

The Vehicle Routing Optimization Problem of Refrigerated Vehicle with Temperature Compartments under Consistent Delivery Model

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Abstract: The lower utilization rate of refrigerated vehicles leads to higher distribution cost. Therefore, this paper proposes a model of refrigerated vehicles with multi temperature area to realize consistent delivery of different product groups at the same customer point. Based on the objective function of loading cost, distribution cost, unloading cost and penalty cost of failure to perform on time, the model is solved by adaptive large neighborhood search (ALNs) algorithm, and the distribution route is optimized by designing ring destroying operator, repair operator and adaptive process. An example is given to analyze the impact of the capacity of refrigerated vehicles with multi temperature compartments on distribution time, cost and average utilization compartments. Finally, an appropriate refrigerated vehicle with multi temperature compartments is selected for delivery according to the distribution characteristics of customers.

Keywords: Refrigerated vehicles with multi temperature compartments, Consistent delivery, Loading and unloading costs, Adaptive large neighborhood search.

1. Introduction

In the global cold chain transportation network, in order to meet the needs of customers with multiple varieties and small batches, more and more logistics enterprises choose joint transportation for products with different processing requirements (such as temperature and humidity). This transportation mode puts forward higher requirements for the freshness maintenance technology of different products. Multi compartment vehicles (MCVs) use the new partition concept to divide the single compartment of single compartment vehicles (SCVs) into a limited number, and use science and technology to realize the different requirements of products for temperature and humidity, so as to realize the joint delivery of different products.

Nowadays, the research on refrigerated vehicles with multi temperature compartments is mainly divided into two aspects: one is the research on the temperature control of refrigerated vehicles with multi temperature compartments, and the other is the research on the solution of the path optimization problem of refrigerated vehicles with multi temperature compartments. In the context of grocery distribution, how to plan the number of compartments and allocate the number of product segments of refrigerated vehicles with multi temperature compartments is the key for us to use refrigerated vehicles with multi temperature compartments for transportation. The research on the route optimization of refrigerated vehicles with multi temperature compartments will help us to reasonably select and arrange the transportation of cold chain vehicles, effectively reduce the loss of fresh products and improve economic benefits.

2. Problem Description and Model Establishment

2.1. Problem Description

MCVRPTW problem is a deformation of MCVRP problem. In the undirected graph $G = \{N, E\}$, $N = \{0, 1, 2, \dots, n\}$ is the

vertex set, $E = \{i, j \mid i, j \in N\}$ is the arc set, $K = N \setminus \{0\}$ is the customer point set, $\{0\}$ represents the distribution center, and the non negative number q_i represents the demand of customer i . c_{ij} represents the driving cost of the vehicle on the arc. $V = \{1, 2, 3, \dots, v\}$ is the vehicle set. Q represents the capacity of the vehicle. In a distribution area, it is assumed that there is a distribution center and a distribution network of countless customer points. In this distribution network, the customers are large supermarkets, and the distribution center has multiple vehicles of the same type, the capacity of each vehicle is equal, and its compartment can be flexibly adjusted according to the number of product groups and the demand of each product segments; Each customer point has multiple product segment needs, and the items of different product segments need to be distributed in different temperature compartments. At the same time, the needs of each customer point must be met in one distribution service as far as possible; Assuming that the distance between the distribution center and the customer point is known, the customer order has been determined before the vehicle distribution, and the vehicle starts from the distribution center and finally returns to the distribution center, the vehicle driving cost is related to the driving distance. The problem solved in this paper is to determine the vehicle distribution routing under the condition of meeting the vehicle capacity constraints, so as to minimize the total vehicle cost. As shown in Figure 1, the orders of six customers are known, and the orders of customer 1 are composed of thermal insulation product segments, variable temperature product segments and refrigerated product segments; Customer 2's order consists of thermal insulation product segments, variable temperature product segments and frozen product segments; Customer 3's order consists of thermal insulation product segments, refrigerated product segments and frozen product segments; Customer 4's orders are composed of variable temperature product segments, refrigerated product segments and frozen product segments; Customer 5's orders consist of frozen product segments and normal temperature product segments; Customer 6's order is

normal temperature product segments. For the multi product segments needs of six customers, the single temperature zone refrigerated truck can only deliver one product group at a time. The multi temperature compartments refrigerated vehicle can realize the joint delivery of customers' multi variety and small batch orders. According to the types of product segments ordered by customers, there are five product segments in total. The maximum number of compartments of refrigerated vehicles with multi temperature compartments is five. The delivery route of customers is determined according to the geographical location of customers and the number of product segments.

