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Research on Vehicle Routing Optimization for M Company Considering Time Window Constraints

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Abstract: In recent years, with the continuous development and popularity of Internet technology, people's demand for online shopping has gradually increased, which in turn has caused scholars to pay attention to and study the problems existing in courier delivery routes. In this paper, based on the traditional vehicle routeing problem, combined with the customer's demand for time windows and considering the constraints of transport vehicle loading during the pickup and delivery process, the brainstorming optimization algorithm is used to derive the service route of Company M based on the realistic problem of Company M. The service route is designed for 35 customers by taking the shortest total distance of delivery as the goal. The calculation results show that Company M needs to send four trucks to serve 35 customers, and the designed service routes all meet the customers' requirements for time windows. This case shows that the brainstorming optimization algorithm has good performance in solving the simultaneous pickup and delivery problem with time window constraints.

1. Introduction

Vehicle Routing Problem (VRP), also known as the logistics distribution vehicle routing problem, was proposed by Dantzing and Ramser in 1959 [1]. The determination of vehicle routing is one of the important links in logistics distribution operations, which is an important influencing factor in modern logistics systems, and its efficiency directly affects the quality of the entire logistics process. In logistics distribution, vehicle routing problem plays a pivotal role in minimizing distribution costs under various constraints, which greatly improves the efficiency and quality of logistics distribution while meeting customer needs. Once proposed, the vehicle routing problem has attracted the attention of a large number of scholars, and has important significance for the optimization of logistics distribution in various industries [2-5]. When studying the logistics distribution of medical devices, Jin,H et al. proposed a hybrid replenishment model based on a multi-step traveler problem model and a vehicle path problem model in order to solve the problem of long and inefficient drug replenishment pathsM, Osvald et al. established a VRPTW model for vegetable distribution logistics considering the perishability characteristics of vegetable transportation, and combined tabu search algorithm to solve the model to optimize the distribution route of fresh vegetables [6]. Han Mengyi et al. studied the distribution path of materials in emergency situations, constructed a distribution model with the minimum penalty cost, and fused the savings algorithm, genetic algorithm, and domain search algorithm to provide a decision-making basis for the distribution path of materials through practical cases [7].

Considering time window constraints when studying vehicle routing problems can improve customer satisfaction with delivery services [8-12]. Tas D introduced the electric vehicle routing problem with flexible time windows, developed mathematical models including travel costs, early lateness costs, and electric vehicle costs, and developed a customer best service time system [13]. Considering the impact of carbon emissions on dynamic vehicle routing problems, Zhang Jinliang constructed an improved genetic algorithm vehicle routing optimization model to reduce vehicle delivery costs while reducing carbon emissions costs, while meeting the time window requirements [14]. Li M et al. are studying the distribution of fresh agricultural products, modeling with product freshness, time windows, fixed distribution costs, and transportation costs as constraints. The research results show that cold chain distribution based on real-time information on road conditions can make distribution costs lower and customer satisfaction higher [15].

Based on previous research on vehicle routing optimization considering time window constraints, and taking into account the customer's return demand, this article adds pickup operations while delivering goods in order to better meet customer demand, optimize logistics distribution paths, and reduce the total travel distance of goods logistics distribution. A vehicle routing optimization model is constructed and designed using a brainstorming optimization algorithm.

2. Problem Description and Model Construction

2.1. Problem Description

Based on the traditional VRP problem, this article considers the actual customer demand for pickup and delivery as well as the time window requirements. The problem can be described as follows: In order to meet the needs of customers, a certain number of distribution vehicles set out from the same distribution center to provide delivery and pickup services to customers located in the distribution range. In addition to meeting the customer's delivery and pickup needs, constraints such as time windows and vehicle transportation weight should also be considered during the distribution process. With the goal of minimizing the total distribution distance, optimization research should be conducted on the distribution path and time.

During the research, it is assumed that the distribution center and customer locations are known, and the demand for pickup and delivery is known; The distribution center has all the goods and quantities required by the customer; The limited weight of the delivery vehicle is known, and the vehicle maintains a constant speed during transportation; Each customer needs only one vehicle for service, and all customers are served. Vehicles return to the distribution center after completing their respective pickup and delivery services; Vehicles are not allowed to service outside the time window, and trucks are not allowed to arrive at the customer service point after the right time window of the customer's time window. Trucks can arrive before the customer's left time window, but they must wait until the customer's left time window before performing service.

