การจัดหาเส้นทางการขนส่งที่เหมาะสมของสายโซ่ความเย็นโลจิสติกส์ของผลิตภัณฑ์ทางการเกษตรตามจุดเชื่อมต่อ

Optimization of Distribution Route for Cold Chain Logistics of Agricultural Products Based on Connection Point

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บทคัดย่อ

การศึกษาในครั้งนี้มีวัตถุประสงค์เพื่อการจัดหาเส้นทางการขนส่งที่เหมาะสมของสายโซ่ความเย็นโลจิสติกส์ของผลิตภัณฑ์ทางการเกษตรตามจุดเชื่อมต่อซึ่งได้ทำการวิเคราะห์ต้นทุนประจำ ต้นทุนการขนส่ง ต้นทุนการทำความเย็น ต้นทุนความเสียหายและการลงโทษตามสายโซ่ความเย็นโลจิสติกส์ของผลิตภัณฑ์ทางการเกษตรและสร้างต้นแบบการกำหนดเส้นทางยานพาหนะตามจุดเชื่อมต่อ เพื่อเพิ่มประสิทธิภาพสายโซ่ความเย็นโลจิสติกส์โดยใช้วิธีการวิเคราะห์แบบคลัสเตอร์ เพื่อกำหนดจุดเชื่อมต่อ จากนั้นถือว่าเป็นจุดเสมือนที่ต้องการแล้ว จึงแก้แบบจำลองด้วยอัลกอริทึมที่เหมาะสม ผลการทดลองแสดงให้เห็นว่า เส้นทางการกระจายสินค้าที่ดีที่สุดโดยใช้จุดเชื่อมต่อ สามารถลดต้นทุนการขนส่งสินค้าทางการเกษตรสายโซ่ความเย็นได้อย่างมีประสิทธิภาพ และยังช่วยเพิ่มความพึงพอใจให้แก่ลูกค้า

คำสำคัญ : การจัดเส้นทางการขนส่ง สายโซ่ความเย็นโลจิสติกส์ จุดเชื่อมต่อ

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Abstract

This study aims to optimize the distribution route for cold chain logistics of agricultural products based on connection point. The researchers analyze the fixed cost and the costs of transportation, refrigeration, cargo loss and penalty of cold chain logistics distribution of agricultural products. On this basis, it is proposed to set reasonable connection points in the cold chain distribution and to establish a mathematical model for the distribution route optimization of agricultural products cold chain logistics based on connection points. It uses genetic algorithm to solve the model and conducts an empirical analysis. The study shows that cold chain distribution of agricultural products based on connection point method can effectively reduce the cost of cold chain distribution and increase customer satisfaction.

Keywords: Vehicle Routing Problem, Cold Chain Logistics, Connection Point

1. Introduction

With the gradual improvement for people's material living standards, the demand for diversified, green and nutritious fresh agricultural products such as fruits and vegetables, fresh meat, eggs and milk is also increasing. In order to maximize the freshness of these natural produce and send them to consumers, they need to be pre-cooled, transported, stored and delivered at a suitable low temperature. Cold chain logistics of fresh produce usually refers to a special supply chain system, where fresh produce such as meat (aquatic products included), poultry, eggs, milk, fruits and vegetables after harvesting (or slaughtering, fishing) will be all initially processed, stored, transported and sold in a low-temperature environment that guarantees the product quality and safety, so as to reduce the loss and prevent product contamination. In recent years, as the consumption level of urban residents and their consumption demand for fresh produce have continued to increase, the types, production, and circulation of fresh produce have also increased year by year. When accelerating the development of cold chain logistics of produce, especially in cold chain distribution, to deliver safe and high-quality fresh produce to urban residents, it can not only meet the higher living needs of residents, but also promote rural and agricultural development and guarantee an increasing income for farmers.

With the constant adjustment of energy prices, the cost of cold chain logistics has generally risen. Considering such factors as low original price of produce, low integration of the industrial chain, and more competition than cooperation between upstream and downstream enterprises, produce distributors usually start to reduce cost for logistics (including costs of cold chain transportation and product loss). Distribution is an extremely important part of cold chain logistics, but it is also easy to be "off the chain". In the process of fresh produce from the producer to end consumer, more than 80% of the time is spent on distribution. Considering the importance of distribution in the operation of cold chain logistics of produce, it should make full use of available resources and information (data), and rationally arrange vehicle scheduling and routes. Under such constraints as time windows, it should minimize the transportation time and cargo loss of fresh produce, thus directly or indirectly reduce the operation costs of cold chain logistics. This has great significance in improving the market competitiveness of fresh produce.

Since Dantzig & Ramser (1959) proposed the Vehicle Routing Problem (VRP) for the first time, the VRP has become one of the hot issues in logistics distribution research. Tarantilis & Kiranoudis (2002) used the example of fresh beef distribution in Greece to study the vehicle routing problem of a farm serving multiple distribution centers. On the other hand, fresh produce has a certain shelf life even at low temperature and the cost of low-temperature environment control is huge. Therefore, that how to reduce the time on transportation and storage and deliver the products within a customer-specified time frame has become the focus of cold chain distribution research. That is the extended vehicle routing problem with time windows (VRPTW).

Azi et al. (2007) proposed a VRPTW for fresh food distribution in determining running time for the vehicle, that was to deliver at a specified time point. And then they compared and studied changes in the total cost of distribution after extending a hard time window to a soft time window. Chen et al. (2009) established an optimal model with the minimization of total distribution cost as an objective function when studying the VRP in food cold chain distribution. In the model, the penalty cost for violating the soft time window was included in the total cost of distribution.

