Decision Making: Applications in Management and Engineering, Volume 7, Issue 2 (2024) 221-239

SCIENTIFIC OASIS

Decision Making: Applications in Management and Engineering

Journal homepage: www.dmame-journal.org
ISSN: 2560-6018, eISSN: 2620-0104

Logistics Distribution Route Optimization in Artificial Intelligence and Internet of Things Environment

Qianfei Liu[1,*]

[1] School of Economics and management, Jiaozuo university, Jiaozuo, China

ARTICLE INFO

Article history:
Received 12 December 2023
Received in revised form 19 January 2024
Accepted 17 February 2024
Available online 23 February 2024

Keywords:
Artificial intelligence; Internet of Things; Logistics distribution route optimization; Cost-benefit analysis.

ABSTRACT

With the increasing challenges facing the logistics industry, especially in meeting the growing demand for distribution efficiency and accuracy, the use of modern technology to optimize logistics distribution routes has become a key issue. This study explores the application of artificial intelligence (AI) and Internet of Things (IoT) technologies in the optimization of logistics distribution routes. The research first focused on collecting and processing logistics related data, including historical delivery records, real-time traffic data, and cargo tracking information. Then, by building optimization models based on AI and IoT technologies, the study explores the potential of these technologies to improve logistics distribution efficiency and reduce costs. In addition, through cost-benefit analysis and discussion of challenge coping strategies, this study not only verified the effectiveness of the proposed scheme in theory, but also demonstrated its feasibility in practical application. Finally, the study presents implications for industry practice and recommendations for future research, emphasizing the importance of continuous technology evaluation and adaptation to market changes.

1. Introduction

In the field of modern logistics management, the optimization of distribution routes is a key factor to improve efficiency and reduce costs. With the rapid development of e-commerce and the increasing expectations of consumers for fast delivery services, logistics companies are faced with a huge challenge of how to effectively manage transportation costs and time while ensuring service quality. In this context, logistics distribution route optimization has become a crucial research topic. The traditional logistics distribution model usually relies on experience and simple planning algorithm, which is powerless to deal with large-scale and dynamic logistics needs. The complexity of modern logistics systems requires more efficient and intelligent methods to deal with the planning and optimization of distribution routes. This demand has spawned research interest in using artificial intelligence (AI) and Internet of Things (IoT) technologies to enhance logistics distribution route optimization.

[*] *Corresponding author.*
E-mail address: qianfei_liu@outlook.com

https://doi.org/10.31181/dmame7220241072

Artificial intelligence technologies, especially machine learning and deep learning, can predict logistics needs, optimize inventory management, and improve the efficiency of distribution paths by analyzing historical and real-time data. At the same time, IoT technology provides a wealth of real-time data by tracking goods and vehicles in real time, which can be used to optimize delivery routes, reduce delays, and improve customer satisfaction. Therefore, studying how to effectively apply artificial intelligence and Internet of Things technology to logistics distribution route optimization is not only a hot issue in the field of logistics management, but also the key to improve the competitiveness of the logistics industry. The results of this research direction are expected to provide scientific decision support for logistics companies, and then promote the technological progress and economic benefits of the entire industry.

In recent years, many scholars have adopted advanced calculation methods and techniques in the field of logistics distribution route optimization. The study of Bhalotia *et al.,* [1] emphasized the versatility and adaptability of AI and IoT technologies in practical applications, which is particularly important for the study of logistics distribution route optimization. In the field of logistics distribution, AI can be used to analyze and predict the flow of goods and traffic conditions, while IoT devices can monitor the location and status of goods in real time, and the combination of the two provides the possibility to improve logistics efficiency and accuracy. The study also shows the challenges that can be encountered when implementing these technologies, such as data security and privacy issues, which are also important considerations for logistics distribution route optimization. Xin *et al.,* [2] and Gan [3] respectively adopted genetic algorithm and hybrid intelligent algorithm to optimize logistics distribution routes, and these studies demonstrated the effectiveness of genetic algorithm in solving complex optimization problems. In addition, Ma and Wang [4] discussed the optimization of logistics distribution routes based on RFID and sensor technology, highlighting the application of IoT technology in real-time data tracking and processing. This is consistent with the focus of this study, which is to use IoT technology to optimize logistics distribution routes. In terms of using specific algorithms for route optimization, Wu *et al.,* [5] and Liu [6] used improved ant colony algorithm and particle swarm optimization algorithm respectively to prove the effectiveness of these algorithms in optimizing logistics distribution routes. These studies show that the efficiency and accuracy of logistics distribution routes can be significantly improved by adopting different algorithms and technologies. Stopka [7] applied the method of operations research to model the urban logistics distribution path, which emphasized the importance of the method of operations research in dealing with such problems. In addition, for specific types of logistics distribution, such as cold chain logistics, Yu [8] and Yan *et al.,* [9] proposed a cold chain logistics distribution route optimization model based on low-carbon perspective, which provided a new perspective for this study to take environmental factors into consideration. The existing literature shows that the application of artificial intelligence, Internet of Things technology and various optimization algorithms can effectively improve the optimization efficiency of logistics distribution routes. At the same time, these studies also provide valuable theoretical and practical guidance for this research, especially in the aspects of technology selection and algorithm application.