The problem of simultaneous delivery with time windows (VRPSDPTW) can be defined in a directed graph G (V, A), where V= {0, 1, 2, n, n+1} represents the collection of all nodes, 0 and n+1 represent the distribution center. The distribution vehicles depart from the distribution center 0, and return to the distribution center n+1 after the distribution task is completed. 1, 2, n represents the customer receiving point, and A represents the set of arcs. The specific parameters involved in the VRPSDPTW model are shown in Table 1.

Table 1: Parameters

Variable symbol	parameter meaning	Variable symbol	Parameter meaning
Cij	Distance between node i and node j	E	Left time window of the distribution center
v	Vehicle traveling speed	L	Right time window of the distribution center
si	Service time for customer i	di	Distribution demand of customer i
tij	Vehicle travel time from node i to node j	pi	Recovered amount of customer i
ai	Left time window for customer i	C	Maximum vehicle loading capacity
bi	Right time window for customer i	M	Infinite positive numbers

The decision variables involved in constructing a simultaneous delivery path optimization model with time windows include wik, L0k, Li, and xijk. Where wik is the start time of service provided by the delivery vehicle k to the customer i; L0k is the loading capacity of the vehicle k when it leaves the distribution center 0; Li is the loading capacity of the vehicle after the completion of customer service; Xijk is whether the vehicle k experiences a transition from customer i point to customer j point. If so, then xijk=1, and if not, then xijk=0.

2.2. Model Construction

The purpose of route optimization is to find the distribution route with the smallest total distribution distance, while meeting the requirements of each customer's pickup and delivery as well as the time window, and meeting the constraints of various objective conditions. Based on the above problem description and parameter settings, the following brainstorming optimization algorithm model is established:

$$\min \sum_{k\in K} \sum_{(i,j)\in A} c_{ij} x_{ijk} \tag{1}$$

$$\sum_{k\in K} \sum_{j\in\Delta^{+}(\mathrm{i})} x_{ijk} = 1, \forall i \in N \tag{2}$$

$$\sum_{j\in\Delta^{+}(0)} x_{0jk} = 1, \forall \mathrm{k} \in K \tag{3}$$

$$\sum_{i\in\Delta_{-}(j)} x_{ijk} - \sum_{i\in\Delta^{+}(j)} x_{jik} = 0, \forall j \in N, \forall \mathrm{k} \in K \tag{4}$$

$$\sum_{i\in\Delta_{-}(\mathrm{n+1})} x_{i,n+1,k} = 1, \forall \mathrm{k} \in K \tag{5}$$

$$t_{ij} = \frac{c_{ij}}{v} \tag{6}$$

$$w_{ik} + s_i + t_{ij} - w_{jk} \le (1 - x_{ijk}) M, \forall (i,j) \in \mathrm{A}, \forall k \in K \tag{7}$$

$$a_i(\sum_{j\in\Delta^+(i)} x_{ijk}) \le w_{ik} \le b_i(\sum_{j\in\Delta^+(i)} x_{ijk}), \forall i \in N, \forall \mathrm{k} \in K \tag{8}$$

$$E \le w_{ik} \le L, \forall i \in \{0, \mathrm{n}+1\}, \forall \mathrm{k} \in K \tag{9}$$

$$L_{OK} = \sum_{i\in N} d_i \sum_{j\in\Delta^+(i)} x_{ijk}, \forall \mathrm{k} \in K \tag{10}$$

$$L_j \ge L_{0k} - d_j + p_j - M(1 - x_{0jk}), \forall j \in N, \forall \mathrm{k} \in K \tag{11}$$

$$L_j \ge L_i - d_j + p_j - M(1 - \sum_{k\in K} x_{ijk}), \forall i \in N, \forall j \in N \tag{12}$$