The goal of MCVRPTW is to minimize the total route cost by considering the transportation, loading, unloading costs and the penalty cost of early or late delivery under the condition of meeting the store order. Due to the flexible adjustment of the size and temperature of vehicle compartments and the different uses of different compartments, the allocation of product segments and the number of compartments on the vehicle are related to decision-making. This must take into account the different loading and unloading costs caused by different product segments loaded in different compartments, and all orders

assigned to the same compartment on the vehicle must be sorted to determine the travel of the vehicle. The model minimizes the sum of loading, transportation and unloading costs by determining the number of compartments per vehicle, assigning orders for product segmentation to different compartments, and creating a travel plan that meets the vehicle capacity.

This paper describes MCVRPTW as follows: In the transportation network, multiple product segments required by customers are stored in different compartments with the same vehicle for delivery; The multi temperature compartment refrigerated vehicle starts from the distribution center and returns to the distribution center after delivery; The demand of customer points shall be delivered at one time as far as possible, and the time of product delivery shall be limited by time window. On the premise of meeting the customer's time window restrictions and that the driving path of each vehicle is a closed loop, determine the appropriate number of vehicles and how to reasonably arrange the driving route to minimize the total cost of vehicles and meet the customer's requirements for products and requirements for time.

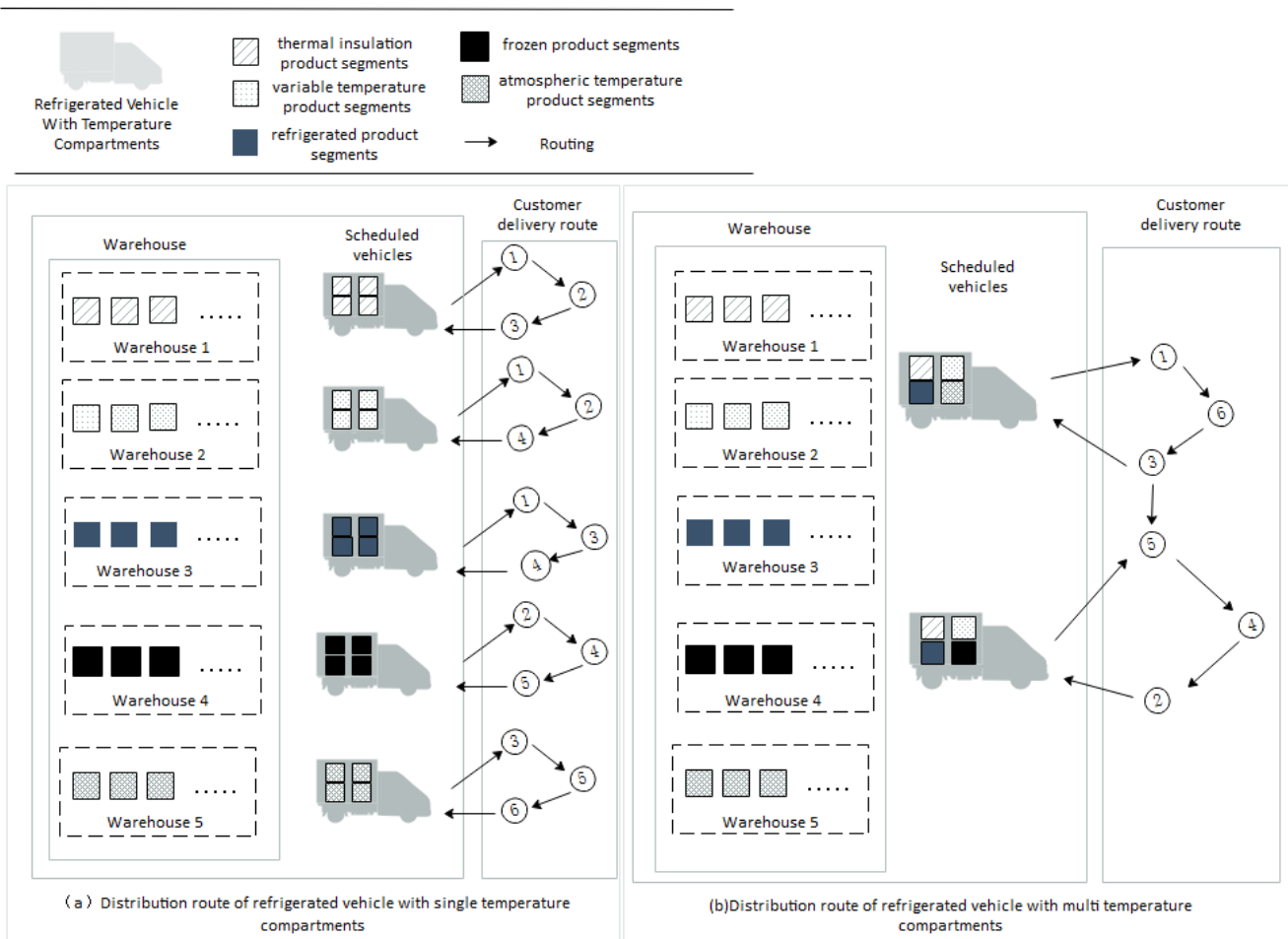


Figure 1. Single-temperature and multi-temperature compartment refrigerated vehicle distribution routing

