, where the charging time of an electric vehicle is determined by its charging power and charging amount, i.e., ; constraints(7) denotes the time when vehicle e arrives at the next customer point (*i*+1); constraints(8) denotes that vehicle *e* is fully charged when it departs from the distribution center; to protect the battery, the constraint(9)denotes that the remaining power of vehicle e at any node is greater than 10% of its rated power; constraints(10) denotes that the charge of vehicle *e* arriving at the next node (*i*+1) is equal to the charge of leaving the previous node *i* minus the charge consumed while traveling; constraints(11)denotes that vehicle *e* leaves any node *i* with more power remaining than the power required to return to the distribution center or travel to the charging station; constraints(12) denotes that vehicle *e* does not consume power while performing service at a customer point; constraints(13) denotes the amount of charge of vehicle *e* at charging station s; constraints(14) Define the decision variables X, Y are both binary 0-1 variables.

3. Algorithm Design

The electric vehicle path problem with soft time window constraints has more constraints, a more complex solution environment, and more stringent quality requirements for the algorithm, so this paper adopts the Large Neighborhood Search (LNS) improved Genetic Algorithm (GA) to solve the problem. The traditional genetic algorithm is easy to fall into local optimization when solving, the improved genetic algorithm can improve the search ability of the genetic algorithm by introducing the ideas of "destruction" and "repair" in the LNS algorithm to achieve the optimization goal through the destruction operator and the repair operator. The optimization goal is achieved through the destruction operator and repair operator.

3.1. Greedy heuristic to construct the initial solution

Setting the initial population plays a crucial role in the final solution of the algorithm, and a better quality initial solution is conducive to the algorithm's solution speed and quality.[17] The initial solution with better quality is conducive to the algorithm's solution speed and quality, which facilitates faster search for the optimal solution with higher quality. In this paper, when generating the solution of the initial distribution scheme, the greedy heuristic algorithm is used to construct the initial solution, and the greedy principle set is to minimize the increase after each insertion of customer points, which in turn makes the total cost of the final initial solution as small as possible, and the specific operation steps are as follows:

Step1: Create an initial path, add the closest customer to the distribution center as the first point, then select the closest customer point to the current node to join the path, if there is more than one closest point, then select the point with the earliest latest arrival time among the customer points to join the path;

Step2: Repeat the above steps with the current node as the target and continue with the new distance determination until all the client points are joined;

Step3: Store the client points on each path and check if it meets the load constraint, if it does then continue, if not then delete this path and regenerate the initial solution;

Step4: Calculate the remaining power at each node and determine whether it satisfies the power constraints, if it does then go to Step7, if not then continue for charging station point selection;

Step5: Select the location of the charging station closest to the previous node to enter charging with any value between 0 and the remaining charge to the rated charge;

Step6: Judge whether the charging is able to satisfy the subsequent distribution task after completion, if it can, then continue, if not, then return to Step5 for charging station point selection;

Step7: Update and save the current path information as the initial solution.

3.2. Local search operations

The local search operation adopts the idea of "destruction" and "repair" in the large-neighborhood search algorithm, using the destruction operator to remove a number of customers from the current solution, and then using the repair operator to reinsert the removed customers back into the destroyed solution.

The destruction operator removes a number of similar customers according to the similarity formula $R(i,j) = \frac{1}{c'_{ij} + V_{ij}}$, where c'_{ij} is the value after standardizing c_{ij}, $c'_{ij} = c_{ij} / \max c_{ij}$, in the range of [0,1], c_{ij} is the Euclidean distance between i and j; V_{ij} is whether i and j are on the same path, i.e., whether they are serviced by the same vehicle, and if yes, then it is 0, and if no, then it is 1. It can be seen from the above equation that the greater $R(i,j)$ is, the greater the relevance between customers i and j is; the role of repair operator is to insert the removed customers back to the position that will increase the total distribution cost of vehicles the least possible, provided that each constraint is satisfied. serves to insert the removed customer back to the position that minimizes the increase in the total vehicle delivery cost as far as possible while satisfying each constraint.

4. Experimental Design

4.1. Data selection and parameterization

In order to verify the validity of the model and the algorithm constructed in this paper, this section constructs an arithmetic example that matches the actual scenario on the basis of the Solomon dataset and conducts experiments using the improved genetic algorithm. To utilize electric logistics vehicles to complete distribution services for 50 customer sites distributed in a certain area. For details, see Table 3-1. 0 indicates the distribution center. 1, 2, 3,... 50 represents customer points, 51,52,53,54 represents public charging stations.

