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Research on Location-Route Problem of New Energy Logistics Vehicle Distribution System

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Abstract. This paper takes the comprehensive system problem of charging station location and shortest path optimization faced by new energy vehicles in the distribution process as the research object. We hope to obtain a combination optimization method that can further support China's use of new energy vehicles to complete urban distribution problems. This paper addresses the existing comprehensive challenges related to route selection and site allocation. It takes into account the short transportation mileage and low load capacity of new energy vehicles caused by charging constraints. At the same time, considering the timeliness of modern urban distribution, time window constraints and logic constraints are added. Taking the minimum number of charging stations and the minimum transportation cost as the multi-objective problem of combinatorial optimization, the mathematical model is finally established. After transforming the multi-objective problem into a single-objective problem, the genetic algorithm the genetic algorithm is used to solve the system problem comprehensively. Finally, an example is used to verify the feasibility and effectiveness of genetic algorithm in solving the new energy vehicle distribution - location path combination optimization problem. It provides theoretical support and development prospects for further promoting urban distribution of new energy vehicles in the future.

Keywords. New energy vehicles, System location, routing problem, genetic algorithm

1. Introduction

In recent years, the rapid development of China's economy, the rapid advancement of urbanization, and the huge transformation of consumption patterns have brought new challenges to urban logistics and distribution. New energy vehicles are the most promising means of transportation for future urban logistics distribution, with many advantages such as environmental protection, low-carbon, and low noise. However, due to the unique performance characteristics of new energy vehicles, the application of new energy logistics vehicles in distribution cannot simply draw on the operating experience of traditional fuel trucks. For new energy logistics vehicles, their logistics management, driving environment, energy replenishment, and mileage limitations are all new issues

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faced in distribution. How to establish and improve the logistics network distribution system for new energy vehicles, the selection of supporting facilities, and the optimization of distribution routes have become important issues that need to be urgently solved.

In terms of path optimization problems, Erdogan and Miller-hook first considered the charging station factor in the modeling of green vehicle path problems, with the overall goal of minimizing the total delivery mileage [1-2]. Chen proposed a time scheduling model that considers the degradation effect of batteries and achieves orderly charging of vehicles according to the time schedule [3]. Fu Zhengtan developed an electric vehicle path optimization problem that considers time windows, and took the lead in considering charging behavior on the road [4]. DOMINIK GOEKE has expanded this model, taking into account different types of hybrid electric logistics vehicles[5].

In terms of location problem, Wu Di. embedded transportation cost, time limit, warehouse operation cost and other parameters into the model analysis, modified the flow model of goods, and finally obtained the optimal location of the third-party logistics company's distribution center[6]. Mekhum found a logistics distribution center address that meets the logistics service needs of various major logistics service objects by conducting a sampling questionnaire survey on the location selection of logistics enterprise distribution centers[7]. Maximilian Schiffe takes the research on the location selection of distribution centers in St. John's Port as an example, introduces a virtual transportation logistics model, and obtains the optimal configuration address, effectively reducing the cost of agricultural product distribution for many small farmers[8].

This article takes into account the current popular situation of new energy vehicle delivery, and further adds constraints by considering the limited delivery mileage and strict load constraints of new energy vehicles. In order to solve the more complex location path combinatorial optimization problem in this paper, genetic algorithm is selected to solve the optimization problem in this paper by using its convergence speed block, which can jump out of the local optimal solution to the global optimal solution, which proves the feasibility of this method in solving the location path combination problem.

2. Design of New Energy Vehicle Delivery Site Selection and Path Optimization Model

2.1. Conditional Assumptions

It is necessary to fully consider the actual situation and the characteristics of new energy vehicles, such as weather conditions, congested road conditions, sudden situations, etc. Therefore, the following assumptions are made:

(1) All delivery vehicles depart from the same distribution center to complete the delivery task.

(2) During the delivery task, no new delivery tasks are accepted and the goods carried meet the demand at the beginning of the task.

(3) During transportation, weather, traffic congestion, and unexpected situations are not considered.