2.2. Symbol Description

2.2.1. Symbol and Parameter Description

L : The set of customer points in the distribution path, where $i, j \in L, L = \{0\}$ represents the distribution center DC;

V : The set of distribution vehicle;

O : All order sets of customers;

S : The set of Product segments, where $p, q \in S, p, q$ represents two different product segments;

Q : Vehicle capacity;

$lc_{a_{vk}}$: Total vehicle loading cost;

ulc_{d_v} : Total cost of vehicle unloading;

p_{is} : Penalty costs incurred for early or late delivery of orders;

$cost_{ij}$: Total transportation cost of vehicles

c : Compartment of the vehicle, If the compartment has been assigned a product segment, the compartment is active;

q_{is} : Order quantity of product segment s delivered to customer i

u_{iv} : The position of the customer i in the vehicle v distribution route. If $u_{jv} > u_{iv}$, it means that the vehicle visits the customer i first and then visit the customer j in the distribution route;

tc_{ij} :Unit transportation cost;

tt_{ij} : Vehicle transportation time;

st_{is} : Service time of product segment s delivered to customers i ;

sf : Fixed service time per customer;

γ : Unit penalty cost for early delivery of orders;

β : Unit penalty cost for late delivery of orders;

w_{iv} : Time when the vehicle v arrives at the customer i ;

f_v : Number of times the vehicle v stops in the distribution route;

(i, s) : Customer and segment pair, which is equivalent to the coordinate of the midpoint of mathematics and the customer's demand for product segment s ;

TW :The Set of time window, where TW_{is} , $t \in TW$, TW_{is} Represents the Customer -segment pair (i, s) allocated time window;

$[e_t, h_t]$: Time window range, e_t indicating the earliest delivery time of the time window t and h_t indicating the latest delivery time of the time window t ;

2.2.2. Decision Variables

$b_{jv} = \begin{cases} 1, & \text{if vehicle } v \text{ travels from location } i \text{ to } j ; \\ 0, & \text{otherwise} \end{cases}$

$x_{isv} = \begin{cases} 1, & \text{if segment } s \text{ is delivered by vehicle } v \text{ to customer } i; \\ 0, & \text{otherwise} \end{cases}$

$\delta_{vs} = \begin{cases} 1, & \text{if vehicle } v \text{ transports segment } s; \\ 0, & \text{otherwise} \end{cases}$

$a_{vk} = \begin{cases} 1, & \text{if vehicle } v \text{ has } k \text{ active compartments;} \\ 0, & \text{otherwise} \end{cases}$

$y_{ist} = \begin{cases} 1, & \text{if customer-segment pair } (i, s) \text{ is assigned to time window } t; \\ 0, & \text{otherwise} \end{cases}$

2.3. Model Establishment

2.3.1. Constraints

(1) Each vehicle can only start from DC and can only start from DC once;

$$\sum_{j \in L} b_{0jv} \leq 1, \quad v \in V \quad h \in L \quad (1)$$

(2) After the vehicle arrives at the customer point and delivers the order, it needs to leave the customer point. The vehicle starts from the distribution center and finally must return to the distribution center;

$$\sum_{i \in L} b_{ihv} = \sum_{j \in L} b_{hjv}, \quad v \in V, h \in L \quad (2)$$

(3) All product groups of customer orders can be met;

$$\sum_{v \in V} x_{isv} \cdot |O| \geq q_{is}, \quad i \in L, s \in S \quad (3)$$

(4) Eliminate the itinerant access in the distribution route, and set the DC as the starting point and ending point of the distribution route;

$$u_{iv} - u_{jv} + |L| \cdot b_{ijv} \leq |L_c| \quad v \in V, i \in L, j \in L_c \quad (4)$$

$$u_{0v} = 1 \quad v \in V \quad (5)$$

(5) Ensure that each product segment can only be assigned to one temperature compartment of the vehicle;

$$\sum_{v \in V} \sum_{c \in C} x_{svc} = 1, \quad s \in S, S \subseteq O \quad (6)$$

(6) Constraint different product segments will not be assigned to the same temperature compartment;

$$\sum_{s \in S_p} x_{scv} \leq |O| (1 - x_{rcv}), \quad v \in V, c \in C, p, q \in S: p \neq q, r \in S_q, S \subseteq O \quad (7)$$

(7) Ensure that the customer's order is loaded on the vehicle, the customer must be visited;

$$\sum_{s \in S} x_{jsv} \leq |S| \sum_{i \in N} b_{ijv} \quad v \in V, j \in L \quad (8)$$