While in the cold chain distribution model established by Miao et al. (2011), besides penalty cost for the violation of time window, cost of cargo loss in distribution and cost of heat exchange generated by the refrigerated vehicle switching doors were also brought into consideration in actual conditions. Lv & Shun (2013) established a vehicle routing model for food cold chain distribution with time window under a time-varying transport network. In the model, they assumed that vehicles would face some unexpected interference in the actual distribution process, such as traffic jams, weather conditions and other emergencies.

Previous studies on the cold chain distribution mainly focused on the distribution center, distribution vehicles, road conditions, demand volume, and how to arrange loading and plan distribution routes under the determined time windows, to optimize distribution costs. However, due to such factors as capital investment, regional planning and urban land prices, cold chain logistics enterprises are not likely to set up too many cold chain distribution centers. Meanwhile, considering the higher land prices in urban centres, the enterprises will generally set up the distribution centers in the suburbs where land prices are low.

However, demand sites such as supermarkets, convenience stores, restaurants and canteens are often located in traffic-congested downtown areas, or even at narrow streets and alleys. If the vehicle for cold chain distribution is too large, frequent switching of the door will increase cooling cost, and transportation cost will also rise when the vehicle carries few products later.

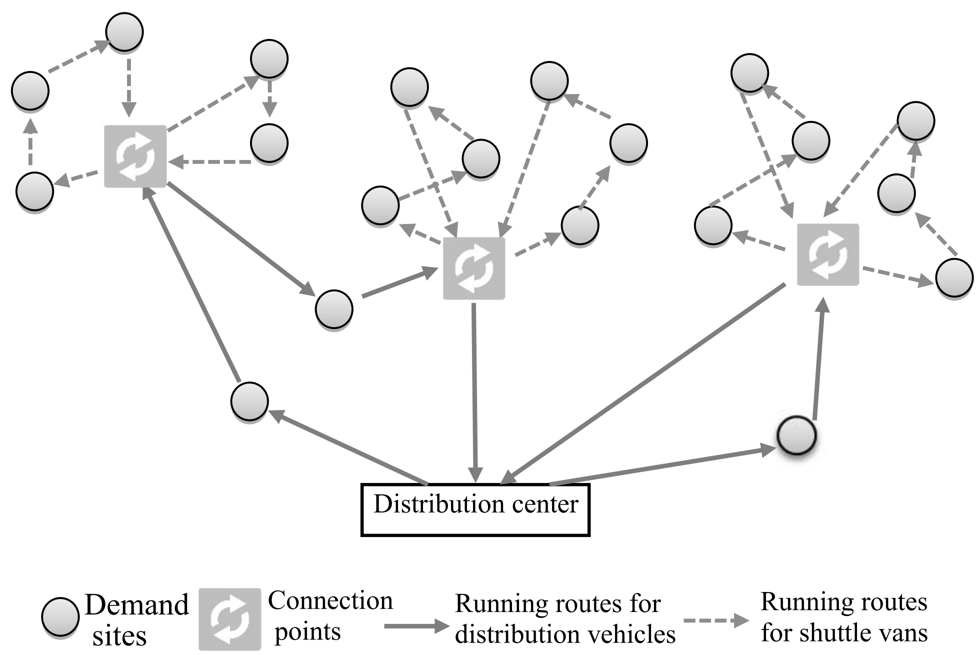
To reduce refrigerated vehicle's round trips from the distribution center, referring the idea of some express companies using large trucks for connection replenishment, this paper proposes to introduce connection points in the cold chain distribution of fresh produce, equipped with vehicles for connection

(Vehicles of cold chain distribution mainly adopt small and mini-sized electric vans with lower input and operating costs. Generally, phase transition cold storage materials (A cooling method that uses a cold storage material such as an ice pack or dry ice to release the cold during the phase transition.) or foam box insulation are used to ensure the low temperature of fresh produce). Under the circumstance of adopting connection points, this paper studies the selection of connection points and the optimization of cold chain logistics VRP, and then establishes an optimal model on this basis, to minimize the distribution cost of cold chain logistics of produce on the "last mile".

2. Problem description and hypothesis

A cold chain logistics distribution center distributes fresh produce under low temperature at multiple demand sites in the urban area, where the cold storage is large enough and the supply is adequate. The center has M_1 vehicles exclusive for refrigerated delivery and M_2 shuttle vans to connect the distribution of fresh produce for N demand sites in the urban area. In order to improve distribution efficiency and save costs, R connection points are set in urban areas where the conditions permit. Refrigerated distribution vehicles can temporarily stop at the connection points and transfer all or part of the produce to one or more shuttle vans. And the shuttle vans will continue their subsequent low-temperature delivery. Each refrigerated distribution vehicle departs from the distribution center and returns after passing through the connection points or demand sites. The shuttle vans load products from the refrigerated vehicles at each connection point and return after delivering produce to demand sites. The schematic diagram of cold chain distribution with connection modes is shown in Figure 1:

Figure 1. Schematic diagram of cold chain distribution based on connection points



The optimization is to build a mathematical model based on such conditions as the existing distribution resources, alternative connecting points, demand volume, and required time windows, and quickly select connection points through appropriate algorithms to seek a distribution strategy: The arrangements involved in the distribution process include starting from the distribution center, the refrigerated distribution vehicles' starting order, sizes, starting time and their running routes, the shuttle vans' loading time, delivery order, delivery volume and running routes. The total distribution costs, such as transportation and distribution cost, cargo loss cost, cooling cost, penalty cost, and fixed cost, are all minimized during the process from the distribution center or connection point until the completion of the service to the customer (demand site).

