Research on Green Distribution Route Design based on Customer's on-time Demand

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Abstract: This paper focuses on the vehicle routing optimization problem with carbon emission and time window double constraints for on time demand of customers. Based on the characteristics of on-time demand and green distribution, the distribution cost model covering vehicle transportation time cost, time window deviation cost, fossil consumption cost and PM2.5 emission cost has been established; the greedy algorithm has been designed to plan the distribution route to obtain the lowest distribution cost and the shortest distribution time in order to achieve green distribution. This paper, taking Guangxi a Diary Co., Ltd as an example and using the greedy algorithm, calculates the green distribution route of the company's milk. Researches indicate that in the dynamic route planning where simply increase customer's new demand, the total cost and total driving time of green distribution by means of greedy algorithm are respectively 592.13 yuan and 521 minutes ; in the dynamic route planning where increase both new customer points and new demand, the total cost and total driving time of green distribution by means of greedy algorithm are respectively 723.29 yuan and 633 minutes.

1. Introduction

The express delivery industry is booming with the rapid development of e-commerce. In 2017, the volume of logistics express transactions was 40.1 billion, an increase of 28% year-on-year, with an average of more than 70,000 consumer orders per minute. How to send a large number of orders to consumers within the prescribed time is a problem facing the express delivery industry [1]. Traditionally, logistics distribution mainly plans the route in advance according to the customer's order information. If there occurs a sudden customer demand, the delivery is directly sent out from the distribution point, and the high distribution cost generated by the customer is borne by the customer. This kind of distribution method not only generates high distribution cost [2], but also brings about serious environment pollution caused by the large amount of gases, such as NO, HC, CO and black carbon emitted by distribution vehicles pollutes [3]. Therefore, in order to achieve energy conservation and emission reduction, logistics enterprises need to re-allocate resources, reduce greenhouse gas emissions occurring in vehicle distribution, scientifically plan vehicle routes, reduce costs on the premise of meeting customer needs, and achieve green distribution [4][5].

The research results of the Vehicle Routing Problem (VRP) are relatively fruitful. VRP was first proposed by Dantzig and Ramser, given a distribution center, vehicle collection and customer collection, VPR achieves a specific target under certain constraints [6]. In general, there are four types of targets: (1) the lowest total cost; (2) the shortest mileage; (3) the shortest delivery time; (4) the least use of vehicles. These targets tend to focus on economic costs, and the calculation method is mainly based on genetic algorithms. Considering the shortest total mileage, Lang Maoxiang solved the VRP problem of a single vehicle with a hybrid genetic algorithm [7]. Ge Xianlong extended the single-model VRP problem to multi-model VRP and solved it globally using genetic algorithm [8]. Although economic costs are important, social and environmental costs cannot be ignored [9][10], which leads to the emergence of VRP. For example, Vehicle Routing Problem with Carbon

Emissions (VRPCE), Vehicle Routing Problem with Time Window (VRPTW), Vehicle Routing Problem with Carbon Emission and Time Window Constraints (VRPCETW).

As for VRPCE, YANGYU provides five models for calculating vehicle carbon emissions: model based on input variables, model based on formula estimates, model based on explanatory variables, model based on economic value, and model based on multi-dimension [11]. Zhu Changzheng designed an improved genetic algorithm to solve VRPCE with the goal of reducing carbon emissions, but he did not consider the impact of driving speed on carbon emissions [12]. Tang Jinhuan further considered the multi-objective VRPCE model based on driving speed and solved it by particle swarm optimization algorithm, but he ignored the influence of load on carbon emissions [13]. Considering the driving speed and vehicle load, Li Jin constructed a low-carbon path model under non-full-load transportation mode, and used Tabu Search algorithm for path planning [14].

As for VRPTW, the time window constraint is considered, but the influence of carbon emissions is neglected. The calculation method is mainly based on genetic algorithm and particle swarm algorithm [15][16]. VRPCETW is more complicated than VRPCE and VRPTW, and it is a combination of VRPCE and VRPTW. Li Jin considered carbon emissions, driving speed and vehicle routing problems with time windows and solved them with a two-stage heuristic algorithm [17]. Xie Shi'an optimized the problem of integrated distribution that considered carbon emissions and time window, and proposed an improved particle swarm optimization algorithm for path optimization [18]. Jane Lin constructed the VRPKETW problem that is based on the distribution and minimum cost of the day, and designed a heuristic algorithm [19].

However, the above researches are carried out based only on the static demand of customers, they have not considered the dynamic needs of customers. This paper aimed at customer’s on-time demand, designs reasonable vehicle paths and optimized paths to solve Vehicle Routing Problem with Carbon Emission and Time Window Constraints(VRPCETW).Taking both economic costs and social costs into consideration, this paper constructs a distribution cost model including vehicle transportation time cost, time window deviation cost, fuel consumption cost and PM2.5 emission cost, and designs a greedy algorithm to solve the dynamic vehicle routing problem that considers customer’s immediate demand.