(4) For any delivery point, up to one vehicle can complete the delivery task.

(5) Considering various factors such as the optimal cruising range with a maximum speed of 120km/h and 80km/h, as well as the speed limit of 60km/h on urban roads, the

speed of new energy vehicles designed in this article is uniformly driven at a speed of 60km/h.

(6) Considering the appropriate load capacity and maximum transportation distance, in order to better complete the delivery task, the design limits the load capacity of a single vehicle to less than 3 tons, and the transportation distance is 160km.

2.2. Parameter Description

The parameter assumptions are shown in Table 1.

Table 1 Parameter Definition

parameter	meaning	parameter	meaning
p_0	Represents a distribution center point	LT_i	Indicates the latest time allowed for delivery vehicles to arrive at store i
p_i	Indicates the i-th customer demand point	t_{ij}^k	Indicates the transportation time from store i to j
M	Represents a set of customer numbers	RT_i	Indicates the time when the delivery vehicle arrived at store i
K	Represents the collection of vehicles in the distribution center	β_1	Unit penalty cost for early arrival
d_{oi}	Indicates the distance between the distribution center and store i	β_2	Unit penalty cost for late arrival
d_{ij}	Indicates the distance between store i and store j	a_1	Deterioration rate of goods during transportation
S_i	Indicates the demand for products in each store (in tons)	a_2	Deterioration rate of goods during unloading
C_k	Fixed cost of the k-th vehicle	t_{ij}^k	Transport time of the k-th vehicle from i to j
q_k	Indicates the loading capacity of the k-th delivery vehicle	U_j	The unloading time of the delivery truck at the store
α	Represents the transportation and distribution cost per unit distance	r_i	Mass of cargo compartment when leaving cargo i
C_v^k	Represents the driving cost incurred by the k-th vehicle	P_i	Is it necessary to set up a charging station at the i-th store? 1 is set, 0 is not set
ET_i	Indicates the earliest allowed delivery vehicle arrival time for store i		

Due to the time characteristics of customer demand involved in urban delivery, customers generally require goods to be delivered within a certain time interval, which must be within a time acceptable to customers in order to meet their requirements. If delivered too early or too late, dissatisfaction will occur and penalty costs will be incurred. This is a soft time window constraint, RT_i where the delivery vehicle arrives within the interval $[ET_i, LT_i]$; If customer point j is on the same delivery route CT_j , $CT_j = RT_i + UT + T_{ij} - RT_j$ then $RT_i = T_{oi}$.

To facilitate the establishment of the model, binary variables are defined as follows:

$$x_{ij}^k = \begin{cases} 1 & \text{Vehicle k travels from i to j} \\ 0 & \text{else} \end{cases} \tag{2-1}$$

$$y_{ij}^k = \begin{cases} 1 & \text{The demand for i is met by vehicle k} \\ 0 & \text{else} \end{cases} \tag{2-2}$$

2.3. Objective function

2.3.1 Total transportation cost

(1) Fixed costs: The fixed cost of vehicles, including expenses such as vehicle consumption, maintenance, and driver's wages:

$$C_1 = \sum_{k=1}^{K} C_k \tag{2-3}$$

(2) Transportation costs: Transportation costs refer to the electricity, repair, and rental costs incurred by new energy vehicles during transportation. These variable transportation costs are divided into transportation distances, so the transportation costs are as follows:

$$C_2 = \sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{M} C_v^k d_{ij} x_{ij}^k \tag{2-4}$$

(3) Cost of damage to goods: The cost of goods loss refers to the loss of goods that occurs during the transportation and unloading process of the product. The cost of goods loss is the cost of transportation plus the cost of unloading:

$$C_3 = \alpha \sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{M} x_{ij}^k \left(a_1 t_{ij}^k + a_2 U_j\right) r_i \tag{2-5}$$

(4) Time penalty cost: Due to the special nature of perishable fresh food, it is necessary to complete the delivery task within the customer's acceptable service time. If the food is not delivered to the demand point within the customer's acceptable time, there will be penalty costs.