The core purpose of this study is to explore and analyze the application potential and practical effect of artificial intelligence and Internet of Things technology in logistics distribution route optimization. This aim is to solve the problems of low efficiency, high cost and slow response in traditional logistics route planning. By integrating advanced AI and IoT technologies into the planning and optimization of logistics distribution routes, the research aims to propose more scientific, efficient and economical solutions.

The significance of this study is mainly reflected in the following aspects. First, it provides the logistics industry with an innovative route optimization framework that combines the latest technological advances to help improve the efficiency and reliability of the entire logistics system. Second, the research results will help logistics companies reduce operating costs and improve service quality, which is essential to remain competitive in an increasingly competitive market. In addition, from a social perspective, optimizing logistics distribution routes helps to reduce energy consumption and carbon emissions, which is of great significance for promoting sustainable development. In addition, this study will also provide valuable empirical research cases for the academic community. Through in-depth analysis of the application of AI and IoT technology in practical logistics distribution, relevant theories can be enriched and future scientific research and technology development can be guided. In general, this study not only has important guiding value for logistics industry practice, but also provides new research perspectives and ideas for related disciplines.

The content of this study is mainly focused on exploring and analyzing how to optimize the logistics distribution route through artificial intelligence and Internet of Things technology. The study will explore this topic in depth from multiple dimensions, aiming to provide a comprehensive and systematic perspective. The study will first evaluate and analyze the main challenges and problems of current logistics distribution route optimization. This includes a comprehensive assessment of the efficiency, cost and reliability of existing logistics models, as well as the identification of limitations of current methods. Next, the research will delve into the application potential of artificial intelligence technologies, especially machine learning and deep learning, in the optimization of logistics distribution routes. This involves how these technologies can be used to process and analyze large amounts of logistics data, and how to improve the efficiency and effectiveness of logistics distribution based on data-driven insights. In addition, the study will also explore the role of iot technology in improving the efficiency of logistics distribution. This includes analyzing how IoT devices track goods and vehicles in real time, and how that information can be used to optimize delivery routes and adjust shipping plans. Finally, this study will also design and evaluate a series of optimization algorithms designed to integrate the advantages of AI and IoT technologies to provide more efficient, reliable and economical logistics distribution routing solutions. The research will also include empirical testing of these algorithms to verify their effectiveness and feasibility in practical applications.

In general, this study covers all aspects from theoretical exploration to technical application, from algorithm design to empirical verification, aiming to provide a multi-dimensional and in-depth analysis and solution framework for logistics distribution route optimization.

2. Theoretical basis and application

2.1 Overview of artificial intelligence and Internet of Things technology

Ai technology has become a key force transforming multiple industries, especially when it comes to processing complex data and making intelligent decisions. In logistics, AI technologies, especially machine learning and deep learning, are being used to predict demand, optimize inventory management, and increase the efficiency of path planning. By analyzing historical and real-time data, AI can provide insights on things like traffic conditions, the flow of goods, and customer needs, making logistics deliveries more efficient and accurate [10, 11].

Iot technology connects the physical world with the digital world through a network of smart devices and sensors. In the field of logistics, IoT devices can track goods and vehicles in real time, providing real-time data such as location, temperature, speed and other information [12]. For example, an international logistics company deployed IoT sensors to monitor the condition of its transport vehicles and cargo in real time, and this data helped the company optimize delivery routes, improve cargo security and transparency.