2. Problem Description and Model Building

2.1 Problem Description

For the distribution center, there are two situations where customer’s on-time demand occurs: one is that the number of customers in the distribution plan remains the same, and the customer demand in the original distribution plan suddenly increases. That is, after goods are send out by vehicles, certain or several customers in the distribution plan suddenly increase the new demand and request to be delivered within the prescribed time window; the other is that the customer demand outside the distribution plan increases, which are reflected in the increase of the demand point and of the corresponding demand.

The two vehicle routing problems out of customer’s on-time demand can be described as follows: the distribution center generally formulates an initial distribution plan based on the customer's original order information, and the vehicle delivers according to the established distribution route. After the distribution vehicle departs, the distribution center receives the customer's on-time demand information, re-plans the route and notifies the distribution vehicle, aiming at seeking the best distribution route and achieving the green distribution with the minimum cost under the premise of meeting customer’s demand.

2.2 Model Building

This model is based on the following assumptions:(1) Take a single distribution center as an example. The vehicle departs from the distribution center, passes the customer point, and then returns from the customer point to the distribution center;(2)In view of the condition that the actual pickup quantity is far less than the delivery quantity, the problem of integrating the pickup and delivery service is not considered;(3) The number of vehicles in the distribution center basically meets the demand;(4) The customer point or demand is uncertain because the order information will change;(5) The customer requests delivery service within the [ai, bi] time window. The earliest and latest delivery time is ai and bi respectively. If the delivery exceeds the time required by the customer, the penalty cost will arise from the deviation from the time window;(6) The distribution center can grasp all the information in real time and perform real-time regulation on the distribution vehicles.

Table 1. Parameter interpretation in the model

N	The set of customers in the distribution center, N= {1,2, 3, … n}
N_0	Represent $N \cup \{0\}, \{0\}$ is the distribution center
k	The set of all same type vehicles in the distribution center, *k*=1, 2, … K
i	Customer *i*
c	Vehicle transportation cost per unit time
C_f	Fuel cost per unit
Ce	PM2.5 emission cost per unit
P_{ij}	Fuel consumption when drive from customer i to customer j on the arc (i, j)
E_f	PM2.5 emission speed (g/km)
Q	Vehicle load limit
q_i	Demand of customer i
d_{ij}	Driving distance from customer i to customer j
t_{ij}	Driving time from customer i to customer j
V^S_{ij}	Driving speed(km/h) on arc s (i, j) $\forall s \in S$
w	Non-load vehicle weight(kg)
l_{ij}	Vehicle load on arc (i, j), $\forall i, j \in N$
a_i	The earliest service time required by customer i
b_i	The latest service time required by customer i
s_i	Time when the vehicle arrives at customer i point
f_i	The service time at customer i point

The overall goal of Vehicle Routing Problem with Carbon Emission and Time Window Constraints (VRPCETW) is to achieve the minimum total cost Z of transportation time cost Zt, time window deviation cost Ct, fuel consumption cost Zf and $PM_{2.5}$ emission cost Zpm:

$$\min Z = Z_t + C_t + Z_f + Z_{pm} \tag{1}$$

And:

$$Z_t = \sum_{k}^{K} \sum_{i=0}^{N} \sum_{j=0}^{N} c t_{ij} x_{ijk} \tag{2}$$

$$C_t = c_1\sum_{i=1}^{N}\max[(a_i - s_i),0] + c_2\sum_{i=1}^{N}\max[(s_i - b_i),0] \tag{3}$$

$$Z_f = C_f(\lambda_0 + \frac{\lambda - \lambda_0}{Q} l_{ij}) d_{ij} \tag{4}$$

$$Z_{pm} = C_e E_f d_{ij} = C_e \frac{\gamma}{v_{ij}^s + \eta} d_{ij} + 0.001\sigma C_e (w + l_{ij}) d_{ij} \tag{5}$$

The constraint conditions are:

$$\sum_i q_i y_{ik} \le Q \tag{6}$$

$$\sum_i x_{ijk} - \sum_i x_{jik} = 0 \tag{7}$$

$$\sum_{i\in N, i\neq j}\sum_{k\in K} x_{ijk} = 1 \quad \forall j \in N_0$$

$$\sum_{i\in N_0, i\neq j}\sum_{k\in K} x_{ijk} = 1 \quad \forall j \in N$$

$$\sum_{k\in K} y_{ik} = 1 \quad \forall i \in N \tag{8}$$

$$\sum_i x_{oik} = 1 \quad i \in N$$

$$\sum_i x_{ijk} = 1 \quad i \in N_0, j \in N, \forall k$$

$$\sum_i x_{iok} = 1 \quad i \in N_0, j \in N, \forall k \tag{9}$$

2.3 Algorithm Design

The vehicle departs from the distribution center, and the customer's on-time demand appears during the distribution process. The general procedure of the greedy algorithm is: (1) reading the problem; (2) greedy sorting; (3) selecting the current optimal solution; (4) obtaining the overall optimal solution. Since the greedy algorithm only considers the current state, it can find a satisfactory solution faster, and saves a lot of time to find the optimal solution, which is in line with the idea of re-planning the in-transit vehicle path when the immediate demand arises.