Hypothesis as follows:

(1) Such uncertain factors as road congestion and restricted traffic are not taken into consideration. That is, refrigerated distribution vehicles and shuttle vans for connection run at an even speed during the distribution process.

(2) The number of refrigerated distribution vehicles and shuttle vans is fixed, and the weight of each vehicle is limited. The total demand of each customer does not exceed the maximum load of a single vehicle (this hypothesis is for the convenience to solve the model. In actual practice, in case the total demand of a certain customer is greater than the maximum load of a single vehicle, this customer may be treated as two or more customers).

(3) Each demand site receives delivery service and the fresh produce required can only be delivered by one single refrigerated vehicle or by shuttle vans. If the connection point is adopted, it can only be distributed by a refrigerated vehicle and the vehicle is not empty there.

(4) The total length of each distribution route shall not be greater than the continuous course of each vehicle (i.e. the distribution vehicle doesn't need to refuel on the way).

(5) The distribution center has sufficient fresh produce storage to meet customer demand, and the customer demand and time window required are known;

(6) Geographical locations of the distribution center, connection points and demand sites are known, i.e. the distances between these points are known and meet the triangle inequality: $d_{ij} \leq d_{ik} + d_{kj}$;

(7) Fresh produce needs to be delivered at the designated time window, and penalty will be paid if it exceeds the time range;

(8) After the refrigerated distribution vehicle departs from the distribution center, there is no temporary task during the delivery, and the vehicle immediately returns to the distribution center after delivery. The shuttle van starts from the connection point, and there is no midway task during the one-off delivery process. It returns to the connection point after the delivery task completed.

(9) The loading time of the refrigerated distribution vehicle at the distribution center and the waiting time for the shuttle van at the connection point are not taken into consideration. But the unloading time at the demand site and the time for loading and unloading at the connection point are taken into

consideration and the time is related to the volume of goods loaded and unloaded.

(10) Refrigerated distribution vehicles can always maintain a safe temperature for storage of agricultural products during delivery, and the temperature change inside the refrigerated vehicles during delivery is not taken into consideration. However, shuttle vans use insulated compartments, and the temperature will rise gradually as time goes by, therefore, the delivery time of shuttle vans shall be restricted.

3. Modeling

1. Parameter Settings and Variable Definitions

According to the modeling requirements, the parameter settings and variables are defined as follows:

M_1: the number of refrigerated distribution vehicles at the distribution center;

M_2: the number of insulated shuttle vans at each connection point;

N: the number of customers (demand sites for produce) to be served by the distribution center;

R: the number of connection points in urban areas;

v_i: representing distribution center, demand site and connection point, v_0 representing the distribution center, v_i(i =1,2,...N)representing each customer (demand) site, v_i(i = N +1, N +2,... N + R)representing each connection point;

d_{ij}: indicating the distance between two points (v_i , v_j), d_{ij} =d_{ji};

V: indicating the normal average speed of refrigerated distribution vehicles and shuttle vans;

g_i: indicating the demand volume of fresh produce of the i-th customer (demand site) or the connection point, i=1, 2, ...N;

t: indicating the time required for unloading specific weight of goods (including reloading on the shuttle van);

t_i: indicating the time spent on serving customer i, t_i=$g_i t$;

G_1: representing the maximum load of each refrigerated distribution vehicle;

G_2: representing the maximum load of each shuttle van;

x_{kij}: representing the running flag variable of a refrigerated vehicle, which is represented by 0, 1. And x_{kij}=1, indicating that the k-th refrigerated vehicle has passed the route from v_i to v_j (v_i, v_j), otherwise x_{kij}=0;

y_{kij}: representing the running flag variable of a shuttle van, which is represented by 0, 1. When y_{kij} =1, it indicates that the k-th shuttle van has passed the route (v_i, v_j) from v_i to v_j, otherwise y_{kij} =0;

f_1: fixed expense of using a refrigerated distribution vehicle for delivery;

f_2: fixed expense of using a shuttle van for delivery;

h_1: transportation cost of a refrigerated distribution vehicle for each unit mileage;

h_2: transportation cost of a shuttle van for each unit mileage;

Pr: energy consumption price for each cooling unit;

Q_0: cooling (energy consumption) volume for a refrigerated vehicle to open the door each time;

Q_1: cool air (energy) consumption volume per unit time when the vehicle door is closed;

Q_2: cooling (energy consumption) volume per unit time when the vehicle door is open for unloading;

β_0: cost coefficient of freight loss per unit time when the vehicle is unloading goods;

β_1: cost coefficient of freight loss per unit time of a refrigerated distribution vehicle in the process of transportation;

β_2: cost coefficient of freight loss per unit time of a shuttle van in the process of transportation;

$[b_i, e_i]$: time period that customer i expects to have fresh produce delivery;

$[B_i, E_i]$: time period acceptable for customer i to have fresh produce delivery, $B_i \leq b_i$, $E_i \geq e_i$

T_i: indicating the time when the distribution vehicle or shuttle van arrives at customer i;

w_1: penalty coefficient for late delivery before delivery time window $[b_i, e_i]$;

w_2: penalty coefficient for late delivery after delivery time window $[b_i, e_i]$;

L: the maximum travel distance of an insulated shuttle van.