The combination of AI and IoT technology applied to logistics distribution route optimization means that a higher level of automation and intelligence can be achieved. The data processing and forecasting capabilities of AI technology, combined with the real-time monitoring and tracking data provided by IoT, provide new possibilities for the optimization of logistics distribution paths [13, 14]. For example, a logistics company used a combination of AI and IoT technologies to effectively reduce delays, reduce costs and improve overall service quality through predictive analytics and real-time tracking.

In short, the application of artificial intelligence and Internet of Things technology in the optimization of logistics distribution routes is not only the embodiment of technological progress, but also the inevitable trend of the logistics industry to adapt to the digital era.

2.2 Application of technology in logistics distribution route optimization

The application of artificial intelligence technology in logistics distribution path optimization is mainly reflected in its data processing and analysis capabilities. By leveraging machine learning and deep learning algorithms, AI is able to learn from historical data and predict future logistics needs to optimize inventory management and distribution plans. For example, AI can analyze the efficiency of distribution over different time periods and predict traffic conditions, thereby providing decision-makers with recommendations for optimizing routes [15, 16]. In addition, AI can identify patterns and trends in complex environments, helping logistics companies respond more effectively to market changes and customer needs.

Logistics information technology is an important technical force in the development of contemporary logistics. The establishment of railway logistics intelligent identification system can not only establish the systematic ground IoT, but also shorten the logistics time, which is an important condition for optimizing railway transport and distribution services [17].

The application of Internet of Things technology in the optimization of logistics distribution routes is mainly reflected in the provision of real-time data and the enhancement of cargo tracking capabilities. By installing IoT sensors on transport vehicles and packages, logistics companies can monitor the location, status and environmental conditions of goods in real time. This real-time tracking capability not only increases the transparency of cargo management, but also makes it possible to adjust shipping routes in real time. For example, in the event of traffic congestion or emergencies, logistics companies can adjust delivery routes based on real-time information to avoid delays.

In addition, the combination of AI and IoT also shows great potential in the optimization of logistics distribution routes. AI algorithms can conduct in-depth analysis based on the large amounts of real-time data provided by IoT devices, enabling more intelligent and automated distribution path planning [18, 19]. For example, AI systems can automatically adjust delivery routes based on real-time traffic data to avoid congested areas, shorten delivery times, and improve customer satisfaction.

However, in practical applications, these technologies also face some challenges and limitations. One is that high-quality data sets are essential for the effective application of AI. The quality and quantity of data collected, especially in a changing logistics environment, can affect the accuracy of forecasts and the effectiveness of decisions. The deployment and maintenance of IoT devices requires significant investment and faces issues such as cybersecurity and data privacy.

To overcome these challenges, logistics companies need to adopt a variety of strategies. For example, by sharing data with partners, more comprehensive data sets can be built, improving the accuracy and applicability of AI models. At the same time, network security measures and data privacy protection are strengthened to ensure the safe operation of IoT devices and the security of data. In addition, through continuous technological innovation and optimization, the stability and efficiency of the system can be improved, and operating costs can be reduced.

To sum up, although the application of artificial intelligence and Internet of Things technology in the optimization of logistics distribution routes faces challenges and limitations, by adopting appropriate strategies and continuous technological innovation, operational efficiency can be effectively improved, costs can be reduced, and customer service quality can be improved, which is of great significance to the development of the logistics industry.

2.3 Limitations and development trends of prior art

When exploring the application of artificial intelligence (AI) and Internet of Things (IoT) technologies in the optimization of logistics distribution routes, it is critical to understand the current limitations of these technologies and their future trends.

While AI technology shows great potential in the field of logistics, it shows limitations when dealing with complex and uncertain environments, especially in dynamically changing logistics scenarios. For example, AI algorithms may not be accurate enough to predict routes affected by weather, traffic congestion, or unexpected events, leading to delivery delays. In addition, small and medium-sized logistics enterprises may face the challenge of high cost of implementing AI technology and insufficient technical expertise [20,21]. To address these issues, logistics companies can work with universities and research institutions to jointly develop customized AI solutions for specific scenarios, and reduce costs and technical barriers through training and technology introduction.