(8) Ensure that the number of orders loaded into all temperature compartments of the vehicle does not exceed the total capacity Q of the vehicle;

$$\sum_{i \in L} \sum_{s \in S} q_{is} \cdot x_{isv} \leq Q, \quad v \in V \quad (9)$$

(9) Limit the number of product segments loaded on the vehicle and the number of vehicle compartments;

$$\sum_{i \in L} x_{isv} \leq |O| \cdot \delta_{vs} \quad v \in V, s \in S \quad (10)$$

$$\sum_{s \in S} \delta_{vs} = \sum_{k \in K} k \cdot a_{vk} \quad v \in V, k \in K \quad (11)$$

$$\sum_{k \in K} a_{vk} = 1, \quad v \in V \quad (12)$$

(10) Restrict the number of parking times of vehicles in the distribution route to be greater than or equal to the number of customer points visited;

$$f_v \geq \sum_{i \in L} \sum_{j \in L} b_{ijv}, \quad v \in V \quad (13)$$

(11) Restrict the consistent delivery of product segments, ensure that only one time window can be allocated to customer-product segment pairs, and ensure the consistency of customer order delivery;

$$\sum_{t \in TW_{is}} y_{ist} = 1 \quad i \in L, s \in S \quad (14)$$

(12) The time when the vehicle leaves the DC is set to time 0, that is, the delivery start time of the vehicle;

$$w_{0v} = 0, \quad v \in V \quad (15)$$

(13) Limit the time when vehicles arrive at customer points and ensure that waiting time is eliminated in the distribution route between customers;

$$w_{iv} \leq |O| \cdot \sum_{s \in S} x_{siv} \quad v \in V, \quad j \in L \quad (16)$$

$$w_{iv} + tt_{ij} + sf + \sum x_{isv} \cdot st_{is} - |O| \cdot (1 - b_{jv}) \leq w_{jv}, \quad v \in V, i \in L, s \in S, S \subseteq O \quad (17)$$

$$w_{iv} + tt_{ij} + sf + \sum x_{isv} \cdot st_{is} + |O| \cdot (1 - b_{jv}) \leq w_{jv}, \quad v \in V, i \in L, s \in S, S \subseteq O \quad (18)$$

(14) Restrict the penalty cost incurred by early or late delivery of orders within the specified time window;

$$P_{is} \geq \left(\left(\sum_{t \in TW} y_{ist} \cdot e_t \right) - w_{iv} \right) \cdot \gamma - M \cdot (1 - b_{jv}), \quad v \in V, i \in L, j \in L, s \in S \quad (19)$$

$$P_{is} \geq \left(w_{iv} - \sum_{t \in TW} y_{ist} \cdot h_t \right) \cdot \beta - M \cdot (1 - b_{jv}), \quad v \in V, i \in L, j \in L, s \in S \quad (20)$$

2.3.2. Objective Function

The objective function is to minimize the total vehicle cost, which includes the total loading cost, total transportation cost, unloading cost and penalty cost caused by early or late delivery of orders.

$$\min \sum_{v \in V} \left[lc_{a_{vk}} + \sum_{i \in L} \sum_{i \in L} \text{cost}_{ij} + ulc_{d_v} \left(\sum_{i \in L} \sum_{i \in L} b_{ijv} \right) \right] + \sum_{v \in V} \sum_{s \in S} P_{is} \quad (21)$$

(1) Loading cost

The loading cost is related to the type and number of product segments allocated by the multi temperature compartment refrigerated vehicle. For example, when the vehicle is loaded with refrigerated product groups, thermal insulation product groups and frozen product groups, the temperature compartments of the refrigerated vehicle is three. The relationship between the loading cost and the number of product groups is shown in formula (22), in which the number of product segments is equal to the number of temperature compartments.

$$lc_{a_{vk}} = \sum_{k \in K} l_k \cdot a_{vk}, \quad v \in V \quad (22)$$

(2) Transportation cost

The transportation cost is related to the unit transportation cost and the distance between customers. The calculation formula of transportation cost is shown in formula (23).

$$\text{cost}_{ij} = \sum_{i \in N} \sum_{j \in N} tc_{ij} \cdot d_{ij} \quad (23)$$

In the above formula, d_{ij} is the distance between customer i and customer j . d_{ij} is equal to the product of vehicle speed and driving time. The calculation formula is shown in formula (24).

$$d_{ij} = v_{\text{speed}} \cdot tt_{ij} \quad (24)$$

(3) Unloading cost

The unloading cost is related to times of the vehicle stops in the distribution route. For convenience of calculation, the influence of traffic lights and traffic congestion is ignored in the model. The number of parking times is equal to the number of customer points visited by the vehicle. The calculation formula of unloading cost is shown in (25).

$$ucl_{d_v} = u \cdot f_v \quad (25)$$

In the above formula, u is the unit cost of unloading, d_v is the number of customer points visited in the vehicle distribution route, And $d_v = f_v$.