Table 3-1. Customer point demand information table

serial number	Customer coordinates	Customer coordinates	Customer demand	left time window	right time window	length of stay
0	80	80	0	0	1000	0
1	40	66	1.4	8	10	0.3
2	56	30	0.5	11	20	0.2
3	99	45	0.9	9	15	0.2
4	110	70	0.5	8	18	0.2
5	10	30	0.4	9	16	0.15
6	40	48	0.6	14	20	0.4
7	30	95	0.7	0	24	0.6
8	78	33	0.3	7	18	0.2
			……			
51	30	110	0	0	1000	0-0.3
52	35	35	0	0	1000	0-0.3
53	115	100	0	0	1000	0-0.3
54	115	40	0	0	1000	0-0.3

4.2. Solution results

Based on the characteristics of the current experimental data and the conclusions drawn after several arithmetic experiments, the parameters of the algorithm were set as follows: the maximum number of iterations was 500, the initial population was 300, the crossover probability was 0.9, the variance probability was 0.05, and the genetic generation gap was 0.9. The program was written using MATLAB R2022b, and the simulation environment was an AMD Ryzen 5 5500U, CPU 2.10 GHz, 16GB RAM, and Windows 11. The following results and the results in the sensitivity analysis are all taken as the optimal distribution scheme after 10 repeated runs under each parameter, in which the route with the smallest distribution cost is taken as the optimal distribution scheme, and the optimal paths plotted after the solution under partial charging strategy are shown in Figure 3-1, and the experimental optimization results under different charging strategies are specifically shown in Tables 3-2 to 3-4.

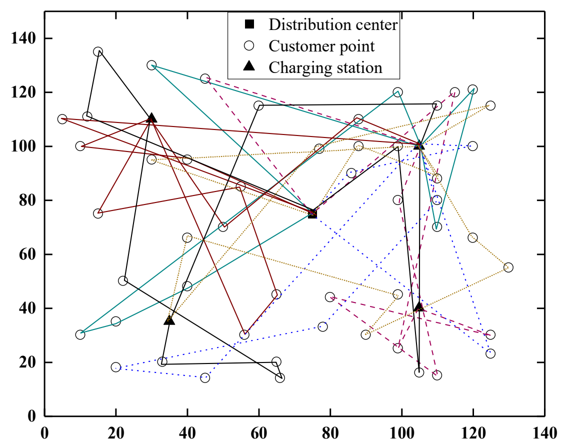

Fig. 3-1. Optimal path diagram in partial charging mode

Table 3-2. Table of optimal delivery plans under partial charging methods

traffic	Distribution path	Charg position	charge (kWh)	Travel distance (km)	carrying capacity (t)
1	0→18→[53]→15→4→[53]→11→5→10→6→0	53,53	93.42	486.73	2.6
2	0→47→[53]→48→37→[51]→45→38→41→2→[51]→46→50→0	53,51,51	144.72	613.62	3.3
3	0→25→[53]→26→24→12→22→[54]→27→23→0	53,54	85.32	494.03	3.2
4	0→21→13→[53]→9→30→[52]→34→33→31→36→[51]→35→44→0	53,52,51	156.06	649.00	3.2
5	0→14→[53]→16→8→17→19→[53]→20→28→0	53,53	82.62	488.30	3.1
6	0→7→[53]→49→32→[52]→1→3→29→42→43→[53]→40→39→0	53,52,53	127.44	553.51	3.3
total	—	—	689.58	3285.18	18.7

The main difference between the path planning study under the full charging strategy and the partial charging strategy is the different amount of supplemental power at the charging station, so (13) in the constraints are modified and solved using MATLAB programming, and the results of the optimal distribution scheme for the same set of data under the full charging method are shown in Table 3-3.