The flow chart of the greedy algorithm is as the following Figure 1.

3. Case Analysis

3.1 Company Background

Guangxi A Dairy Co., Ltd. mainly produces high-grade dairy products. The company has an annual output of 100,000 tons and is a leading enterprise in the dairy industry in Guangxi. Taking A's dairy industry's customer demand in a certain area for a certain day as the research object, the company's milk distribution route is planned. The coordinates, demand quantity and time window of the distribution center and each customer point are shown in Table 2.

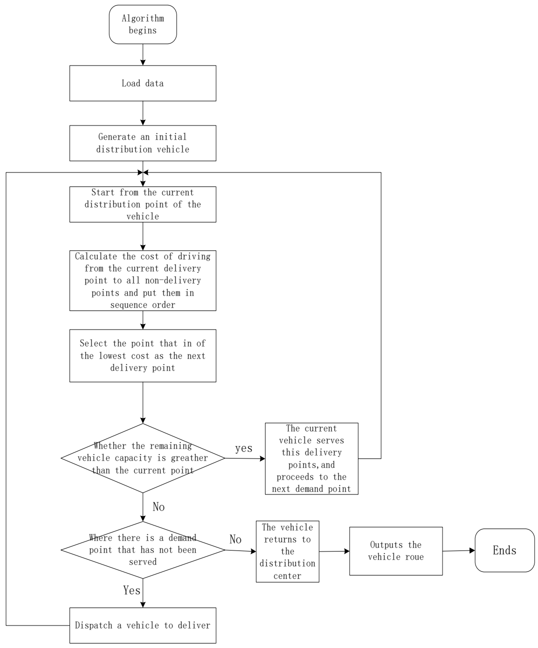

Fig.1 The Flow Chart of the Greedy algorithm

Table 2. Demand and Time Window at Customer Points

Customer Points	Coordinate	Demand(kg)	Time Window
0	(30,30)	0	6:00
1	(13,17)	220	6:30-7:30
2	(20,47)	200	8:30-9:30
3	(17,24)	66	7:00-7:30
4	(19,30)	253	8:30-9:00
5	(12,36)	187	8:00-9:00
6	(18,14)	68	6:00-7:00
7	(40,31)	143	6:00-6:30
8	(27,39)	198	7:30-8:30
9	(35,14)	154	6:00-7:00
10	(42,37)	140	6:00-7:00
11	(52,28)	220	7:30-8:30
12	(34,46)	140	7:30-8:00
13	(41,46)	167	7:00-8:00
14	(44,20)	209	6:00-8:00
15	(26,20)	110	6:00-6:30

3.2 Preliminary Route Planning

Before the model is calculated, the parameters are as follows: vehicle weight is 1310 kg, load is 1000 kg, running cost per unit time is 0.5 yuan, fuel cost per unit is 7.2 yuan/L, emission cost of PM2.5 per unit is 2 yuan/g, waiting time cost per unit is 0.3 yuan/min, penalty coefficient is 0.5 yuan/min, Service time for Customer i is 12 min, fuel consumption rate of the full-loaded vehicle is 0.13 L/km, fuel consumption rate of the non-loaded vehicle is 0.08 L/km.

Before the vehicle departs from the distribution center, the distribution center uses the scanning method to formulate the initial distribution plan based on the order information. Start scanning by using the customer 7 in front of the time window as a starting point. Each time a customer point is scanned, the limit of whether the vehicle weight exceeds 1000 kg is checked, and when the limit is reached, the scanning is stopped. The customer points that are scanned in sequence are 10, 13, 12, 8, 2, and the total vehicle load is 988 kg. Considering the time window, demand and other factors, the distribution route is 0-7-10-13-12-8-2-0.Repeat the scanning method step with the customer 15 as the starting point, and find the distribution route as 0-15-6-1-3-5-4-0.Repeat the scanning method step with customer 9 as the starting point, and find the distribution route as 0-9-14-11-0.

The results of the preliminary distribution route obtained by the scanning method are shown in Fig. 2 and Table 3.