In terms of IoT technology, despite its advantages in real-time data provision and cargo tracking, data security and privacy protection risks are a significant limitation. For example, large amounts of personal and corporate information in logistics processes may be at risk of being hacked or used unauthorised. In response to this challenge, logistics companies need to invest in strengthening cybersecurity measures, such as the use of encryption technologies and firewalls, and develop strict data access and processing policies [22,23]. Maintenance costs and technical support for IoT devices are also a consideration. To solve these problems, logistics companies can consider cooperating with equipment manufacturers to reduce equipment costs and provide technical support.

Looking ahead, as technology advances, the application of AI and IoT technologies in logistics distribution route optimization is expected to become more precise, efficient, and user-friendly. For example, improvements in machine learning algorithms and increased computing power will enhance AI's ability to process complex logistics data and real-time decision-making [24]. At the same time, the development of Internet of Things technology will make equipment more stable and reliable, and data collection and processing more secure and efficient.

To sum up, although existing AI and IoT technologies have certain limitations in the optimization of logistics distribution routes, they are still an important force to promote the development of the field. Future research and practice should focus on the continuous improvement and innovative application of these technologies to achieve long-term sustainable development of the logistics industry.

3. Data collection and processing

3.1 Selection of data sources and types

In the process of data collection and processing, it is crucial to choose the right data source and type. These data will directly affect the accuracy of subsequent analysis and the effectiveness of the optimized model.

(1) Historical delivery records:

Source: Logistics company database

Type: delivery date, time, starting point, end point, delivery duration, type of goods, etc.

Objective: To analyze historical distribution efficiency and identify patterns

(2) Real-time traffic data:

Source: Traffic management system, GPS data

Type: Road congestion, traffic accident, construction information, etc.

Objective: To dynamically adjust delivery routes to avoid delays

Example: A logistics company can effectively avoid delays caused by traffic congestion by integrating GPS and traffic management system data.

Data collection method: API interface is used to obtain data from the traffic management system, and GPS device transmits data in real time.

Data representativeness: reflects the current traffic conditions and is time-sensitive, but may be limited by the frequency of data update.

(3) Cargo tracking information:

Source: IoT devices, RFID tags

Type: Cargo location, temperature, humidity, etc.

Objective: To ensure the safety of goods and update the distribution status in time

Data collection methods: RFID and IoT devices automatically collect and transmit data.

Data accuracy: High accuracy, but may be affected by environmental factors.

(4) Customer feedback data:

Source: Customer service system, online survey

Type: Customer satisfaction, delivery timeliness, service quality feedback, etc

Objective: To improve customer service quality and optimize delivery experience

Data collection method: Through online survey and customer service feedback acquisition, data analysis software processing.

Data representation: reflects customer views, subjective, but essential for service quality assessment.

(5) Market and economic data:

Source: Market Research Reports, public databases

Type: Industry trends, economic indicators, competitor information, etc.

Objective: To understand market dynamics and develop strategic plans

As shown in Table 1 below:

Table 1
Choice of data source and type

Data type	Data attribute	Data sample	Data use
Historical delivery record	Delivery date, time, start and end	2023-06-15, 09:00, City A to City B	Analyze distribution efficiency and identify distribution patterns
Real-time traffic data	Road congestion	Traffic is slow on Section B	Dynamically adjust the delivery path
Cargo tracking information	Cargo location, environmental conditions	The goods are at place C, temperature 10 °C	Ensure the safety of goods, timely update the delivery status
Customer feedback data	Satisfaction evaluation	Customer satisfaction rating: 4.5	Improve service quality and customer experience
Market and economic data	Industry trends, economic indicators	Logistics growth rate: 5%	Understand market dynamics and develop strategic plans

Effective data collection and processing is the basis of optimizing logistics distribution route research to ensure the accuracy and practicability of the research.

3.2 Data preprocessing and cleaning methods

Data preprocessing, including cleaning, conversion, normalization and other steps, aims to remove noise and inconsistency from the original data and improve the quality and availability of data.

(1) Missing value processing:

Specific strategy: For historical data, the time series analysis method is used to predict the missing value; For real-time data, consider using nearest neighbors or interpolation methods to fill in missing values.

Application: Fill in missing delivery times using a time series prediction model in historical delivery records.

(2) Outlier detection and processing:

Specific strategy: Use machine learning algorithms, such as isolated forests, to automatically detect and handle outliers.

Application: Use machine learning models to automatically identify and correct abnormal temperature or humidity readings in cargo tracking information.

(3) Unified data format:

Specific strategy: Use data parsing and transformation tools to unify data formats from different sources.