(4) Penalty cost for early or late delivery of orders

In order to ensure the on-time performance rate of vehicles, set the limit of soft time window. Paying orders outside the limit range of soft time window will produce corresponding penalty costs. The calculation formula is shown in equations (26) - (28).

$$P_{is} = \sum_{i=0}^N \sum_{v=1}^V (\gamma A_{iv} + \beta B_{iv}) = \begin{cases} M, w_{iv} \notin [0, E_t], \\ \gamma(e_t - E_t), w_{iv} \notin [E_t, e_t], \\ 0, w_{iv} \notin [e_t, h_t], \\ \beta(H_t - h_t), w_{iv} \notin [h_t, H_t], \\ M, w_{iv} \notin [H_t, \infty), \end{cases} \quad (26)$$

$$A_{iv} = e_t - w_{iv} \quad (27)$$

$$B_{iv} = w_{iv} - h_t \quad (28)$$

In the above formula, e_t is the lower time limit to serve customer i for vehicles v ; h_t is the upper time limit for serving customer i for vehicles v ; E_t is the lower limit of time window for customer i to receive services; H_t is

the upper limit of the time window for customer i to receive services; M is the penalty coefficient, When M is infinite, the customer will refuse the vehicle to deliver the order within the soft time window.

3. Literature References

3.1. The Temperature Control of Refrigerator Vehicle with Multi Temperature Compartments

The multi compartment refrigerated vehicle is developed from the multi compartment compartment. The earliest multi compartment compartment compartment is mainly used for the transportation of oil. The multi compartment vehicle has a variety of purposes, such as the classification and recycling of garbage, the transportation of oil and natural gas, and the transportation of various fresh products. The multi compartment vehicle problem was first proposed by brown and graves. This paper describes a highly automated real-time scheduling system applied to the compartment allocation and scheduling of oil tank vehicles [1]. The refrigerated vehicles with multi temperature compartments with single evaporating agent was studied by Xinxin Zhao through the heat transfer calculation of the carriage, the layout optimization of air supply system and the design of temperature control method and designed a fuzzy controller to improve the accuracy of temperature control [2]. Shihua Zhang combined with vacuum insulation technology, a refrigerated multi temperature compartments refrigerated vehicle is designed to ensure the quality of fruits and vegetables in the process of transportation [3]. Rodolfo ranck Jú nior studied the vehicle packaging problem of multi compartment vehicles in beverage distribution environment under the condition of ensuring the direction of the box, the stability of goods, the bearing strength and load balance of the box [4]. Rahma lahyani takes the olive oil collection process in Tunisia as the research background and uses the accurate branch cutting algorithm to solve it, showing the advantages of multi compartment vehicles [5]. Under the background of solid waste collection, Elham MOFID nakhaee studied the multi compartment arc route problem of intermediate facilities (MCARPIF). In the literature, two algorithms were proposed to solve the problem, they are adaptive large neighborhood search algorithm (ALNs) and hybrid ALNs and whale optimization algorithm [6]. Yuhong Lin designed the cloud temperature monitoring system, which improves the space utilization of less than truckload logistics and realizes the accurate temperature control in multi temperature compartments [7]. Li Jin established the cooling mathematical model of each temperature zone in the multi temperature compartments refrigerator vehicle, and analyzed the factors affecting the cooling performance of the multi temperature refrigerator vehicle [8].

3.2. Solving the Routing Optimization Problem of Refrigerated Vehicle with Multi Temperature Compartments

The routing optimization problem of refrigerated vehicles with multi temperature compartments is mainly divided into two subproblems: assigning orders to compartments and routing optimization problem. Alexander h ü bner studied the influence of loading and unloading cost on route optimization by using large neighborhood search under the background of

