**Journal of Computer Technology and Applied Mathematics**
**Journal Home: www.jctam.online**
**Vol. 1, No. 3, 2024 | ISSN 3007-4126 (Print) | ISSN 3007-4134 (Online)**

# An Empirical Study on Optimization of Multipath Cold-Chain Delivery Network

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**Abstract:** Distribution of food ingredients for restaurants generally involves the optimization of multi-input and multi-output logistics system of the secondary distribution network. Based on the location distribution of 6 restaurants and the layout of 3 front-end warehouses determined by hierarchical clustering analysis algorithm, the innovative "time-distance saving algorithm", considering the influence of distance and time at the same time, is designed to optimize the design and empirical research on the real delivery routes from the food cold chain distribution center to the front-end warehouses. Using “auto navigation" and comprehensively considering the weighting factors of delivery time and delivery distance, the satisfactory solution of the distribution of multiple actual delivery routes was obtained. The results showed that the total delivery distance and time saving of the optimized cold chain delivery network are significantly better than those of traditional saving algorithms.

**Keywords:** Hierarchical Clustering Analysis Algorithm, Time-distance Saving Algorithm, Cold Chain of Food ingredients, Optimization of Delivery Route, Empirical Analysis.

**DOI:** https://doi.org/10.5281/zenodo.13358817 **ARK:** https://n2t.net/ark:/40704/JCTAM.v1n3a03

## 1 INTRODUCTION

As the pace of work continues to accelerate, people have raised higher demands for the speed at which restaurants serve food. To meet the dining needs of the working class, businesses have set up front-end warehouses to speed up delivery times, storing the necessary ingredients for restaurants in nearby front-end warehouses in advance. This not only greatly reduces delivery times but also decreases the occurrence of ingredient shortages. Achieving refined logistics organization and rapid delivery services within effective time and space to meet the diversified cold chain needs of food ingredients will inevitably place high demands on the operation and management of the cold chain supply chain system. By reviewing published literatures, this article finds that research on food cold chain supply chains starts from a regional distribution center to front-end warehouses and a front-end warehouse to the restaurants, a two-level delivery system and employs different algorithms to reach the goals. These research results have been implemented and applied at different levels in different fields.

In the research of clustering analysis algorithms, Sunil Kumar et al. (2019) put forward a new clustering algorithm called the hybrid clustering algorithm to overcome the defects of low clustering quality in existing clustering algorithms. The algorithm demonstrated certain advantages in accuracy, recovery rate, execution time, and result precision, but its practical application had limitations. Mengsu Zhang et al. (2021) proposed a teaching quality fuzzy comprehensive evaluation model based on the K-means clustering algorithm to address the problems of traditional teaching quality evaluation methods that required substantial human and material resources, and had low evaluation efficiency and accuracy. The experimental results showed that the evaluation method was both fast and accurate. While the aforementioned papers have demonstrated the effectiveness of clustering analysis algorithms from various perspectives, they are limited in their scope of application and do not address practical applications in logistics and distribution network layout design. In contrast, the hierarchical clustering analysis algorithm proposed in this paper aims to fill this gap by providing a more comprehensive and practical approach to these areas.

Regarding delivery route optimization after logistics and distribution nodes have been determined, numerous scholars have employed various algorithms, such as genetic algorithms, ant algorithms, and mileage-saving algorithms, to develop specific route plans for different delivery vehicles. Forouzanfar et al. (2017) investigated the problem of "site selection-routing-inventory" in a multi-period closed-loop supply chain with multiple suppliers, manufacturers, distribution centers, users, and recycling centers, where chain links were multi-level, considering vehicle arrival and departure times to optimize system and operating costs of different chain links. Perez et al. (2016) studied supplier

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selection, the location-inventory at the intermediate level, and the quantity distribution among nodes in a multi-level supply chain. Cordeau et al. (2015) studied the multi-product replenishment and distribution problem in a secondary supply chain composed of suppliers and customers using finite and discrete programming, proposing a three-stage heuristic algorithm based on the decomposition of the supplier's decision-making process. The effectiveness of the method was verified through example analysis, yielding better feasible solutions in a short time. Many papers have investigated delivery route optimization problems in various domains, albeit with differing objectives and outcomes. However, they share practical application shortcomings primarily in two aspects. First, these studies often neglect the complexity of actual road conditions, considering only the distance factor while disregarding random variables such as traffic congestion, the number of traffic lights, delivery time, the car accident, the weather etc., Second, the algorithmic analyses tend to be overly idealized, failing to incorporate electronic map navigation tools that leverage big data, cloud computing, and other advanced information technologies. Consequently, the calculated distances between nodes are not reflective of the actual routes but rather represent straight-line distances, leading to significant deviations from the realities of delivery routes.