Application: Dates and times in all historical delivery records are converted to follow the same format (for example, YYYY-MM-DD HH:MM).

(4) Data normalization:

Specific strategy: Data from different sources and types are normalized to ensure that data is compared on the same scale.

Application: MinMax normalization of customer satisfaction scores to range between 0 and 1.

(5) Data integration

Specific strategy: Use advanced data integration tools to integrate data from different sources into a unified data set to ensure data integrity and consistency.

Application: Integrate historical delivery records, real-time traffic data and cargo tracking information into a complete delivery data set, as shown in Table 2 below.

Table 2
Data preprocessing

Data type	Raw data sample	Data processing method	Example of post-processing data
Historical delivery record	2023-06-15 - City A to City B	Fill missing value	2023-06-15, 02:00, City A to City B
Real-time traffic data	Road B, slow	Unified format	Slow traffic on section B
Cargo tracking information	C, -30°C	Outlier processing	C, 10°C
Customer feedback data	Rating: 90/100	Data normalization	Satisfaction: 0.9
Market and economic data	Increase by 5%	Unified format	Growth rate: 5%

Actual data preprocessing and cleaning should be adjusted according to the specific data characteristics and research needs. Processing at this stage is crucial for subsequent data analysis and modeling, ensuring the accuracy and consistency of the data.

3.3 Choice and reason of data analysis method

It is critical to choose the right data analysis methods, which should be able to support in-depth analysis of the collected and pre-processed data to discover insights and patterns that will help optimize the logistics distribution path. Here are the recommended analysis methods for different types of data and the reasons for choosing them.

(1) Descriptive statistical analysis:

Applied to: historical delivery records, customer feedback data

Reason: Through descriptive statistical analysis, you can quickly understand the basic characteristics of the data, such as the average delivery time, the distribution of customer satisfaction, etc., to provide a basis for more in-depth analysis.

(2) Time series analysis:

Apply to: Historical delivery records

Reason: Time series analysis helps to identify trends in distribution efficiency and demand over time for effective resource planning and distribution scheduling.

(3) Cluster analysis:

Used for: cargo tracking information

Reason: Cluster analysis can group goods according to their distribution path or state characteristics, helping to identify similar distribution patterns for more efficient route planning.

(4) Prediction model:

Applied to: historical delivery records, real-time traffic data

Rationale: Predictive models, such as machine learning algorithms, can predict future delivery demand and traffic conditions based on historical data, thus planning the best delivery path in advance.

(5) Association rule mining:

Applied to: historical delivery records, customer feedback data

Reason: Association rule mining can help discover correlations between different variables, such as the relationship between delivery time and customer satisfaction, to guide optimization decisions.

As shown in Table 3 below:

Table 3
Application of data analysis methods

Data type	Data analysis method	Application example	Argument
Historical delivery record	Time series analysis	Analyze the seasonal variation of delivery time	Identify demand trends and optimize resource allocation
Real-time traffic data	Cluster analysis	Group goods according to temperature and humidity data	Optimize distribution strategies for different types of goods
Cargo tracking information	Prediction model	Forecast traffic conditions at different time periods	Plan the best delivery route in advance
Customer feedback data	Descriptive statistical analysis	Analyze the distribution of customer satisfaction	Understand service quality and guide service improvement
Market and economic data	Association rule mining	Explore the relationship between economic index and logistics demand	It provides the basis for the strategy adjustment under the change of market trend

The above table is only an example of the application of data analysis methods. In the actual analysis, the appropriate method should be selected according to the specific characteristics of the data and the research objectives, and it may be necessary to combine multiple methods to obtain a more comprehensive insight. These analysis results will provide important decision support for logistics distribution route optimization.

For example, in the process of conducting cluster analysis, the research can better understand the needs and preferences of different customer groups through more customer feedback data. As shown in Figure 1 below, 10 randomly selected customer data from "Customer Feedback Data" are displayed:

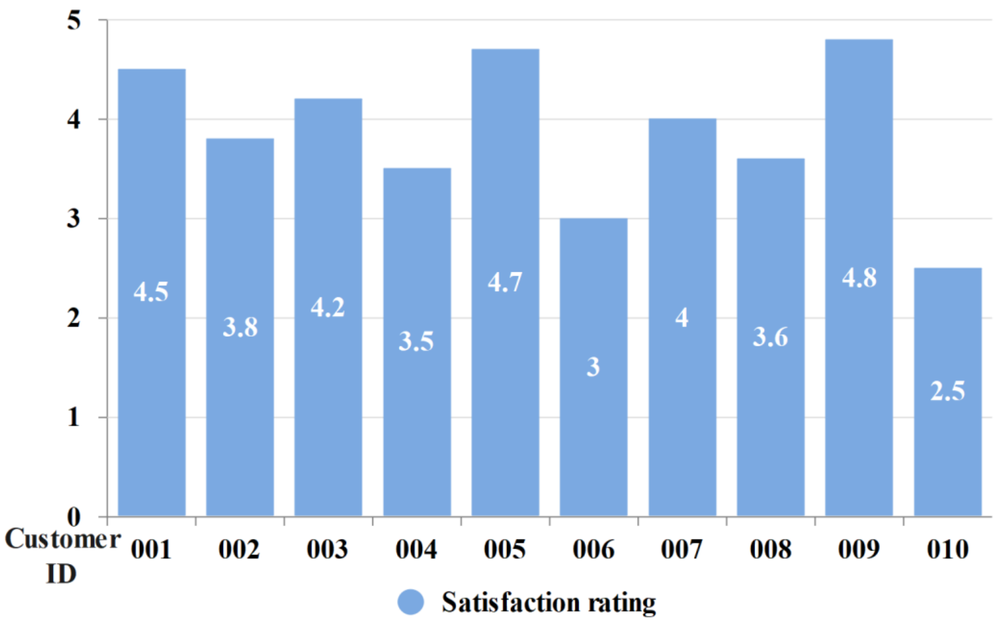

Fig. 1. Analysis of customer feedback data

In this data set, it can be observed that different customers' satisfaction with logistics services, delivery time and delivery quality are different evaluations. This data can be used for cluster analysis to classify customers into different groups based on their satisfaction and service ratings. For example, studies may find that highly satisfied groups generally rate delivery timeliness and quality higher, while low-satisfied groups may rate these aspects lower. Such analysis helps logistics companies better understand customer needs and adjust service strategies according to the characteristics of different groups.

4. Optimization model of logistics distribution route

4.1 Theoretical basis of model construction

It is one of the core tasks to construct an effective logistics distribution route optimization model. The theoretical basis of this model mainly includes optimization theory of operations research, graph theory, and machine learning algorithms. The following is the theoretical basis of the model construction:

(1) Application of graph theory in path optimization:

The logistics network is abstracted as a Graph, where Nodes represent distribution centers, warehouses or customer locations, and Edges represent possible distribution paths. Suppose an expression, as shown in Eq. (1):

$$G = (N, E) \tag{1}$$

Where N is the node set and E is the edge set.

Graph theory provides a way to represent and analyze a logistics network to find the most efficient distribution path.

(2) Optimization theory in operations research:

Use linear programming, integer programming and other methods in operations research to minimize logistics costs or maximize efficiency.

The objective function can be represented by the following Eq. (2):

$$\min \sum_{(i,j)\in E} c_{ij} x_{ij} \tag{2}$$

Where c_{ij} is the cost from node i to node j, and x_{ij} is the decision variable, indicating whether the path is chosen.

This theory provides a mathematical model for the optimization of logistics distribution path, and the optimal solution is obtained by solving the model.

(3) Application of machine learning algorithm:

Use machine learning algorithms, such as random forests and neural networks, to analyze historical data and predict future demand and traffic conditions.

For example, a prediction model using the random forest algorithm can be represented as follows in Eq. (3):

$$y = f(X; \Theta) \tag{3}$$

Where X is the input feature set, y is the predicted output, and Θ is the model parameter.

Machine learning algorithm can improve the intelligence and accuracy of path optimization decision, as shown in Table 4 below.

Table 4
Theoretical basis of model construction

Data type	Data sample	Application analysis
Graph theory	Node: A, B, C; Side: A-B, B-C	Represents the structure of the logistics network
Optimization theory	Cost: A-B:10, B-C: 15	Minimize delivery costs
Machine learning	Data on demand, traffic conditions, etc.	Anticipate future demand and traffic changes

The above table shows the theoretical basis of logistics distribution route optimization model construction and its application in data. In the actual research, according to the specific data characteristics and optimization goals, it may be necessary to use these theories and methods to build more accurate and applicable models. The application of these theories not only improves the optimization efficiency of logistics distribution routes, but also provides scientific basis for decision-making.