Table 3-3. Table of optimal delivery plans under fully charged mode

traffic	Distribution path	Charging position	charge (kWh)	Travel distance (km)	carrying capacity (t)
1	0→7→[54]→12→9→28→26→11→[52]→10→5→45→0	54,52	108.00	573.56	3.1
2	0→13→[51]→25→15→20→[52]→17→36→19→[51]→35→18→0	51,52,51	162.00	721.42	3.1
3	0→47→[53]→16→1→[54]→3→48→49→[51]→50→6→0	53,54,51	162.00	656.20	3.2
4	0→21→[51]→46→8→4→[51]→30→29→27→31→34→[52]→41→39→0	51,51,52	162.00	694.28	3.3
5	0→2→24→[54]→22→23→0	54	54.00	303.51	2.8
6	0→14→[52]→33→44→37→38→[53]→32→43→42→40→0	52,53	108.00	598.71	3.2
total	—	—	756.00	3547.68	18.7

Table 3-4. Cost comparison table under different charging strategies

Charging strategy	fixed costs (yuan)	Electricity costs (yuan)	time window cost (yuan)	Cost of carbon emissions (yuan)	total distance (km)	total cost (yuan)
partial charge	600	757.98	614.58	1248.37	3285.18	3220.92
Fully charged	600	831.60	709.58	1348.12	3547.68	3489.30
gap(%)	0	8.85	13.39	7.40	7.40	7.69

Due to constraints such as the number of customer service points, soft time window and vehicle endurance, the number of vehicles required by logistics distribution routes with different charging strategies and the number of times each vehicle visits the charging station are the same. However, under partial charging strategies, the charging rate of vehicles when they pass through the charging station for the last time is 73%, 68%, 58%, 89%, 53%, 36%, respectively. Compared with the full charging strategy, the advantage is to save charging time on the one hand, and effectively prevent the waste of the remaining power of the vehicle on the other hand. Under the partial charging strategy, the driving distance is reduced by 262.5km, and the total distribution cost is reduced by 268.38 yuan due to the greatly reduced electricity cost, and the optimization degree is 7.69%. Therefore, some charging strategies can significantly reduce a number of costs and have obvious advantages, and the three data indicators of electricity cost, time window cost and carbon emission cost have increased by 8.85%, 13.39% and 7.40% respectively.

4.3. Sensitivity analysis

4.3.1. Battery capacity

Battery capacity affects the range of electric vehicles, which in turn affects the number of times and length of time the vehicle needs to enter the charging station for charging. Under the premise of controlling a single variable, changing the battery capacity of the electric logistics vehicle sequentially by 0%，10%，20%，30%，40%，50% and 60% causes changes in the costs of the various costs in the optimal distribution scheme as shown in Table 3-5.

Table 3-5. Comparison of results under different battery capacities

battery capacity (kWh)	total cost (yuan)	fixed costs (yuan)	Electricity costs (yuan)	time window cost (yuan)	Cost of carbon emissions (yuan)	total distance (km)	charge (kWh)
60	3220.92	600.00	757.98	614.58	1248.37	3547.68	689.07
66	3378.91	600.00	665.95	992.26	1120.69	2949.20	605.41
72	3381.28	600.00	695.43	780.18	1305.67	3435.97	632.21
78	3354.53	600.00	649.59	833.82	1271.12	3345.05	590.54
84	3343.21	600.00	663.03	756.10	1324.08	3484.42	602.75
90	3366.44	600.00	579.59	942.86	1243.99	3273.65	526.90

4.3.2. Charging prices

Charging price will affect the charging cost of logistics enterprises, sensitivity analysis of the total cost of choosing electric vehicle distribution under different charging prices, increasing the charging price of electric logistics vehicles in order of -20%, -10%, 0%, 10%, 20%, 30%, 40%, 50%, causing changes in the optimal distribution program of the various costs as shown in Table 3-6.

Table 3-6. Comparison of results at different charging prices

Charge Price (yuan/kWh)	total cost (yuan)	fixed costs (yuan)	Electricity costs (yuan)	time window cost (yuan)	Cost of carbon emissions (yuan)	total distance (km)	charge (kWh)
0.88	3037.16	600.00	613.33	562.04	1261.79	3320.51	697.14
0.99	3130.68	600.00	654.34	581.10	1295.23	3408.51	660.95
1.10	3220.92	600.00	757.98	614.58	1248.37	3547.68	689.07
1.21	3233.59	600.00	713.56	759.55	1160.48	3053.89	589.72
1.32	3260.04	600.00	780.55	733.59	1145.90	3015.53	591.33
1.43	3329.66	600.00	892.39	763.33	1073.94	2826.15	624.05
1.54	3465.15	600.00	944.08	737.88	1183.20	3113.69	613.04
1.65	3504.90	600.00	933.45	811.81	1159.64	3051.69	565.73

Based on the above, the curve for sensitivity analysis is drawn as shown in Figure 3-2.