4.Cost Analysis

It is aimed at establishing the minimum total cost as its objective function to analyze the vehicle routing problem for cold chain logistics distribution of agricultural products based on the connection points. The cost analysis is as follows:

(1) Fixed costs for delivery vehicles (C_1)

The fixed costs required for the delivery service of refrigerated distribution vehicles and shuffle vans, such as the driver's salary and the cost of vehicle wear, are mostly constant in the same distribution center, so the cost of this part is related to the number of refrigerated distribution vehicles and shuffle vans used for delivery. Therefore, the total fixed cost of all delivery vehicles is:

$$C_1 = f_1 \sum_{k=1}^{M_1} sign_1(k) + f_2 \sum_{k=1}^{M_2} sign_2(k) \quad (1)$$

Among them, $sing_1(k)$ and $sing_2(k)$ are the identification functions for the *k*-th refrigerated vehicle and shuffle van, which indicates 1 as using, and 0 as not using.

$$sign_1(k) = \begin{cases} 0, & \sum_{i=0}^{N+R} \sum_{j=0}^{N+R} x_{kij} = 0 \\ 1, & \text{others} \end{cases} \quad (2)$$

$$sign_2(k)=\begin{cases}0, & \sum_{i=0}^{N+R}\sum_{j=0}^{N+R} y_{kij}=0\\ 1, & \text{others}\end{cases} \quad (3)$$

(2) Variable transportation cost of delivery vehicles (C_2)

The transportation costs of refrigerated distribution vehicles and shuffle vans include fuel cost and cost of repair and maintenance, which are positively correlated to the traveling mileage of the vehicles. The transportation cost of unit mileage of the refrigerated vehicle is h_1, and that of the shuffle van is h_2. Therefore, the variable transportation cost for them is:

$$C_2=\sum_{k=1}^{M_1}\sum_{i=0}^{N+R}\sum_{j=0}^{N+R} h_1 x_{kij} d_{ij}+\sum_{k=1}^{M_2}\sum_{i=0}^{N+R}\sum_{j=0}^{N+R} h_2 y_{kij} d_{ij} \quad (4)$$

(3) Cost of cooling and energy consumption of a refrigerated distribution vehicle (C_3)

Cost of cooling and energy consumption of a refrigerated distribution vehicle is mainly the cost to resupply cool air after consumption. Cooling and energy consumption is related to the cooling time, compartment size, temperature difference inside and outside the compartment, cargo volume loaded in the compartment, how many times and how long (unloading time) that the compartment door is open. As the compartment size is fixed and temperature required in the compartment for produce delivery is stable, so the external environment is relatively stable. The cooling cost for a refrigerated vehicle can be considered approximately to have positive correlation with the vehicle running time, how many times and how long that the compartment door is open (unloading time refers to the period staying at the connection point or the customer site). In contrast, insulated shuffle vans are generally insulated with foam insulation boxes. Mostly, ice bags or dry ice bags are added to the insulation boxes. Therefore, the cooling cost for shuffle vans is not considered in this study.

In addition, since the loading at the distribution center is generally carried out in a cold storage, the cost of cooling and energy consumption of a refrigerated distribution vehicle during such loading is not considered.

Therefore, the cost of cooling and energy consumption in the entire distribution process is related to three points: the frequency of opening door for a refrigerated distribution vehicle, the driving time for a refrigerated distribution vehicle with its door closed and the time of opening the door of a refrigerated distribution vehicle for unloading. Therefore, the cooling cost of a refrigerated distribution delivery vehicle can be expressed as:

$$C_3=Pr\left(Q_0\sum_{k=1}^{M_1}\sum_{i=0}^{N+R}\sum_{j=1}^{N+R} x_{kij}+Q_1\frac{\sum_{k=1}^{M_1}\sum_{i=0}^{N+R}\sum_{j=0}^{N+R} x_{kij} d_{ij}}{V}+Q_2\sum_{i=1}^{N} g_i t\right) \quad (5)$$

Herein, $\sum_{k=1}^{M_1}\sum_{i=0}^{N+R}\sum_{j=1}^{N+R} x_{kij}$ indicates the times of a refrigerated vehicle stopping to unload,

$\sum_{k=1}^{M_1}\sum_{i=0}^{N+R}\sum_{j=0}^{N+R} x_{kij}d_{ij}$ indicates the total travel distance of each refrigerated vehicle, and $\sum_{i=1}^{N} g_i t$

indicates the total unloading time of each refrigerated vehicle.