4.2 Detailed model construction steps

Combined with data collection and processing and theoretical basis, the research can describe in detail the construction steps of logistics distribution path optimization model.

(1) Define model parameters and variables:

There are three distribution centers (A, B, C) and two customer locations (X, Y).

Let d_{ij} represent the distance from location i to location j, and c_{ij} represent the corresponding cost.

Decision variable: Let x_{ij} be a binary variable, $x_{ij} = 1$ if the path from i to j is selected, otherwise it is 0.

(2) Construct the objective function:

Purpose: Minimize total delivery costs.

The mathematical expression is shown in Eq. (4) below:

$$\min \sum_{(i,j)\in E} c_{ij} x_{ij} \tag{4}$$

Where E is the set of all possible paths.

(3) Set constraints:

Constraint type: Ensure that each customer is visited once and that the total amount of goods departing from each distribution center does not exceed its capacity.

Mathematical expression: For each customer k, the following Eq. (5) is shown:

$$\sum_{i\in N} x_{ik} = 1 \tag{5}$$

Where N is the set of all nodes. For each distribution center j, $\sum_{k\in C} q_k x_{jk} \le Q_j$, where C is the collection of customers, q_k is the demand of customers k, and Q_j is the capacity of distribution center j.

(4) Integrating machine learning prediction results:

Data application: Use predictive models to predict future demand and traffic conditions.

Integrated approach: Dynamically adjust c_{ij} (cost) based on forecast results to reflect real-time traffic conditions and demand changes.

(5) Solving model:

Methods: Suitable optimization algorithms, such as linear programming and integer programming, were used to find the path with the lowest cost.

Implementation: For example, models can be solved using the PuLP library in Python or other optimization tools.

These steps demonstrate the entire process from defining parameters and variables to constructing objective functions and constraints, to integrating predictions and solving models, ensuring the comprehensiveness and usefulness of the models, especially in specific scenarios.

4.3 Verification and testing methods of the model

In this study, validating and testing the optimization model was a key step to ensure its validity and reliability. Model validation and testing involves not only the accuracy of mathematical calculations, but also the evaluation of the performance of the model in practical applications.

(1) Cross verification

The purpose is to evaluate the performance of the model on unseen data and ensure that the model has good generalization ability. The process is to divide the data set into a training set and a test set, and evaluate the model on the test set after training.

The mean square error (MSE) is used as the performance indicator, as shown in the following Eq. (6):

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2 \tag{6}$$

Where y_i is the actual value in the test set and $\hat{y}_i$ is the predicted value of the model.

The actual delivery cost with 5 data points is $[10,12,15,11,13]$ respectively, and the cost predicted by the model is $[11,12,14,12,14]$.

Calculat $MSE = \frac{1}{5}[(10-11)^2 + (12-12)^2 + (15-14)^2 + (11-12)^2 + (13-14)^2] = 1.6$.

As shown in Figure 2 below:

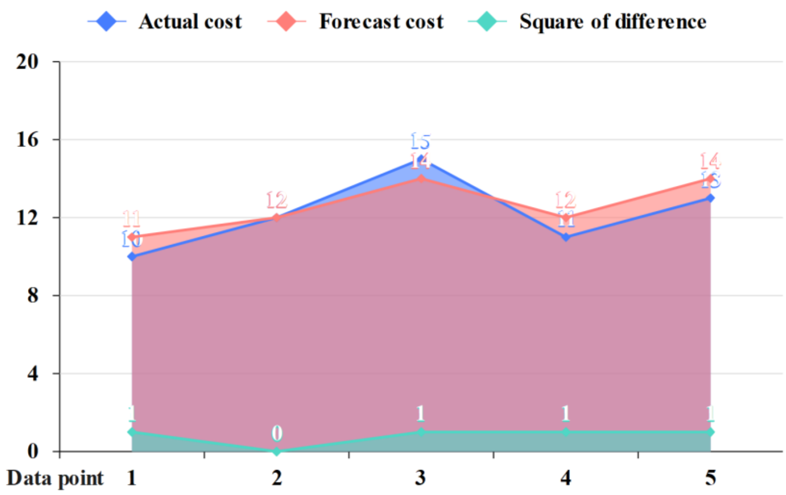

Fig. 2. Cross-validation results

(2) Sensitivity analysis

The goal is to evaluate the model's response to changes in key parameters, such as cost increases, demand changes, etc. The process is to change the value of one or more parameters and observe the effect on the optimization result.