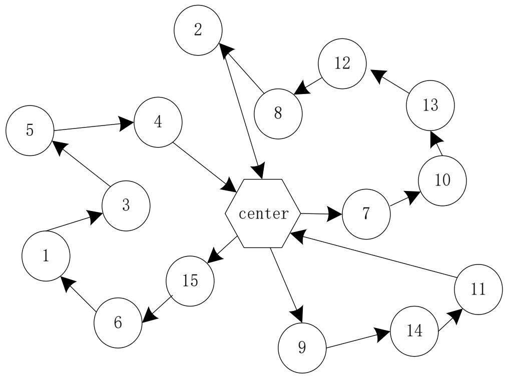

Fig. 2 Vehicle driving path

Table 3. Vehicle Cost List

vehicle	Transportation Time Cost	Time Deviation Cost	Fuel Consumption Cost	PM2.5 Emission Cost	Total Cost
1	88.5	1	51.35	52.68	193.5
2	74	0	39.77	44.28	158.05
3	83.5	25	49.77	49.72	207.99

3.3 Dynamic Route Planning Considering the Immediate Demand

(1) An increase in demand from the current customers

After the vehicle departs, the scanning method no longer satisfies the characteristics of on-time demand, so the greedy algorithm is used for route design. Assume that customer 13 requires an increase in demand of 150, which is required to be delivered between 7:00 and 8:00; customer 12 requires an increase in demand of 150, which is required to be delivered between 7:30 and 8:00; customer 4 requires an increase in demand of 100, which is required to be delivered between 8:30 and 9:00; customer 3 requires an increase in demand of 20, which is required to be delivered between 7:00 and 7:30. After one hour of vehicle travel, the distribution center performs scheduling. At this time, the vehicle 1 travels to the customer point 10, the vehicle 2 travels to the customer point 9, and the vehicle 3 travels to the customer point 6. This paper uses MATLAB R2016a to implement the greedy algorithm. After 4 trials, the vehicle route is shown in Table 4.

Table 4. Vehicle Cost List

vehicle	Transportation Time Cost	Time Deviation Cost	Fuel Consumption Cost	PM2.5 Emission Cost	Total Cost
1	60.5	0	36.86	36.18	133.54
2	74	0	39.77	44.28	158.05
3	63	16.7	38.85	37.71	156.26
4	63	11.1	32.69	37.49	144.28

As can be seen from Tables 4, after the original customer points 13, 12, 4, and 3 increase the on-time demand, the greedy algorithm is used to plan the route and the distribution can be completed with 4 vehicles. In terms of distribution cost, the vehicle cost when we plan the route with the greedy algorithm is: 133.54, 155.05, 156.26, 144.28, and the total cost is 592.13. In terms of the delivery time, the total time when we apply the greedy algorithm is 521 minutes.

(2) New customer points and its demand

Assume that a new customer point 16 (30, 40) requires to delivery 200 milk between 8:30 and 9:30; a new customer point 17(13, 40) requires to delivery 100 milk between 8:30 and 9:00. At 8 o'clock, the distribution center again dispatches the in-transit vehicle, at which time the vehicle 1 travels to the customer point 12, the vehicle 2 travels to the customer point 11, the vehicle 3 travels to the customer point 3, and the vehicle 4 travels to the customer point 2. The results obtained by MATLAB R2016a are shown in Table 5:

Table 5. Vehicle Cost List

vehicle	Transportation Time Cost	Time Deviation Cost	Fuel Consumption Cost	PM2.5 Emission Cost	Total Cost
1	60.5	0	36.86	36.18	133.54
2	74	0	39.77	44.28	158.05
3	63	16.7	38.85	37.71	156.26
4	61.5	11.1	32.54	36.75	141.89
5	57.5	12.5	29.1	34.45	133.55

It can be seen from Table 5 that after adding new customer points 16, 17, the distribution can be completed with 5 vehicles using the greedy algorithm to plan the route. In terms of distribution cost, the total cost of 5 vehicles is 723.29. In terms of delivery time, the total time of 5 vehicles is 633 minutes.

4. Summary

This paper designs greedy algorithms to plan dynamic vehicle routes, solve the problem of customer's on-time demand, and minimize the total cost.

(1) This paper studies the dynamic vehicle routing problem considering customer's on-time demand. On the basis of the preliminary route planning, the paper proposes a greedy algorithm to solve the model. The greedy algorithm can quickly solve the problem when the on-time demand arises.

(2) Taking the milk distribution of Guangxi, A Dairy Co., Ltd. as an example, the solution results show that whether the existing customers increase the new demand, or there are new customer points

and demand, the greedy algorithm can be used for dynamic route planning to achieve a less cost and faster speed of distribution.

(3) The green distribution routing problem based on the immediate demand is a very complicated NP-hard problem. The problem that the immediate demand may be generated at a certain point of time and then disappears quickly makes the distribution more difficult. Road congestion and road restrictions during transportation are also subject to further research.

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