(4) Loss cost of fresh produce (C_4)

Fresh produce is perishable. Temperature, humidity, environment, and vibrations during transportation will affect the quality of fresh produce. With time extension and increasing number of carrying, fresh produce will decline in quality or even the product safety can't be guaranteed and thus cause loss. The loss of fresh produce is related to the transport vehicles, transport time and unloading time. When using the shuttle vans, the goods will be unloaded twice, while the refrigerated vehicle returns to the distribution center and the shuttle van returns to the connection point, they will be empty and no loss will occur. Therefore, the total loss cost can be expressed as:

$$C_4 = \beta_0 T(\sum_{i=1}^{N} g_i + \sum_{k=1}^{M_2}\sum_{i=N+1}^{N+R}\sum_{j=1}^{N} y_{kij} g_j) + \beta_1 \frac{\sum_{k=1}^{M_1}\sum_{i=0}^{N+R}\sum_{j=1}^{N+R} x_{kij}d_{ij}}{V} + \beta_2 \frac{\sum_{k=1}^{M_2}\sum_{i=N+1}^{N+R}\sum_{j=1}^{N} y_{kij}d_{ij}}{V} \quad (6)$$

(5) Penalty cost for violation of window time required by customer (C_5)

Due to the timeliness of fresh produce, such demand sites as supermarkets and canteens impose strict time limits on the distribution of fresh produce. Early or late arrivals will affect the satisfaction of delivery services and even be rejected. The delivery time window is divided into a soft time window and a hard time window. Generally, customers can accept slightly early or late delivery of fresh produce. Therefore, the distribution model studied in this paper uses a soft time window. The time window of cold chain delivery for fresh produce requested by customer *i* is $[b_i, e_i]$, and the maximum time window tolerable is $[B_i, E_i]$ ($B_i \leq b_i$, $e_i \leq E_i$). That is, if the delivery time is within $[b_i, e_i]$, the penalty cost is 0; if beyond $[b_i, e_i]$ but within $[B_i, E_i]$ there is a penalty cost; and if beyond $[B_i, E_i]$ and resulting in rejection, the penalty cost is $+\infty$. In practice, the penalty cost is negotiated between the cold chain distribution company and the customer. The penalty coefficient for early delivery is w_1, for delay is w_2, and T_i is the time at which the delivery vehicle reaches customer *i* ($B_i \leq T_i \leq E_i$). The penalty cost for violation of window time required by customer can be expressed as:

$$C_5 = w_1 \sum_{i=1}^{N} \max\{b_i - T_i,\ 0\} + w_2 \sum_{i=1}^{N} \max\{T_i - e_i, 0\} \quad (7)$$

Optimal model of cold chain distribution route based on connection points

Based on the above analysis, the optimal mathematical model of distribution route for produce cold chain logistics based on connection points is to find a distribution route that minimizes the total cost of distribution under the resource constraints (constraints).

Objective function C includes fixed cost, transportation cost, product loss cost, energy consumption cost, and penalty cost.

The number of distribution routes from the distribution center cannot exceed M_1, the total number of refrigerated vehicles. The constraints are expressed as:

$$\sum_{k=1}^{M_1}\sum_{j=1}^{N+R} x_{kij} \le M_1, \qquad (i=0) \quad (8)$$

The number of distribution routes from the connection points cannot exceed M_2, the total number of shuttle vans. The constraints are expressed as:

$$\sum_{k=1}^{M_2}\sum_{j=1}^{N+R} y_{kij} \le M_2, \qquad (i=0) \quad (9)$$

The initial starting point and the final return point of the refrigerated vehicle are all required to be the distribution center v_0. The constraints are expressed as:

$$\sum_{j=1}^{N+R} x_{kij} = \sum_{j=1}^{N+R} x_{kji} \le 1, \qquad (i=0, k=1,2,3,\cdots,M_1) \quad (10)$$

Each connection point or customer site should be delivered only once by a refrigerated vehicle. Each customer site should be delivered only once by a shuttle van. The constraints are expressed as:

$$\sum_{k=1}^{M_1}\sum_{i=0}^{N+R} x_{kij} \le 1, \qquad (j=1,2,3,\cdots,N+R, \quad i\ne j) \quad (11)$$

$$\sum_{k=1}^{M_1}\sum_{j=0}^{N+R} x_{kij} \le 1, \qquad (i=1,2,3,\cdots,N+R, \quad i\ne j) \quad (12)$$

$$\sum_{k=1}^{M_2}\sum_{i=N+1}^{N+R} y_{kij} \le 1, \qquad (j=1,2,3,\cdots,N+R, \quad i\ne j) \quad (13)$$

$$\sum_{k=1}^{M_2}\sum_{j=N+1}^{N+R} y_{kij} \le 1, \qquad (i=1,2,3,\cdots,N+R, \quad i\ne j) \quad (14)$$

The total volume of customer demand on each route distributed by the refrigerated vehicle or shuttle van cannot exceed the maximum carrying capacity of a single vehicle. The constraints are expressed as:

$$\sum_{i=0}^{N+R} g_i \sum_{j=0}^{N+R} x_{kij} \le G_1, \qquad (k=1,2,3,\cdots,M_1, \quad i\ne j) \quad (15)$$

$$\sum_{i=0}^{N+R} g_i \sum_{j=1}^{N} y_{kij} \le G_2, \qquad (k=1,2,3,\cdots,M_2, \quad i\ne j) \quad (16)$$

The time for the delivery vehicle to reach the customer site must be within the maximum time window tolerable, and the constraints are expressed as:

$$B_i \le T_i \le E_i, \qquad (i=1,2,3,\cdots,N) \quad (17)$$

The travel distance of each insulated shuttle van cannot exceed L, the longest limit distance. The constraints are expressed as:

$$\sum_{i=N+1}^{N+R}\sum_{j=1}^{N} y_{kij} d_{ij} \le L, \qquad \left(k=1,2,3,\cdots M_2\right) \quad (18)$$