$$C_4 = \beta_1 \sum_{i=1}^{M} \max\left(ET_i - RT_i, 0\right) + \beta_2 \sum_{i=1}^{M} \max\left(RT_i - LT_i, 0\right) \tag{2-6}$$

The total cost of delivery is:

$$\begin{aligned} \min C = C_1 + C_2 + C_3 + C_4 = &\sum_{k=1}^{K} C_k + \sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{M} C_v^k d_{ij} x_{ij}^k + \alpha \sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{M} x_{ij}^k \left(a_1 t_{ij}^k + a_2 U_j\right) r_i \\ &+ \beta_1 \sum_{i=1}^{M} \max\left(ET_i - RT_i, 0\right) + \beta_2 \sum_{i=1}^{M} \max\left(RT_i - LT_i, 0\right) \end{aligned} \tag{2-7}$$

2.3.2 Number of charging stations

The number of charging stations set is appropriate. Having too few charging stations can cause vehicles to wait for charging, making it inconvenient to use and unable to support regional distribution tasks. However, having too many charging stations can result in significant cost and road pressure, especially in cities that are currently using new energy vehicle distribution services, which are mostly large cities or super large cities with high traffic pressure, such as first and second tier cities. Traffic is relatively congested and land space is difficult. Therefore, the design of the number and location of charging stations is also the goal of this study, but it should be designed to minimize the number of charging stations as much as possible after meeting the objective function (2-5). This is the most reasonable and convenient way for new energy vehicles of distribution enterprises to complete distribution tasks.

$$\min P = \sum_{i=1} P_i \tag{2-8}$$

2.4. Constraints

$$\sum_{k} y_{ki} = 1 \qquad i \in M \tag{2-9}$$

$$y_{ki} = \{0,1\} \quad i \in M; \forall A \tag{2-10}$$

$$x_{ki} = \{0,1\} \quad i \in M; \forall A \tag{2-11}$$

$$\beta_{ijk} > 0 \quad i \in M; \forall A \tag{2-12}$$

$$\sum_{i} x_{ijk} = y_{ik} \quad i \in M; \forall A \tag{2-13}$$

$$\sum_{j} x_{ijk} = y_{ik} \quad j \in M; \forall A \tag{2-14}$$

$$RT_i \in [50\% ET_i, 150\% LT_i] \quad i \in M \tag{2-15}$$

$$\sum_{k=1}^{K} q_k \le 3 \tag{2-16}$$

$$\sum_{i=1}^{M}\sum_{j=1}^{M} d_{ij} x_{ij}^{k} \le 100 \tag{2-17}$$

Meet the following constraints. Among them, equations (2-9) indicate that each demand point has only one vehicle for delivery; Equations (2-10) and (2-11) are integer constraints; Equation (2-12) refers to the unit time loss cost caused by the failure to deliver according to the customer's requested time; Equations (2-13) and (2-14) indicate that the delivery route of the delivery vehicle is a closed route; Equation (2-15) indicates that the product has arrived within the delivery time required by the customer; Equations (2-16) represent the allowable load constraints for new energy vehicles; Equation (2-17) represents the maximum mileage constraint for new energy vehicles.

3. Genetic Algorithm for Solving Element Design

The basic steps of genetic algorithm are:

(1) Encoding: Encoding is generally described in mathematical language in a certain order based on the final result of the problem. However, choosing different coding forms will have a great impact on the running time, running speed and fitness value of the algorithm, and even directly affect whether the optimal solution can be found in the end.

(2) Selection operator: In order to ensure that the genetic algorithm can jump out of the local optimal solution and approach the global optimal solution, it is necessary to set the genetic rules of the parents and children, namely the selection operator.

(3) Crossover operator: In the process of inheritance from parents to offspring, organisms recombine chromosomes through certain crossing rules to generate new offspring individuals. Only by continuously increasing the number of offspring individuals can the optimal solution be found.