In order to more accurately reflect the actual delivery situation, this paper conducts an analysis of the food ingredients need of 6 restaurants, takes the real-time map navigation system based on big data and cloud computing as the research platform, then determines the location of the 3 front-end warehouses through a hierarchical clustering analysis algorithm. On the basis of clustering analysis, the innovative time-distance saving algorithm is designed to solve the optimal daily cold chain delivery route plan for all front-end warehouses.

# 2 DEMAND ANALYSIS OF FOOD COLD CHAIN DELIVERY NETWORK

In order to optimize the delivery network, it is imperative to acquire precise and comprehensive information regarding the demand at each node within the network. This entails conducting a rigorous demand analysis that accurately quantifies and characterizes the demand patterns and requirements at each individual node, ensuring that the delivery network is designed and operated in a manner that is tailored to meet the specific needs and characteristics of each node.

## FACTORS AFFECTING THE TOTAL AMOUNT OF FOOD INGREDIENTS IN THE RESTAURANTS

There are many factors which could affect the demand of the restaurant, such as the total number of people, the fluctuation of the total number of people, and the working hours of people in the area it covers.

# 3 LAYOUT OF COLD CHAIN FOOD INGREDIENT DELIVERY NETWORK

## 3.1 LAYOUT DESIGN OF FRONT-END WAREHOUSE BASED ON HIERARCHICAL CLUSTERING ANALYSIS

Clustering analysis determines the degree of similarity among related characteristics and classifies items with similar traits based on the distance between them. This paper employs the hierarchical clustering algorithm to effectively cluster and partition front-end warehouses in rural and urban areas of Jinan. This approach facilitates the optimal design of various cold chain delivery routes in the subsequent stage.

### 3.1.1 Steps of hierarchical clustering analysis

Let $d_{ij}$ denotes the distance between the study object *Xi* and *Xj*, and $D_{pq}$ denotes the distance between classes $G_p$ and $G_q$. Based on the distance of individual differences of study objects, the shortest distance method is used to measure the clustering of classes in hierarchical clustering analysis. The shortest distance method is to calculate the minimum value of the distance between each study object in one class and each study object in another class, $D_{pq} = \min_{x_i \in G_p, x_j \in G_q} \left\{ d_{ij} \right\}$. Its clustering calculation process is to first calculate the distance between study objects, at this time each sample object can be regarded as a class individually, $D_{pq} = d_{pq}$, so as to derive the sample distance matrix of study objects denoted as $D_{(0)}$. Secondly, find out the minimum element on the non-principal diagonal of the distance matrix $D_{(0)}$ and set it as $D_{pq}$, merge $G_p$ and $G_q$ to record $G_r$ as a new class. Then calculate the distance $D_{rk}$ between $G_r$ and other classes:

$$D_{rk} = \min_{\substack{x_i \in G_r \\ x_j \in G_k}} \left\{ d_{ij} \right\} = \{ \min_{\substack{x_i \in G_r \\ x_j \in G_k}} d_{ij}, \min_{\substack{x_i \in G_r \\ x_j \in G_k}} \} = \min \left\{ D_{pk}, D_{qk} \right\}$$

Record the distance matrix as $D_{(1)}$, then repeat the above process of $D_{(0)}$ for $D_{(1)}$, calculate $D_{(2)}$, further calculate $D_{(3)}$, and so on, and repeat until all the research objects can be classified into one class.

### 3.1.2 Implementation of the results of hierarchical cluster analysis

Through a hierarchical clustering analysis, the design

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can be done by setting up the initial site of the front-end warehouse in the restaurants nearby. Take the real distance between each front-end warehouse and each restaurant is 2-15km as the radiation range, and 3 front-end warehouses are set up, specifically undertake the integrated functional services of warehousing, sorting and distribution of the food ingredients for the 6 restaurants.

The layout of the front-end warehouses is shown in Tab. 2.

**Tab. 2 Layout of front-end warehouse**

| Restaurant No. | Front-end warehouse No. | Distance from DC to front-end warehouse (km) | Distance from front-end warehouse to Restaurant (km) |
|---|---|---|---|
| 01 | C | 38 | 3 |
| 02 | B | 16 | 3.4 |
| 03 | | | 5.1 |
| 04 | | | 2.3 |
| 05 | A | 14 | 5.2 |
| 06 | | | 10 |

## 3.2 Optimal design of delivery route based on time-distance saving algorithm

The fundamental concept of the traditional mileage-saving algorithm in the transportation problem is to iteratively combine two routes into a single route. In this paper, a time-distance saving algorithm was developed to solve the delivery route planning problem.