grocery distribution [9]. Jorge E. mendoz considered the uncertainty of demand, modeled the vehicle routing problem of refrigerated vehicles in multi temperature compartments with random demand as a random program with recourse, and solved the model with memetic algorithm [10]. Ostermeier studied the routing problem of single compartment and multi compartment vehicles in grocery distribution [11]. Kaabachi proposed hybrid artificial bee colony algorithm and hybrid adaptive variable neighborhood algorithm to solve the vehicle routing problem of large refrigerated vehicles with multi temperature compartments, so as to minimize the number of vehicles and cost [12]. Lu Chen proposed an adaptive large neighborhood search (ALNS) algorithm to solve the vehicle routing problem of refrigerated vehicles with multi temperature compartments with certain practical constraints [13]. Hiba yahyaoui takes the replenishment problem of gas station as the research background, describes the problem configuration through front trucks with several compartments and customers with demand and front delivery, and proposes adaptive variable neighborhood search algorithm (AVNS) and genetic algorithm based on partially matched crossover pmx to find the optimal path [14]. Paulo Vitor silvestrin proposed a tabu search heuristic algorithm and embedded it into the iterative local search to solve the multi compartment vehicle routing problem [15]. Reza eshtehadi proposed an enhanced adaptive large neighborhood search algorithm to solve the urban distribution routing problem of multi compartment vehicle routing problem [16]. Chen Jingyi takes the distribution center's distribution to the school supermarket as the background, uses genetic algorithm and ArcGIS planning to find the shortest path, effectively reduces the scheduling of two refrigerated vehicles by using the co distribution mode of refrigerated vehicles in multi temperature area, reduces the total cost by 34.1%, and shortens the actual transportation distance by 54.1% [17].

Based on the above theory, under the background of common distribution of groceries, this paper takes the optimization of loading, unloading cost and transportation cost as the goal, and considers the actual situations such as the replenishment strategy of the store (e.g. fresh products need to be replenished before or when the store opens), the availability of replenishment personnel (e.g. store staff can be used when the store passenger flow is low), the requirements of the store (the possibility of using the background for intermediate storage), etc, Due to the complexity of the actual situation, in order to maintain the orderly operation of the store when delivering products, this paper tries to realize the consistent delivery of different product groups of the same customer as much as possible. This paper uses the time window to meet the relevant policies and requirements of the store, and studies the compartment distribution and consistent delivery of products of refrigerated vehicles with multi temperature compartments when the order is known. Aiming at the above problems, the mathematical model is established, and the adaptive large neighborhood algorithm (ALNS) is used to solve the model. Finally, an example is analyzed to verify the stability and superiority of ALNS algorithm in solving the path optimization problem of refrigerated vehicles with multi temperature compartments.

4. Algorithm Design

The concept of LNS was originally proposed by Shaw. He introduced the concept of "Shaw" to select customers to delete [19,20]. pisinger and ropke proposed a heuristic algorithm

LNS based on the principle of neighborhood independence, which aims at the destroy / repair specific problems [18]. Adaptive large neighborhood search (ALNS) is applied as an extension of the basic concept of LNS. For example, ropke and pisinge successfully solved the complex distribution vehicle routing problem with time window [21]. bartodziej et al. Successfully applied ALNS to the joint scheduling problem of personnel and vehicles with rest constraints [22]. Because the LNS algorithm will not travel and search the whole neighborhood of the solution, it can only sample and search some of the solutions. Therefore, based on LNS, ALNS allows multiple destroy and repair methods to be used in the same search to obtain the neighborhood of the current solution. ALNS assigns a weight to each destroy and repair method, which controls how often each destroy and repair method is used during the search. In the search process, ALNS will dynamically adjust the weights of each destroy and repair method to obtain better neighborhood reconciliation.

ALNS algorithm is mainly divided into three parts: destroy solution, repair solution, dynamically adjusting the weight and adapting. The destroy operator destroys a part of the current solution, and then repair the current solution by using the repair operator. All possible conditions form a neighborhood of the original solution, and then reconstruct the destroyed solution to obtain a set of solutions.

4.1. Destroy

The methods of destroy solution mainly include random removal, worst removal and Shaw removal. Random removal indicates random removal orders from the delivery route. The worst removal is represented by the worst removal operator, when the order is removed, the cost of the objective function of the model decreases greatly. Shaw removal is based on the concept of "Shaw", Shaw is a distance measurement based on specific problems. Distance measurement includes the distance of customer location, quantity and the difference of product group φ , ψ , ω Determined by equation (29).

$$R(i, j) = \varphi \cdot \frac{cost_{ij}}{c_{max}} + \psi \cdot \frac{|quantity(i) - quantity(j)|}{q_{max}} + \omega \cdot p(i, j) \quad (29)$$

In the above formula, $cost_{ij}$ represents the distance / cost of two orders, c_{max} represents the maximum distance between any two customers; q_{max} represents the maximum quantity difference between any two orders. $p(i, j)$ indicates whether two products i and j are the same product segment, and its expression is

$$p(i, j) = \begin{cases} 1 & \text{if } segment(i) \neq segment(j) \\ 0 & \text{otherwise} \end{cases} \quad (30)$$

4.2. Repair

There are two main repair methods in ALNS: greedy and regret repair. Greedy insert Search in order the order and vehicle pair, insert the removed order into the driving route with the smallest total cost increment.

$$cost_increase_{o,v} = \min \{ cost_increase_{o,v} \mid o \in O, v \in V \} \quad (31)$$