$$L_{0k} \le C, \forall \mathrm{k} \in K \tag{13}$$

$$L_j \le C + M(1 - \sum_{i\in V\setminus\{0\}} x_{ijk}), \forall j \in N, \forall \mathrm{k} \in K \tag{14}$$

$$xijk \in \{0,1\}, \forall (i,j) \in \mathrm{A}, \forall k \in K \tag{15}$$

The above equation (1) is the model target, which is the formula for obtaining the minimum traveling distance of the delivery vehicle; Equation (2) indicates that each customer can only be served by one vehicle, Equations (3) to (5) indicate the traffic restrictions on the route of the delivery vehicle k, and Equation (6) indicates the time required for the vehicle to travel from customer point i to customer point j; Equation (7) represents the continuity of travel of transport vehicle k; Equation (8) indicates that the service time of vehicle k to customer i must be within the left and right time windows required by the customer; Equation (9) indicates that the departure and return of the vehicle from the distribution center must be within the left and right time windows of the distribution center; Equation (10) represents the calculation formula for the initial loading capacity of vehicle k in the distribution center; Equation (11) is the loading capacity of the vehicle k after serving the first customer within its pickup and delivery route; Equation (12) represents a formula for the loading capacity of a vehicle k after serving any customer except the first customer in its driving route; Equation (13) restricts the loading capacity of vehicle k when departing from the distribution center to not exceed the maximum loading capacity of the vehicle; Equation (14) restricts the loading capacity of the vehicle k after serving any customer in its driving route to no greater than the maximum loading capacity of the truck.

3. Brainstorming

The rise of artificial intelligence has provided more and more algorithmic options for solving combinatorial optimization problems. Brainstorming optimization algorithm (BSO) is a group intelligent optimization algorithm based on human creative problem-solving processes, with advantages such as simple models, rapid convergence, fewer parameters, and strong stability.

When solving the vehicle routing problem with time windows and simultaneous pickup and delivery, the brainstorming optimization algorithm does not rely on the initial solution of the routing problem, and has fast convergence and global search capabilities. Due to space constraints, the main steps of BSO in solving the VRPSDPTW problem are outlined below.

3.1. Coding and Decoding

The first step for BSO to solve VRPSDPTW is to encode individuals, that is, the distribution center and customers are represented in the individuals simultaneously. Its operation helps to improve computing speed. Assuming that there are n customers and k transportation vehicles, BSO uses integer encoding to assign n customers to k transportation routes in the solution. If there are three transportation vehicles that need to serve six customers, the individuals in the BSO are ranked by a random combination of the six numbers from 1 to 6. In order to be able to assign each customer to that specific route, insert the distribution center with two numbers, 7 and 8, into the list of these six customers. The meaning of the arrangement of numbers 1-8 involves the decoding of individuals. For example, 15274683 individuals, distribution centers 7 and 8 divide customers 1, 2, 3, 4, 5, and 6 into three service routes, as follows:

The first service route: 0-1-5-2-0

The second service route: 0-4-6-0

Third service route: 0-3-0

In the above service route, 0 represents the distribution center, which means that the vehicle departs from the distribution center 0 and returns to the distribution center 0 after serving the customer. If there are n customers and k service vehicles, the individuals in the VRPSDPTW problem solved by the brainstorming optimization algorithm are randomly arranged in 1 - (n+k-1).

3.2. Objective Function

In the above coding, there is no guarantee that each transportation route will comply with the time window and vehicle capacity restrictions after decoding. In order to ensure compliance with the constraints, when establishing a model, a penalty is imposed on distribution routes that violate the constraints, that is, increasing costs, to ensure that the decoded distribution routes meet the distribution center, customer left and right time windows, and transportation vehicle load constraints. The formula for calculating the total cost of a distribution route scheme is as follows.