The main steps of the time-distance saving algorithm are as follows:

Step 1: Definition of algorithm. In a delivery network, multiple delivery routes typically exist between the starting point and the destination. These routes can vary in terms of distance, travel time, the number of traffic lights, transportation costs, and other relevant metrics. The time-distance saving algorithm aims to optimize route selection by balancing the impact of both distance and time on the delivery process. To achieve this, the algorithm employs the "golden section value" of 0.618 to assign a higher priority to the time index, reflecting its greater importance in timely deliveries. Correspondingly, a weight of 0.382 is applied to the distance index. By calculating the "time-distance saving values" for each potential delivery route between the starting point and the destination, the algorithm identifies the route with the minimum value as the optimal path for actual deliveries. This approach ensures an efficient and balanced consideration of both time and distance, leading to improved overall delivery performance.

Step 2: Assumptions. (1) There are several delivery routes from the starting point A to the ending point B; (2) The weight of the food ingredients is less than the load capacity of the truck and the volume of the food ingredients is less than the volume capacity of the truck; (3) All the truck are in good condition, the truck's fuel is unlimited, the driver does not need to rest and there is no traffic accident during the delivery.

Step 3: Definition of variables

(1) There are two delivery routes R1 and R2 between the starting point A and the ending point B. The time and distance required for R1 are t1 and d1 respectively, and the time and distance required for R2 are t2 and d2 respectively;

(2) The time-distance value for Route R1 is expressed as:

$$Vtd1=0.618*t1/(t1+t2) +0.382*d1/(d1+d2)$$

The time-distance value for Route R2 is expressed as:

$$Vtd2 = 0.618*t2/(t1+t2) +0.382*d2/(d1+d2)$$

The variables t1, t2, d1 and d2 above come from real-time data from the navigation, obtained by entering the route from starting point A to ending point B;

If Vtd1<=Vtd2, the actual delivery route is chosen as R1, otherwise R2.

Step 4: Distribution area. This paper divides the delivery network for the cold chain into two parts: Urban area distribution and Rural area distribution.

Step 5: Time-distance saving values of delivery routes. The time-distance saving algorithm is used to calculate the time-distance saving values between the Distribution center X and the the front-end warehouses (A, B, C) are respectively, as shown in Tab. 3.

**Tab. 3 Time-distance saving values of delivery routes**

| Starting and ending point | Route R1 (min, km) | | Route R2 (min, km) | | Time-distance values of R1, R2 | | Preferred route $V_{td} \in \min(V_{td1}, V_{td2})$ |
|---|---|---|---|---|---|---|---|
| | *t1* | *d1* | *t2* | *d2* | $V_{td1}$ | $V_{td2}$ | |
| X-A | 30 | 14 | 32 | 16 | 0.477 | 0.523 | 0.477 |
| A-X | 27 | 14 | 26 | 16 | 0.493 | 0.507 | 0.493 |
| X-B | 30 | 16 | 30 | 20 | 0.479 | 0.521 | 0.479 |
| B-X | 32 | 16 | 28 | 20 | 0.499 | 0.501 | 0.499 |
| A-B | 32 | 25 | 31 | 23 | 0.513 | 0.487 | 0.487 |
| B-A | 35 | 25 | 27 | 23 | 0.548 | 0.452 | 0.452 |
| X-C | 60 | 38 | 65 | 45 | 0.472 | 0.528 | 0.472 |
| C-X | 60 | 38 | 60 | 45 | 0.484 | 0.516 | 0.484 |
| B-C | 70 | 48 | 69 | 50 | 0.498 | 0.502 | 0.498 |
| C-B | 73 | 48 | 65 | 50 | 0.514 | 0.486 | 0.486 |
| A-C | 82 | 60 | 78 | 66 | 0.499 | 0.501 | 0.499 |
| C-A | 85 | 60 | 75 | 66 | 0.510 | 0.490 | 0.490 |

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Step 6: Time-distance saving values of all the circuits of delivery from DC to the front-end warehouses

Based on the values of each delivery route, the circuit X-C-B-A-X has been chosen as the best delivery route between the distribution center and the front-end warehouses.