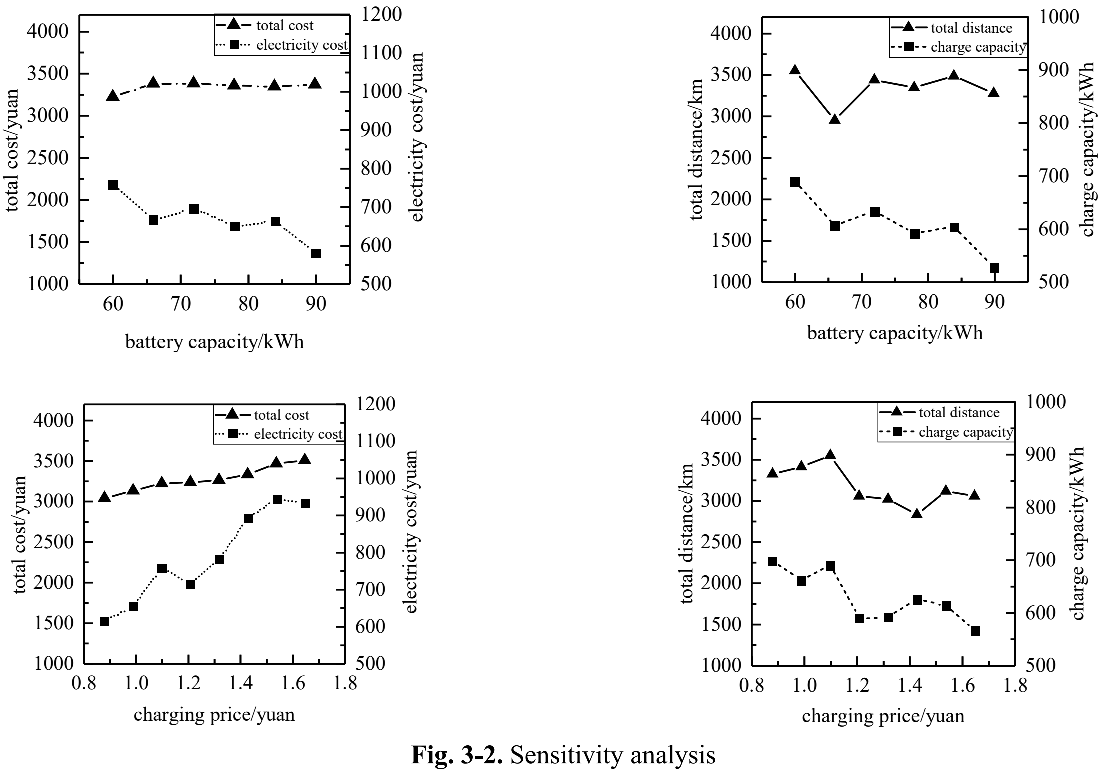

Fig. 3-2. Sensitivity analysis

Through the analysis of the data and curve presented in the chart, it can be seen that under the current customer point location distribution and demand, when the battery capacity is 60kWh and the charging price is 0.88 yuan /kWh, the total distribution cost of the enterprise is the smallest. Firstly, the impact of battery capacity on total cost and total distance is analyzed. When the battery capacity increases from 72kWh to 78kWh, the distribution cost of enterprises decreases for the first time. The total distance of the vehicle decreases with the increase of the battery capacity, especially when the battery capacity increases from 66kWh to 66kWh. In terms of the amount of charging and the cost of electricity, both generally decrease with the increase of the vehicle battery capacity, and the large-capacity vehicle battery will reduce the number of times that the vehicle needs to replenish the electricity. Logistics enterprises usually reserve a variety of models to complete distribution tasks of different sizes. According to the sensitivity results, the solution with the lowest total cost for the distribution task selected in this paper is to send models with a battery capacity of 60kWh. Next, the impact of charging price on various costs and total distance is analyzed. When the charging price increases from 1.1 yuan /kWh to 1.21 yuan /kWh, the total distance, charging amount and electricity cost all decrease, and it can be concluded that 1.21 yuan /kWh is the inflection point of charging price. The conclusion of sensitivity analysis can provide relevant theoretical basis and reference for logistics enterprises to select distribution models and the configuration of charging station facilities, so as to reduce their operating costs.