In summary, the mathematical model for optimizing the distribution route of cold chain logistics of produce based on connection points is constructed as follows:

$$
\begin{aligned}
MinC &= Min\{C_1 + C_2 + C_3 + C_4 + C_5\} \\
&= Min\Big\{ \; f_1 \sum_{k=1}^{M_1} sign_1(k) + f_2 \sum_{k=1}^{M_2} sign_2(k) + \sum_{k=1}^{M_1}\sum_{i=0}^{N+R}\sum_{j=0}^{N+R} h_1 x_{kij} d_{ij} \\
&+ \sum_{k=1}^{M_2}\sum_{i=0}^{N+R}\sum_{j=0}^{N+R} h_2 y_{kij} d_{ij} + Pr(Q_0 \sum_{k=1}^{M_1}\sum_{i=0}^{N+R}\sum_{j=1}^{N+R} x_{kij} + Q_1 \frac{\sum_{k=1}^{M_1}\sum_{i=0}^{N+R}\sum_{j=0}^{N+R} x_{kij} d_{ij}}{V} \\
&+ Q_2 \sum_{i=1}^{N} g_i t) + \beta_0 T(\sum_{i=1}^{N} g_i + \sum_{k=1}^{M_2}\sum_{i=N+1}^{N+R}\sum_{j=1}^{N} y_{kij} g_j) + \beta_1 \frac{\sum_{k=1}^{M_1}\sum_{i=0}^{N+R}\sum_{j=1}^{N+R} x_{kij} d_{ij}}{V} \\
&+ \beta_2 \frac{\sum_{k=1}^{M_2}\sum_{i=N+1}^{N+R}\sum_{j=1}^{N} y_{kij} d_{ij}}{V} + w_1 \sum_{i=1}^{N} \max\{b_i - T_i,\ 0\} \qquad + w_2 \sum_{i=1}^{N} \max\{T_i - e_i, 0\} \; \Big\}
\end{aligned}
$$

$$
s.t.\begin{cases}
\sum_{k=1}^{M_1}\sum_{j=1}^{N+R} x_{kij} \le M_1, \quad (i=0) \\
\sum_{k=1}^{M_2}\sum_{j=1}^{N+R} y_{kij} \le M_2, \quad (i=0) \\
\sum_{j=1}^{N+R} x_{kij} = \sum_{j=1}^{N+R} x_{kji} \le 1, \quad (i=0, k=1,2,3,\cdots,M_1) \\
\sum_{k=1}^{M_1}\sum_{i=0}^{N+R} x_{kij} \le 1, \quad (j=1,2,3,\cdots,N+R, \quad i \ne j) \\
\sum_{k=1}^{M_1}\sum_{j=0}^{N+R} x_{kij} \le 1, \quad (i=1,2,3,\cdots,N+R, \quad i \ne j) \\
\sum_{k=1}^{M_2}\sum_{i=N+1}^{N+R} y_{kij} \le 1, \quad (j=1,2,3,\cdots,N+R, \quad i \ne j) \\
\sum_{k=1}^{M_2}\sum_{j=N+1}^{N+R} y_{kij} \le 1, \quad (i=1,2,3,\cdots,N+R, \quad i \ne j) \\
\sum_{i=0}^{N+R} g_i \sum_{j=0}^{N+R} x_{kij} \le G_1, \quad (k=1,2,3,\cdots,M_1, \quad i \ne j) \\
\sum_{i=0}^{N+R} g_i \sum_{j=1}^{N} y_{kij} \le G_2, \quad (k=1,2,3,\cdots,M_2, \quad i \ne j) \\
B_i \le T_i \le E_i, \qquad (i=1,2,3,\cdots,N) \\
\sum_{i=N+1}^{N+R}\sum_{j=1}^{N} y_{kij} d_{ij} \le L, \quad \left(k=1,2,3,\cdots M_2\right)
\end{cases}
$$

(19)

5. Solution of the Model

This model is a vehicle routing problem for cold chain distribution with connection points. It aims at minimizing the total cost of distribution to find the optimal route for distribution and connection. The solution of this model is divided into two steps. The first step is to determine the connection point (at the same time, to determine demand sites that go through this connection point). This connection point and the next-level demand sites delivered through this connection point will be all treated as a virtual customer demand site. And then it seeks the optimal delivery route.

The cluster analysis method and the centre-of-gravity method are the most widely used and effective in site selection. In addition, the genetic algorithm is a global random search algorithm built on the principle of genetic theory and biological evolution theory. It is also a search heuristic algorithm that is often used in the field of artificial intelligence to find the optimal solution. It is widely applied to such fields as function optimization and combinatorial optimization. In this paper, the cluster analysis method and the centre-of-gravity method are used to select the connection point, and the optimal distribution route is searched via the genetic algorithm to solve the model.

1.Determining connection points

When there are more demand points, cluster analysis is used to classify all demand sites into R categories ($R< M_2$). The classification is based on the distance between demand sites. Demand volume of each demand site is used as the weight, and the seed point (center point) for each category is an alternative option for the connection point. When the number of distribution points is in an observable range, combined with the number of insulated shuttle vans, a simple observation and analysis method is generally used to determine the connection points.

2.Searching for the optimal distribution route

(1)Design of genetic algorithm

In genetic algorithm, it is usually difficult to select the crossover probability P_c and mutation probability P_m, often relying on the stupid method of "temptation". When the selection is inappropriate, it will directly affect the effect and convergence of the algorithm. In order to avoid this situation, this paper introduces the method of parameter adaptation in the solution process, based on the actual problems studied and the existing research results. That is, during the solution process, the crossover probability and the mutation probability are constantly changed to adapt to the obtained solution to avoid premature convergence [7].