**Tab. 4 Time-distance saving values of the circuit of delivery from DC to the front-end warehouses**

| Circuit | t(min) | d(km) | Time-distance value |
|---|---|---|---|
| X-A-B-C-X | 191 | 123 | 0.474 |
| X-A-C-B-X | 209 | 140 | 0.526 |
| | | | |
| X-B-A-C-X | 199 | 137 | 0.493 |
| X-B-C-A-X | 202 | 144 | 0.507 |
| | | | |
| X-C-A-B-X | 198 | 143 | 0.528 |
| X-C-B-A-X | 179 | 125 | 0.472 |

Step 7: Time-distance saving values of all the circuits of delivery from the front-end warehouses to the restaurants

**Tab. 5 Time-distance saving values of the circuit of delivery from the front-end warehouses to restaurants**

| Starting and ending point | *t(min)* | *d(km)* | Starting and ending point | *t(min)* | *d(km)* |
|---|---|---|---|---|---|
| A-5 | 20 | 5.2 | B-4 | 6 | 2.3 |
| 5-A | 20 | 5.2 | 4-B | 6 | 2.1 |
| A-6 | 45 | 10 | 2-3 | 40 | 8 |
| 6-A | 43 | 9 | 3-2 | 41 | 7.9 |
| 5-6 | 32 | 8 | 2-4 | 35 | 6 |
| 6-5 | 32 | 7.5 | 4-2 | 38 | 6,5 |
| B-2 | 8 | 3,4 | 3-4 | 37 | 6.5 |
| 2-B | 9 | 3.6 | 4-3 | 38 | 7 |
| B-3 | 17 | 5.1 | C-1 | 6 | 3 |
| 3-B | 15 | 5.3 | 1-C | 6 | 3 |

**Tab. 6 Time-distance saving values of the circuit of delivery from the front-end warehouses to restaurants**

| Circuit | t(min) | d(km) | Time-distance value |
|---|---|---|---|
| A-5-6-A | 95 | 22.2 | 0.495 |
| A-6-5-A | 97 | 22.7 | 0.505 |
| | | | |
| B-2-3-4-B | 91 | 20 | 0.484 |
| B-2-4-3-B | 96 | 21.7 | 0.516 |
| B-3-4-2-B | 101 | 21.7 | 0.506 |
| B-3-2-4-B | 99 | 21.1 | 0.494 |
| B-4-2-3-B | 99 | 22.1 | 0.514 |
| B-4-3-2-B | 94 | 20.8 | 0.486 |
| C-1-C | 12 | 6 | |

Step 8: Comparison of the results of delivery routes

**Tab. 7 Results of delivery routes from the front-end warehouses to restaurants**

| Time-distance saving result | t(min) | d(km) | Time saving result | t(min) | d(km) | Tistance saving result | t(min) | d(km) |
|---|---|---|---|---|---|---|---|---|
| X-C-B-A-X | 179 | 125 | X-C-B-A-X | 178 | 127 | X-C-B-A-X | 187 | 123 |

Through comparing the 3 methods to design the optimal delivery route, we could find that the delivery sequence calculated by the three methods is consistent. However, when the focus shifts from time saving to distance saving, there are certain differences in the route selection between two nodes for the delivery vehicles. When considering the delivery route, we generally take into account the impact of distance and time on delivery. Therefore, the result calculated by this method can ensure that the efficiency of the delivery vehicle is maintained at a high level.

# 4 CONCLUSION

Considering the location, demand, road complexity, vehicle congestion, distance, and other factors of 6 restaurants, this paper employs a clustering analysis algorithm to design the network layout of three front-end warehouses. This approach ensures that the warehouses are strategically placed to maximize efficiency and accessibility. Utilizing the Navigation, the time-distance saving algorithm is then applied to optimize the real delivery routes from the distribution center to all front-end warehouses, enhancing the practicality and effectiveness of the delivery process. The results demonstrate that the layout of the front-end warehouses determined by the hierarchical clustering algorithm effectively meets the actual distribution needs. This method ensures that each warehouse is optimally located to minimize travel distance and time while addressing the specific demands of each restaurant. Furthermore, when compared with two other algorithms, the time-distance saving algorithm shows a significant optimization effect. It notably shortens the delivery distance, reduces time costs and logistics expenses, and achieves the distribution goal of efficient and low-cost cold supply chain management for food ingredients. By implementing the time-distance saving algorithm, the study also highlights improvements in route planning, which account for real-time traffic conditions and road complexities. This dynamic optimization ensures that delivery routes are not only shorter but also more reliable, SUAS Press

leading to consistent and timely deliveries. Additionally, the reduced logistics expenses translate to lower operational costs for the businesses involved, offering a competitive advantage in the food industry. Overall, this integrated approach to locate the warehouse and optimize the route provides a robust framework for managing cold supply chains efficiently and cost-effectively.

## ACKNOWLEDGMENTS

The authors thank the editor and anonymous reviewers for their helpful comments and valuable suggestions.

## FUNDING

Not applicable.

## INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable.

## INFORMED CONSENT STATEMENT

Not applicable.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## AUTHOR CONTRIBUTIONS

Not applicable.

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