$$f(s) = c(s) + \alpha \times q(s) + \beta \times w(s)$$

$$q(s) = \sum_{k=1}^{K} \{\max\{(L_{ok} - C), 0\} + \sum_{j \in N} \max\{[Lj - C - M(1 - \sum_{i \in V \setminus \{n+1\}} x_{ijk})], 0\}\}$$

$$w(s) = \sum_{i=1}^{n} \max\{(l_i - b_i), 0\} \tag{16}$$

In the above formula, s represents the vehicle distribution and transportation scheme converted by the individual after decoding; F(s) represents the total cost of the delivery solution, including the total vehicle travel distance c(s), the vehicle's violation of the transportation load q(s), and the penalty w(s) for not arriving at all customers within the time window as scheduled to provide service; α, β Penalty factors for vehicles violating load constraints and time window constraints, respectively. K is the collection of distribution vehicles; Lok is the loading capacity of the vehicle when it leaves the distribution center; Lj represents the loading capacity of the vehicle after serving the customer j; V is the collection of distribution centers and customer nodes, where V=(0, 1, 2, 3..., n, n+1); N=V\{0, n+1} represents a customer set; xijk indicates whether the vehicle k moves from customer point i to customer point j. If it does, xijk=1, otherwise xijk=0; Li is the time when the vehicle reaches the customer's point i; Bi is the right time window of customer i.

3.3. Clustering Operations

Clustering analysis of all individuals in a population is a key step in brainstorming optimization algorithms to solve problems. Clustering individuals in a population can converge individuals in the population to a smaller search space. In this paper, K-mesns clustering method is used to cluster the objective function of individuals, assuming that the number of populations is W, and the specific operations are as follows:

(1) Randomly select k individuals from W individuals as the initial clustering center.

(2) Calculate the absolute difference between the objective function values of each individual and the objective function values of the k initial clustering centers in turn, compare the magnitude of the absolute difference, and reclassify the cluster center with the smallest absolute difference between the individual and its absolute value into a cluster.

(3) Calculate the average value of the objective function values of all individuals in each cluster, and find the individual with the lowest average value of the cluster and the objective function, and use this individual as the new cluster center of the cluster.

(4) If the number of iterations set in advance is reached, the termination condition is reached. At this point, the cycle ends and the clustering result is output; If the number of iterations is not reached, proceed to step 2.

3.4. Updating Individuals

Updating individuals in a population is a core step in BSO. After continuous clustering and individual replacement operations, all individuals are divided into k classes, so the brainstorming method is related to the above divided k clusters when updating the population.

Suppose there are W populations in total; K ($k \geq 2$) clusters; A random number with r being 0-1; P1 is the probability of selecting a cluster, and p1 is a number between 0-1; P2 is the probability of selecting two clusters, where p2=1-p1; The code for updating the population is as follows:

(1) Randomly select a cluster:

If r<p1c

X1=new cluster center for this cluster

otherwise

X1=Randomly select an individual from this cluster

Exchange individual X1 to obtain a new individual Xn

otherwise

(2) Randomly select 2 clusters

If r<p2c

X1=cluster center of cluster 1; X2=cluster center of cluster 2

otherwise

X1=randomly selected individuals in cluster 1; X2=randomly selected individual in cluster 2

The crossover operation is performed on individuals X1 and X2 to obtain new individuals Xn1 and Xn2. In Xn1 and Xn2, select the individual with the smallest total cost, that is, the smallest objective function, as the updated new individual.

If the total cost of an individual j in the population is smaller than Xn, update the new individual Xn=j.

4. Example Verification and Analysis

4.1. Calculation Example Design

Zibo M is a subsidiary of S Express under Zibo City, mainly responsible for the collection, sorting, distribution, and accessories of express delivery in the city. M express delivery points use modern intelligent equipment and technology for operation, and advanced automatic scanning and sorting technology can quickly classify express shipments based on geographical location, shortening the delivery time of express delivery while reducing manual operation errors. The use of big data technology can quickly sort out customer mail demand information, combine it with delivery routes, and provide a combination of vehicle delivery and receipt services, which can greatly reduce service costs.

A city express delivery center provides express delivery and delivery services for urban residents. Know the information of the customer to be served before delivery, including the geographic location of the customer's pickup and delivery; Express delivery and pick up weight; The service time window required by the customer, and the specific distribution center and customer information are shown in Table 1, where 0 represents the distribution center. The distribution center allows a maximum of 4 vehicles to serve 35 customers, and the service time is 10 minutes; The vehicles are all of the same model, with a maximum loading capacity of 100kg per vehicle. The vehicle's traveling speed when picking up and delivering goods is 30km/h.