Coding. The gene encoding method make the sequence number of a distribution point and a demand site into a natural number (an array is a route). 0 represents for the distribution center, 1, 2, 3... for each demand site (A, B, C... for the sequence number above 9). For example, there are 3 vehicles that provide delivery service for 13 demand sites. The randomly generated code is (02C4B5038D70A1690), representing the delivery scheme as shown in Table 1:

Table 1 Meaning of random coding

Vehicle number	Delivery route
Vehicle 1	0-2-12-4-11-5-0
Vehicle 2	0-3-8-13-7-0
Vehicle 3	0-10-1-6-9-0

Vehicle route division. The principle is to first determine the distribution order of demand sites and then divide the delivery routes. For example, there is a chromosome, the code "82719A643B5" represents the order of 11 customers. And the distribution order of customer 9 and customer A can be divided into only two types, either on the same delivery route or not. Since we first determine the customer distribution order and then divide the delivery routes, if customer 9 and customer A are not on a same distribution route, customer A must be the first customer on the next route, while customer 9 is the last customer on the current route. Therefore, the basis for judging whether there should be a division point between customer *i* and *i*+1 is to compare the distribution costs under these two modes without exceeding the maximum load capacity of the vehicle. This division method implies the judgment of the constraints Equation 9 to 17.

Fitness function. Fitness function is defined as follows:

$$Fit_j = \frac{1}{C_j} \qquad j \in \{1, 2, 3, \quad , popsize\} \tag{20}$$

In the above formula, C_j is the value of the objective function corresponding to the *j*-th chromosome in the group, and *popsize* represents the size of the group.

Selection. Assuming that there are *n* individuals in a generation group, in which the fitness of individual *i* is Fit_i, the probability that it is inherited to the next generation can be defined as:

$$P_i = \frac{Fit_i}{\sum_{i=1}^{n} Fit_i} \tag{21}$$

Crossover. The crossover probability P_c is defined as follows:

$$P_c = \begin{cases} K \dfrac{\max(Fit_i, Fit_j)}{\max(Fit_i, Fit_j) - \overline{Fit}} & \max(Fit_i, Fit_j) \geq \overline{Fit} \\ \max(Fit_i, Fit_j) & \max(Fit_i, Fit_j) < \overline{Fit} \end{cases} \tag{22}$$

In the above formula, Fit_i and Fit_j are for the fitness of two intersecting individuals *i* and *j*; $\overline{Fit}$ is the average fitness value in the current group; *K* is the constant coefficient for adjusting the crossover probability and generally takes the value of (0, l) interval.

Variation. The purpose of mutation is to maintain the diversity of gene combinations in chromosome individuals. As with crossover operators, the adaptive mutation probability is defined as follows:

$$P_m = \begin{cases} K \dfrac{\max(Fit_i, Fit_j)}{\max(Fit_i, Fit_j) - \overline{Fit}} & \max(Fit_i, Fit_j) \geq \overline{Fit} \\ \max(Fit_i, Fit_j) & \max(Fit_i, Fit_j) < \overline{Fit} \end{cases} \quad (23)$$

Herein, *K* is the same as the value in Equation 22 for adjusting the constant coefficient of mutation probability.

Terminate evolution. The solution of the genetic algorithm is a cyclic process. It is necessary to set a condition for the termination of the cycle, and set $G_{max,}$ the maximum number of cycles (maximum algebra). When the algorithm cycles to this maximum algebra, the operation stops.

(2) Algorithm design and implementation

When the genetic algorithm is used for route optimization, the encoding, group size and termination of evolution algebra should be determined first. The specific implementation steps are as follows:

Step 1: Coding (using the method described in 4.2.1), dividing the appropriate route to construct chromosomes that satisfy hypothesis 2;

Step 2: Set up the group size *Popsize*, adjust coefficient *K* and terminate the evolution of the maximum algebra G_{max};

Step 3: The 0th generation group (initial group) *P*(0) is generated based on Step 1, algebra t=0;

Step 4: Loop count variable i=1 is initialized;

Step 5: Fitness value *Fit(i)* of the *i*-th individual in this generation is calculated;

Step 6: Make i=i+1, and judge if i<=*Popsize*? If yes, go back to Step 4, otherwise go out of the loop and go to Step 7;

Step 7: According to the *Fit* value, choose to copy and generate all individuals of the next generation in proportion;

Step 8: Calculate crossover probability P_C and adaptive mutation probability P_m;

Step 9: Preserve the crossover and reversal transitions, and generate *P(t+1)* based on P_C and P_m;

Step 10: Calculate the objective function *C* of all individuals;

Step 11: Select and label the individuals that minimize the objective function, i.e., the optimal individual. The evolution algebra accumulates *t=t+1*;

Step 12: Judge if $t < G_{max}$? If yes, then go to Step 4, otherwise terminate and output the result.

6. Case Analysis

1. Source of the data

A dairy company in China's Guangxi distributes bottled fresh milk at a low temperature from its product distribution center to 22 demand sites (including community distribution stations, kindergartens, and milk bars) in urban area in Nanning. The weight of each bottle of fresh milk is approximately 380g, 200mL. It is distributed through standard transfer basket loading, 25 bottles per basket, and the refrigerated transport temperature is 2-6 °C.

The serial number of milk distribution center is 0, and demand sites are numbered 1, 2, ..., 22. The specific address, demand volume, and required time are omitted here.