(4) Mutation operator: Due to the crossover operator retaining a segment of dominant genes to the next generation, it is possible to cause offspring individuals to fall into local optima. Therefore, a segment of genes must be set for random mutation.

(5) Fitness value: The greater the fitness value, the better the individual is, the greater the probability of its genes being passed on to the next generation, and vice versa.

(6) Termination Rules: If the optimal solution is not found, it will constantly jump between several local optimal solutions and be difficult to converge. Considering the actual situation, it is necessary to design a termination rule, which often determines the total number of iterations.

4. Example verification

4.1. Background Description

Taking the data collected and organized by a certain enterprise in a city as an example, the enterprise currently has a distribution center (0 points) and 30 demand nodes (1-30 points). The specific coordinates and demand parameters are shown in Table 4-1. In addition, in urban areas, there are 10 coordinate points (C1-C10) where charging stations can be set up, and the coordinates of the 10 charging stations are shown in Table 4-2. The ultimate goal is to choose several routes starting from the distribution center point, around the remaining 50 coordinates and returning to point 0, with the shortest distance traveled; At the same time, it is also considered that in the proposed charging station C1-C10, the minimum number of constructions will be constructed[9].

Table 2 Distribution Center and Demand Node Coordinates and Demand Volume

Serial number	0	1	2	3	4	5	6	7	8	9	10
x	15	80	19	49	45	65	71	76	28	68	66
y	43	25	93	35	20	26	62	48	36	84	59
requirement	/	1140	990	840	930	870	660	750	690	720	750
Serial number	11	12	13	14	15	16	17	18	19	20	21
x	17	12	50	96	35	59	23	76	26	51	70
y	55	92	29	76	76	39	57	8	6	54	78
requirement	870	630	1170	1170	900	900	810	1170	840	690	1080
Serial number	22	23	24	25	26	27	28	29	30		
x	90	96	55	14	15	26	85	26	82		
y	94	13	57	47	2	34	17	80	32		
requirement	840	750	870	660	690	1170	1200	960	660		

Among them, the unit of coordinate distance is km, and the unit of demand is kg.

Table 3 Coordinates of the Proposed Charging Station

Serial number	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
x	94	68	76	75	40	66	18	71	4	28
y	5	10	83	70	32	96	4	44	39	77

Considering the daily use of the vehicle and battery loss, the maximum mileage of a single vehicle is 160km, and the maximum load capacity of a single vehicle is 3t. In order to transform the objective function into a single objective function, the minimum number of locations for charging stations is also converted into cost, that is, the construction cost of charging stations is 50, and the objective functions 3-5 and 3-6 are transformed into:

$$\min C = C_1 + C_2 + C_3 + C_4 = \sum_{k=1}^{K} C_k + \sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{M} C_v^k d_{ij} x_{ij}^k + \alpha \sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{M} x_{ij}^k \left(a_1 t_{ij}^k + a_2 U_j\right) r_i$$
$$+ \beta_1 \sum_{i=1}^{M} \max\left(ET_i - RT_i, 0\right) + \beta_2 \sum_{i=1}^{M} \max\left(RT_i - LT_i, 0\right) + 50 \times \sum_{i=1} P_i \tag{4-1}$$

Considering that the cost as the fitness value will lead to an increase in solving time and calculation, the calculation of its fitness value is the shortest total mileage in the process of using the genetic algorithm[10].

4.2. Output Results

The following is an introduction to the experimental results of genetic algorithm, without additional restrictions such as road conditions. The main steps are as follows to analyze the results of the basic genetic algorithm:

(1) Generate distribution centers and 50 demand points, 10 proposed charging station nodes, with an initial population of 100;

(2) As the result of Equation 4-1, calculate the fitness function, where;

(3) The basic genetic rule is to select and design a crossover genetic probability of 30% and a mutation probability of 5%;

(4) Store the offspring obtained after mutation or crossover, while also saving the offspring back to the parent population to optimize computational efficiency;

(5) Repeat steps 3 and 4 until the designed termination condition is met. In this article, the designed termination condition is 200 generations;

(6) Compare the offspring with the lowest cost and output the length and order of the proposed charging station and the shortest path, and store them as the optimal solution to the problem.