The heuristic of greedy insertion tends to delay the insertion information and can only insert orders at relatively

high cost increments. Without violating the constraints, the number of trips that can be inserted into the order will be reduced and the insertion cost will increase. Therefore, the regret insertion method is set to prevent this from happening.

$$regret_k = \sum_{i=2}^k (cost_increase_{v_k} - cost_increase_{v_i}) \quad (32)$$

4.3. Adaptive process

The adaptive process of ALNS is to score the performance of destruction operator and repair operator, and dynamically adjust the weight and select according to the score of operator. The destruction and repair methods are used together. The solution after one destruction and repair method is equivalent to a neighborhood transformation. At the beginning of the algorithm, all methods set the same weight, and continuously adjust the scores of destroy and repair methods by setting corresponding scoring standards. The greater the weight, the more likely it is to be selected. In the iterative process, the algorithm selects and adjusts the ring breaking operator and repair operator according to the operator weight and the way of roulette. The update way of operator weight is

$$\omega_d = \begin{cases} \omega_d, & \text{if } u_d = 0 \\ (1 - \rho)\omega_d + \rho \frac{s_d}{u_d}, & \text{if } u_d > 0 \end{cases} \quad (33)$$

In the above formula, ω_d is the operator weight, s_d is the operator score, u_d is the number of times the operator is used, ρ is the update for the coefficient of the weight.

At the beginning of ALNS, all operators are set with the same weight of 0.4 and score of 0. In the iterative calculation process, a scoring mechanism is set according to the different performance of destruction and repair operators. The higher the score, the better the performance of the operator.

$$\varphi = \max \begin{cases} \omega_1, & \text{if the new solution is a new global optimal solution} \\ \omega_2, & \text{If the new solution is better than the current solution} \\ \omega_3, & \text{If the new solution is inferior to the current solution} \end{cases} \quad (34)$$

In the above formula, $\omega_1 \geq \omega_2 \geq \omega_3$, they are user-defined parameters. In this paper, the parameters of the evaluation function are set to $\omega_1=30$; $\omega_2=20$; $\omega_3=10$.

ALNS algorithm dynamically adjusts according to the weight of destroy and repair in the search process. The probability of destroy and repair methods being selected is determined by equation (35).

$$\varnothing_j^- = \frac{\rho_j^-}{\sum_{k=1}^n \rho_k^-} \quad (35)$$

4.4. Adaptive Large Neighborhood Search

The algorithmic operation flow of ALNS is shown in Figure 2. ALNS designs multiple groups of destruction operators and repair operators to expand the spatial search range of the solution and improve the current solution. The destruction and repair methods with good performance get high scores and higher weights accordingly. In each iteration, select and adjust the weight of each destroy and repair

operator according to the previous performance, and use an efficient combination method to improve the optimization ability of the algorithm, so as to find the optimal solution.

Algorithm 2 Adaptive large neighborhood search.

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1: input: a feasible solution x
2:  $x^b = x$ ;  $\rho^- = (1, \dots, 1)$ ;  $\rho^+ = (1, \dots, 1)$ ;
3: repeat
4:   select destroy and repair methods  $d \in \Omega^-$  and  $r \in \Omega^+$  using  $\rho^-$  and  $\rho^+$ ;
5:    $x^1 = r(d(x))$ ;
6:   if accept( $x^1, x$ ) then
7:      $x = x^1$ 
8:   end if
9:   if  $c(x^1) < c(x^b)$  then
10:     $x^b = x^1$ ;
11:  end if
12:  update  $\rho^-$  and  $\rho^+$ ;
13: until stop criterion is met
14: return  $x^b$ 

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Figure 2. ALNS algorithm operation program

5. Conclusion

Due to the lack of standard numerical examples of MCVRPTW problem, this paper adapts the research data set of VRPTW based on the famous foreign scholar Solomon, and obtains 18 groups of numerical examples. Based on the Solomon example, this paper selects three different distribution types of data of 50 customer points for calculation and analysis. Each group of data includes three distribution characteristics of customers, C1, C2, R1, R2, RC1 and RC2. Among them, class C (clustered) indicates that the geographical location of customers is clustered, class R (random) indicates that the geographical location of customers is random distributed, and RC indicates that the geographical location of customers is mixed distribution. On this basis, Solomon divides the data with different distribution characteristics into two categories: Category 1 and category 2. The difference mainly lies in the influence of vehicle capacity on the distribution range.