Table 2: Input Data

Serial number	X coordinate /km	Y coordinate /km	Demand /kg	Recycling volume /kg	Left time window	Right Time Window	Service Hours /min
0	37	48	0	0	0	780	0
1	45	78	3	2	510	540	10
2	39	63	8	4	60	100	10
3	32	67	7	0	100	150	10
4	22	83	7.2	0	160	200	10
5	35	70	3	4	0	120	10
6	19	83	0	8	55	310	10
7	17	78	2	10	480	620	10
8	20	80	5	2	340	440	10
9	32	62	10	7	60	313	10
10	33	53	0	3	280	360	10
11	31	47	8	5	370	510	10
12	30	15	4	17	60	180	10
13	20	35	5	6	80	180	10
14	30	15	5	2	440	560	10
15	43	21	7	8	670	720	10
16	49	53	3	3	645	720	10
17	45	34	0	2	110	175	10
18	46	36	9	2	150	210	10
19	15	80	7	1	390	480	10
20	20	50	11	2	555	640	10
21	49	72	6	5	650	715	10
22	57	13	0	3	660	765	10
23	38	83	3	2	50	180	10
24	32	62	5	0	140	220	10
25	43	37	7	4	40	120	10
26	63	46	7	4	90	310	10
27	38	44	5	1	395	560	10
28	36	48	4	2	460	715	10
29	60	58	4	2	660	780	10
30	63	68	3	5	690	750	10
31	53	78	6	8	590	700	10
32	62	57	9	3	490	610	10
33	22	60	10	6	470	585	10
34	31	62	13	4	265	335	10
35	40	51	17	1	170	420	10

The description of the calculation example is as follows: Suppose a express delivery center provides 35 customers with a time window constrained pickup and delivery service, and the specific location, demand, and shipment volume of the customers are shown in Table 2:

From Table 2, it can be seen that customers have a high degree of dispersion, and they have certain restrictions on the time window while demanding delivery and pickup, which adds great difficulty to the design of service paths.

4.2. Calculation Example Solution and Result Analysis

To meet the customer's demand for simultaneous pickup and delivery, this paper uses a brainstorming optimization algorithm to solve the above cases with time window constraints. The penalty function coefficient for violating the vehicle load when using the brainstorming optimization algorithm α Is 10; Penalty coefficient for violating time window constraints β Is 100; The maximum number of iterations is 200; The population number is 50; Cluster number 5; The probability of replacing a cluster center with a random solution p-replace=0.1; p1=0.5; p2=1-p1; p1c=0.3; p2c=0.2.

4.2.1. Solution Results of the Calculation Example

Use the brainstorming optimization algorithm to solve the above case, and the path design results are shown in Figure 1 and Figure 2 below. From the figure, it can be seen that in the distribution plan, the express delivery center dispatched four vehicles to serve customers. The objective function value calculated by the brainstorming optimization algorithm is 444.1909, the total distance traveled by the vehicle is 444.1909 km, the number of paths violating constraints is 0, and the number of customers violating constraints is 0.