It checks the shortest route between the distribution points via Baidu map, query the distance of the shortest route between each distribution node as a distribution distance between each node. (In practice, the distance from point A to point B is not necessarily equal to the distance from point B to point A due to the traffic rules. It is to simplify the problem and treat no difference here).

2.Setting up connection points

As the delivery time of fresh milk overlaps with the early morning peak of work, according to the traffic conditions in the urban area of Nanning, the company is recommended to use small electric vehicle to carry out the distribution. It is planned to equip with four motor tricycles of Oulilai brand for connection. This kind of motor tricycle has a small body and is low in price (the total cost for retrofitting a small insulated cargo box does not exceed 5,000 yuan). It is free from traffic charge with a very low running cost. Its carrying capacity is 500Kg, and its continued running mileage is about 50Km after full charge at a normal driving speed of 30Km/h.

It analyzes the distribution of demand sites based on the number of motor tricycles and divides them into four relatively concentrated areas. According to the demand volume of each demand site, four connection points are determined through observation method: v_1, v_5, v_8 and $v_{9.}$

3.Parameter settings

When using genetic algorithm to solve the problem, how to set the parameters is related to the result. In this paper, the parameters of the algorithm are set according to the existing research results (Wang & Sun, 2014; Pan & Gan, 2016). For example, in the research mentioned above, it is considered more appropriate to set the group size as 2 to 3 times of demand sites. There are 22 demand sites in this problem, so the group size of genetic algorithm is set as 44. Other parameter settings and meanings are shown in Table 2:

Table 2 Parameter values and meanings

Parameter	Parameter Value	Parameter Meaning	Parameter	Parameter Value	Parameter Meaning
G_1	2.0	Maximum load of distribution vehicle (T)	t_0	6:00	Starting time for distribution
$G2$	0.5	Maximum load of shuttle van (T)	t	0.001	Unloading speed (h/Kg)
L	50	Maximum travel distance of shuttle van (Km)	h_1	2.1	Running cost of distribution vehicle
V	30	Average speed of distribution vehicle and shuttle van	h_2	0.1	Running cost of shuttle van
P_r	8	Cooling price per unit of energy consumption	f_1	120	Fixed cost of distribution vehicle
Q_0	12	Cooling (energy) consumed for opening distribution vehicle door	f_2	20	Fixed cost of shuttle van
Q_1	2	Cooling (energy) consumed for the compartment door closed per unit time	M_1	3	Number of distribution vehicles
Q_2	40	Cooling (energy) consumed for the compartment door open per unit time	M_2	4	Number of shuttle vans
β_0	9	Cost coefficient of cargo loss of a distribution vehicle for unloading (Yuan/h)	N	22	Number of demand sites
β_1	3	Cost coefficient of cargo loss of a distribution vehicle for transportation (Yuan/h)	$popsize$	44	Group size
β_2	3.5	Cost coefficient of cargo loss of a shuttle van for transportation (Yuan/h)	K	0.5	Adjusted probability coefficient
w_1	5	Penalty coefficient for early arrival	G_{max}	100	Terminating evolutionary algebra
w_2	20	Penalty coefficient for delay	Ch	12	Chromosome length

7. Calculation results

It uses the optimization model of cold chain distribution route established in this paper and the above algorithm to solve the example and calculates with MATLAB programming. After 5 times of random operation on the personal computer, the results are shown in Table 3.

Table 3 Calculation results

Number of runs	1	2	3	4	5
Optimal solution	873.86	868.50	878.27	897.36	870.12

From the calculation results, the total cost of optimal cold chain distribution with connection method for fresh milk is 868.50 yuan, and the distribution plan is: Distribution route of No. 1 refrigerated vehicle: 0-8* (No. 1 tricycle: 8-22-15-20-17-18-8） -19-9*(No. 2 tricycle: 9-2-12-16-9)-21-0; Distribution route of No. 2 refrigerated vehicle: 0-4-1*(No. 3 tricycle: 1-7-14-13-1)-5*(No. 4 tricycle: 5-10-3-11-5) -6-0. A total of 2 refrigerated vehicles and 4 insulated shuttle vans are used, and 4 connection points (v_1, v_5, v_8 and v_9) coincident with demand points are set.

8. Conclusion

This paper constructs the optimization model of distribution route of produce cold chain logistics based on connection points. In the process of cold chain distribution, it sets reasonable connection points and adopts small-sized insulated vans with lower transport cost and cooling cost as shuttles. It treats each connection point as a virtual demand site and makes analysis and solutions on the cold chain logistics VRP as well as its mathematical model under time windows. The result shows that it can effectively reduce distribution costs and improve customer satisfaction by setting connection points and then adopting the connection method in cold chain distribution. In fact, adjusting the required time through communication with customers can reduce penalty cost and increase the use of distribution vehicles and shuttle vans. In addition, with the large increase in customers (demand sites), refrigerated vehicles and shuttle vans can repeatedly distribute with a higher utilization rate, thus can effectively reduce the fixed costs. The connection points mentioned in this paper are all static ones. There is no mention of dynamic connection points. How to define and select dynamic connection points and integrate them into the distribution optimization scheme will be an issue worthy of further study.

This paper discusses the cold chain logistics distribution of agricultural products. In fact, the results of this study can also be applied to other logistics distribution problems, using the connection point distribution mode to achieve the purpose of cost reduction.

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