4.4. Validation of different customer types

In order to demonstrate that the partial charging strategy has a significant advantage over the completion charging strategy for different customer distribution types as well as different customer size sizes, this section plans to select datasets with different customer classification types and customer sizes for validation.

4.4.1. Comparison of different customer distribution types

In order to test the effectiveness of the model established and the algorithm designed in this paper applied in different types of customer distribution, three sets of data R201, C102, and RC201 are selected in this section for validation, respectively, and the minimum value is taken as the optimal solution after each set of data has been run ten times on MATLAB. After calculation, the solution results are shown in Table 3-7.

Table 3-7. Comparison table of different customer distribution types

Type of customer distribution	R201			C102			RC201		
	FR	PR	△(%)	FR	PR	△(%)	FR	PR	△(%)
Total cost（yuan）	2579.28	2422.14	6.49	2330.07	2249.10	3.60	2836.58	2664.88	6.44
Cost of electricity（yuan）	691.20	669.30	3.27	259.20	156.34	65.79	518.40	446.35	16.14
Cost of time window（yuan）	670.14	546.47	22.63	1001.64	1070.60	-6.44	1063.51	923.78	15.13
Total distance（km）	1889.31	1858.87	-	1234.82	1110.94	-	1722.82	1828.29	-
Charging capacity（kWh）	432.00	418.31	3.27	162	97.71	65.79	324.00	278.97	16.14
Number of charges (times)	8	10	-	3	3	-	6	7	-

4.4.2. Comparison of different customer sizes

In order to test the effectiveness of the model developed and the algorithm designed in this paper applied in different customer sizes , this paper selects three groups of data in the R201 dataset with customer sizes of 25, 50, and 75 respectively, and after each group of data is run on MATLAB for ten times, the minimum value is taken as the optimal solution. After calculation, the solution results are shown in Table 3-8.

Table 3-8. Comparison table of different customer sizes

Client Size	25			50			75		
	FR	PR	△(%)	FR	PR	△(%)	FR	PR	△(%)
Total cost（yuan）	1253.30	1200.83	4.37	2579.28	2435.27	5.91	3876.80	3702.28	4.71
Cost of electricity（yuan）	345.60	313.40	10.27	691.20	579.38	19.30	1209.60	909.36	33.02
Cost of time window（yuan）	252.02	224.46	12.28	670.14	669.40	0.11	879.44	1065.71	-17.48
Total distance（km）	935.99	955.17	-	1889.31	1806.55	-	2862.50	2703.19	5.89
Charging capacity（kWh）	216.00	195.87	12.28	432.00	362.11	19.30	756.00	568.35	33.02
Number of charges (times)	4	5	-	8	9	-	14	14	-
Number of vehicles	3	3	-	5	5	-	7	7	-

5. Summary and Outlook

This paper takes the electric logistics vehicle in urban distribution system as the research object, and proposes a scheme to optimize the distribution path of the electric logistics vehicle with soft time window by using the partial charging strategy. According to the practical application scenarios and problem characteristics, an optimization model is constructed with the objective of minimizing the total cost of distribution, and multiple constraints are considered; an improved genetic algorithm is used to solve the problem, and the effectiveness of the model and algorithm is verified through a set of examples. Through specific example testing and in-depth analysis, it can be found that the partial charging strategy can not only effectively reduce the total distribution cost of the logistics company, but also significantly improve the power usage efficiency of the on-board batteries; in addition, the sensitivity analysis session can determine the battery capacity that best meets the current demand of the distribution task based on the actual operation data, which will provide a reference for the enterprise to select the vehicle model that can fulfill the distribution task, and further reduce the enterprise's distribution costs; finally, multiple sets of data with different customer distribution types and different customer sizes are selected for repeated verification.

The research in this paper shows that the use of partial charging strategy for electric vehicle power supplementation in urban logistics distribution can effectively reduce the overall distribution cost, reduce the idleness and waste of vehicle resources and power resources, and provide useful insights for the selection of charging strategy and the selection of distribution models in the scheduling of enterprise's urban distribution program, and will continue to optimize the research problem when the customer demand changes dynamically in the future.

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