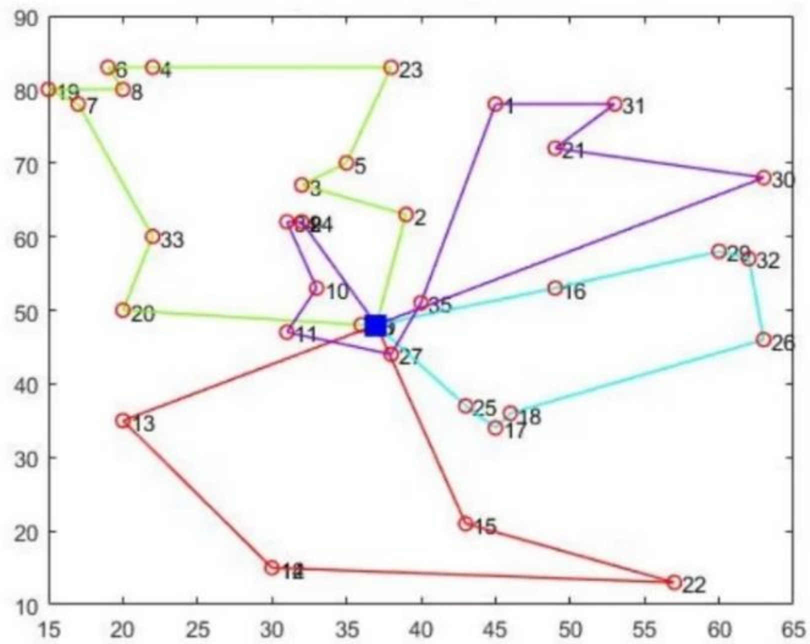

Figure 1: Roadmap to Optimal Distribution Solution

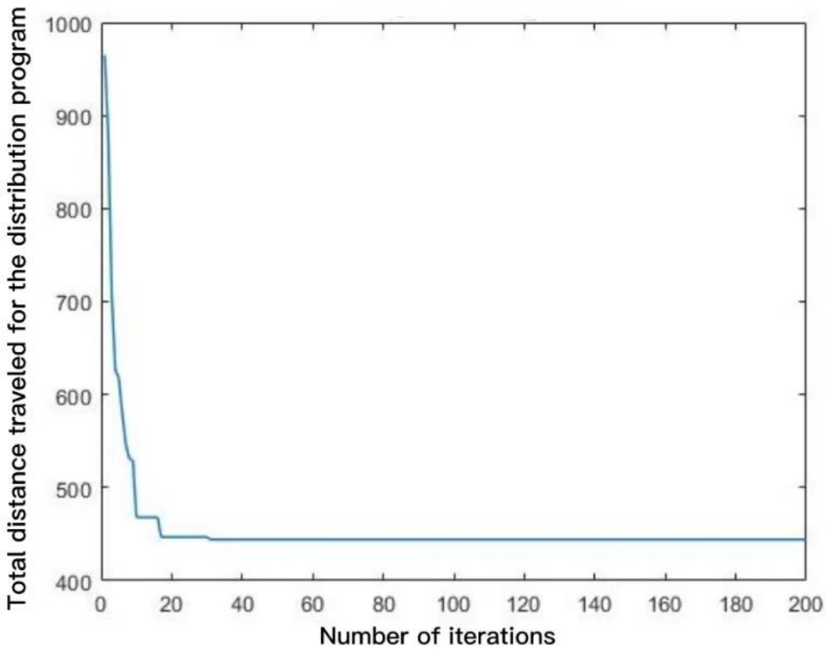

Figure 2: Optimization Process

Service route of the vehicle:
Service Route 1: 0→13→12→14→22→15→0
Service Route 2: 0→2→3→5→23→4→6→8→19→7→33→20→28→0
Service Route 3: 0→25→17→18→26→32→29→16→0
Service Route 4: 0→24→9→34→10→11→27→35→1→31→21→30→0

4.2.2. Result Analysis

The brainstorming optimization algorithm designs a service route for 35 customers in the M express delivery center to pick up and deliver goods. The service route satisfies the time window constraints of the distribution center and customers, as well as the vehicle load constraints. The calculation results show that the brainstorming optimization algorithm has good performance in solving the simultaneous pickup and delivery problem with time window constraints.

5. Conclusion

According to the requirements of M distribution center to provide customers with pickup and delivery services in reality, this paper selects a brainstorming optimization algorithm to solve the problem. Brainstorming optimization algorithms have strong exploration and mining capabilities, which can effectively ensure classification performance and iteration speed when used to solve realistic problems of simultaneous pickup and delivery with time windows. Compared to traditional heuristic algorithms, Brainstorming optimization algorithms have good performance in both solution time and numerical value of solution results, It provides practical guidance for M distribution centers to arrive at customer service locations and fulfill customer needs in a timely manner, and also lays a certain foundation for other industries or enterprises to optimize their distribution routes. This article has made some explorations and improvements in the application of brainstorming optimization algorithms and vehicle routing optimization problems considering time windows, but it still lacks certain universality and practicality, and there are also imperfections in the algorithm design. Further theoretical research and practical application are needed.

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