This article is based on MATLAB R2017a software and uses genetic algorithm to solve the case. Generate an initial population of 100, and after running, the convergence of the algorithm is shown in Figure 1. It can be seen that after approximately 90 iterations, the algorithm begins to converge and tends towards the optimal solution.

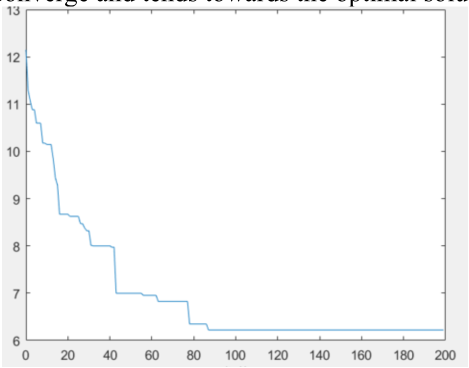

Figure 1 Algorithm Convergence

The optimal solution appears after 163 iterations, and the total driving distance is 1392.6652km.

Finally, the design scheme of combinatorial optimization is shown in Table 4.

Table 4 Final Vehicle Delivery Plan

Plan	Mileage	Load capacity	Plan	Mileage	Load capacity
0-25-27-8-0	39.4082	2520	0-15-2-12-0	118.0956	2520
0-20-24-10-6-0	118.7898	2970	0-1-30-28-0	158.8330	3000
0-3-13-4-0	89.1090	2940	0-16-26-19-0	151.9758	2430
0-21-(C3)-22-9-0	207.5928	2640	0-5-23-(C1)-18-0	203.8643	2790
0-17-29-11-0	78.0555	2640	0-7-(C4)-14-0	226.9412	1920

As can be seen from Table 4, when using genetic algorithm to solve the location path combinatorial optimization problem, a total of 10 new energy vehicles need to be configured, with an average mileage of 139.27 kilometers per vehicle, reaching 87.04%

of the maximum mileage of 160 kilometers for new energy vehicles; The average load capacity is 2637 kilograms, reaching 87.9% of the maximum load capacity of 3 tons, which is a relatively satisfactory state. Compared with the single point delivery plan, the number of vehicles allocated is reduced by 20, the average mileage per vehicle is increased by 92.84 kilometers, and the average load per vehicle is increased by 1758 kilograms. The optimization effect is relatively significant.

5. Conclusion

This article conducts in-depth research on the comprehensive optimization problem of layout planning and optimal path selection of charging station facilities for new energy vehicles in urban distribution systems. This paper summarizes the current situation and research basis of the development of new energy vehicles in urban short and medium distance distribution, and makes a preliminary exploration of the problem of logistics enterprises choosing to establish charging stations by themselves. Finally, with the goal of minimizing the number of charging stations and the shortest transportation mileage, and with logic, travel conditions, time windows, maximum mileage, maximum load capacity and other conditions as constraints, a location path combinatorial optimization model is finally established. At the same time, considering the difficulty of solving multi-objective problems, we have changed the problem of short transportation mileage and fewer charging stations to a single objective optimization problem that comprehensively solves operational costs. On this basis, considering that such practical problems are generally large in scale and involve many factors, a heuristic algorithm is selected to solve the combinatorial optimization model. Taking full advantage of the advantages of the fast convergence speed of genetic algorithm and the ability to jump out of the local optimal search for the global optimal, a genetic algorithm for combinatorial optimization is designed. Finally, an example is used to verify the feasibility and practicability of using genetic algorithm to solve the location routing combinatorial optimization problem of new energy vehicle distribution system.

Due to the fact that this study focuses on the Chinese urban distribution system using new energy vehicles, therefore, the maximum mileage constraint for new energy vehicles is set in the constraint conditions of the model. In other geographical locations or situations where ordinary delivery vehicles coexist with new energy delivery vehicles, further adjustments need to be made to the model based on the cost and operating mileage of different vehicle models.

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