5.1. Example Parameter Setting

5.1.1. Loading and Unloading Cost Parameter Setting

In this paper, the loading cost and unloading cost are considered. The loading cost is mainly caused by the distance and time between loading goods and delivering to customers. The loading cost is related to the number of compartments of refrigerated vehicles with multi temperature compartments, and the unloading cost is related to the number of customer points. As for the loading cost and unloading cost, Alexander hübner and Manuel Ostermeier calculated that the loading cost of each compartment of each vehicle is 2.6 times of the transportation cost and the unloading cost is 2.05 times of the transportation cost through a large amount of empirical data collected[23]. the specific quantitative relationship between the number of compartments, loading cost and unloading cost of multi temperature compartments refrigerated vehicle is shown in Table 1:

Table 1. The relationship between the number of refrigerated vehicle compartments and the cost of loading and unloading in multiple temperature compartments

Number of compartments c	Loading costs per compartment c	Unloading costs per customer j
2	206	112
3	306	112
4	406	112
5	506	112

5.1.2. Relevant Parameter Settings of ALNS Algorithm

The speed of refrigerated vehicles in urban areas is generally 40km/h-50km/h. In this paper, the driving speed of vehicles is set as 40km/h and the capacity of vehicles is set as 60 and 100. The relevant parameter settings of destroy operator, repair operator and adaptive process of ALNS algorithm are shown in Table 2.

Table 2. Related parameter settings

Parameter	Parameter description	Value
rand_d _{max}	The highest value of random destroy operator	0.4
rand_d _{min}	The lowest value of random destroy operator	0.1
greedy_d _{min}	The lowest value of greedy destruction operator	5
greedy_d _{max}	The highest value of greedy destruction operator	20
repair _n	Number of nodes to insert when repairing	5
rho	Operator weight	0.4
phi	Maximum range of weight change	0.9
pu	Weight update coefficient	10
v_speed	The speed of vehicle	40
T	Simulated annealing initial temperature	30
v_cap	Total vehicle capacity	60\100

5.2. Analysis of Experimental Results

Use Python 3.7 write the algorithm solution in the pycharm Community Edition 2020 environment. This paper plans the distribution route of one distribution center and 50 customer points. The distribution types of customers include cluster distribution, uniform distribution and mixed distribution. Each customer point changes the capacity of refrigerated vehicles with multi temperature compartments, studies the

impact of capacity on distribution route, distribution time and total cost, and selects the appropriate distribution strategy according to the experimental results.

Different distribution types of customer points have a great impact on the distribution route, changing the capacity of vehicles and the number of vehicles. For customers with cluster distribution, when the capacity of vehicles increases, the number of vehicles and delivery time will decrease, the

total cost will decrease significantly, the average utilization rate of carriages will decrease, and the utilization rate of a single compartment will increase, so customers with cluster distribution are more suitable for high-capacity multi temperature zone refrigerated vehicles; When the vehicle capacity of evenly distributed customers increases, the number of vehicles will be reduced, the distribution time will be greatly reduced, and the total cost and the average utilization rate of carriages will be reduced. Therefore, the evenly distributed customer points should select appropriate multi temperature zone refrigerated vehicles for distribution

according to the needs of customers, such as timeliness and distribution cost; For customers with mixed distribution, when the capacity of vehicles increases, the total cost will be reduced, the number of vehicles and distribution time will be greatly reduced, and the average utilization rate of carriages will be improved. Therefore, customers with mixed distribution should choose multi temperature zone refrigerated vehicles with large capacity for distribution. The specific experimental results of the example are shown in Table 3.

Table 3. Experimental results of examples

Distribution characteristics of customers	Refrigerated vehicle capacity	Number of vehicles	Distribution time	Total cost	Average utilization rate of compartment
C1	60	15	5437	111307.39	0.956
C2	100	10	5141	81028.47	0.860
R1	60	14	1728	114249.70	0.858
R2	100	10	1441	91598.92	0.721
RC1	60	17	5437	111307.39	0.951
RC2	100	10	1743	105960.11	0.970

Acknowledgment

In order to improve the utilization rate of refrigerated vehicles and improve the economic benefits of refrigerated vehicles, this paper focuses on the optimization of the distribution routing of refrigerated vehicles with multi temperature compartments. Considering the business model of large supermarkets in the actual situation, the time window is used to ensure the consistent delivery of different product segments of the same customer, the basic model of the consistent delivery model of refrigerated vehicles with multi temperature compartments is constructed, and through the adaptive large neighborhood search algorithm (ALNS), combined with the corresponding examples, the model is solved. The necessity of the research on this problem and the effectiveness of ALNS algorithm in solving this problem are verified.

In future research, we can consider different time windows for different product segments at the same customer point, the joint allocation of multiple models of refrigerated vehicles with multi temperature compartment and refrigerated vehicles with single temperature compartment, comprehensively consider the distribution problems such as traffic congestion, scheduling of drivers and large supermarket staff, multiple distribution centers, and use reasonable algorithms to improve the utilization rate of refrigerated vehicles with multi temperature compartments, so as to reduce the distribution cost on the premise of ensuring the quality and timeliness of fresh segments, Improve the economic benefits of enterprises.

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