For example, consider the increase in cost, let the original cost $c_{ij} = 10$, increase by 10% to become $c'_{ij} = 11$.

Observe the change of the objective function, as shown in the following Eq. (7):

$$\Delta = \min \sum c'ijxij - \min \sum c_{ij} x_{ij} \tag{7}$$

For example, let the total cost of the original optimization result be 50, and the total cost after a 10% increase in cost is 55. Calculate the cost change $\Delta = 55 - 50 = 5$.

Practical case: Evaluate the sensitivity of the model to cost fluctuations by analyzing cost changes in real logistics operations, considering cost increases.

(3) Scene simulation

The goal is to test how the model performs under different operating conditions or assumptions. The process is to create different logistics scenarios (such as seasonal high demand, special weather conditions) and observe how the model performs under each scenario.

In a high-demand scenario, the demand q_k increases. For example, the original demand $q_k = 10$ increases to $q'_k = 15$.

Recalculate the optimization results and observe the cost changes.

For example, if the original total cost is 50, the total cost after the increase in demand is 60. Calculate the cost change.

Real-world cases: Create logistics scenarios based on seasonal high demand or special weather conditions, and use the model to calculate optimization results to evaluate the model's adaptability under actual changing conditions.

(4) Practical application test

The aim is to assess the effectiveness and accuracy of the model under real world conditions. The process is to apply the model in the actual logistics operation, collect data, and compare the predicted results with the actual results.

Compare the actual delivery cost and time with the model prediction.

For example, let the average delivery time predicted by the model be 2 hours, and the actual average delivery time be 1.8 hours. Calculate the time difference $\Delta = 2 - 1.8 = 0.2$ hour.

Actual case: Select the logistics distribution within a certain period of time as a test case, and compare the delivery cost and time predicted by the model with the actual data to verify the accuracy of the model.

Through these validation and testing methods, the performance of the model can be comprehensively evaluated, including its accuracy, robustness, and adaptability. This not only helps to improve the accuracy of the model, but also enhances its usability and effectiveness in real logistics operations.

5. Technical evaluation and strategy analysis

5.1 Feasibility analysis of technical solutions

In this study, the feasibility analysis of the technical solution is a key step to ensure that the proposed solution is both practical and efficient. This analysis considers not only the effectiveness of the technology, but also the cost, difficulty of implementation, and potential risks.

Feasibility analysis model:

(1) Cost-benefit analysis

Specific scenario: Assume that the technical solution is applied to a large-scale cross-city logistics distribution network.

Compare the total cost of implementing a new technology solution with the economic benefits it brings.

Assuming that the technology implementation cost is C_{tech} and the expected cost savings is S_{save}, the cost-benefit ratio is Eq. (8):

$$CE = \frac{S_{save}}{C_{tech}} \tag{8}$$

If the technology implementation cost is 100,000 units and the expected cost savings are 150,000 units, then $CE = \frac{150,000}{100,000} = 1.5$.

(2) Implementation difficulty assessment

Specific scenarios: Consider the difficulty of implementing technical solutions in logistics centers of different sizes.

Assess the complexity of the technical solution implementation, including the level of technology required, time and resources.

The implementation difficulty index is set as D_{index}, weighted according to different factors. Considering the technical complexity, time requirements and resource requirements, the following Eq. (9) is shown:

$$D_{index} = 0.4 \times technicalcomplexity + 0.3 \times timerequirements + 0.3 \times resourcerequirements \tag{9}$$

(3) Risk assessment

Specific scenarios: Consider the impact of operational errors and data security issues in different types of logistics operations.

Assess the possible risks associated with the implementation of new technologies, such as operational errors, data security issues, etc.

Set the risk level as R_{level}, weighted according to potential risk factors. The following Eq. (10) is shown:

$$R_{level} = 0.5 \times \ Operational\ risk + 0.5 \times \ Data\ security\ risk \tag{10}$$

The risk level is shown in Table 5 below.

Table 5
Feasibility analysis

Evaluation item	Argument	Value	Instructions
Cost-benefit analysis	C_{tech}	100,000	Technology implementation cost
	S_{save}	150,000	Expected cost savings
	CE	1.5	Cost-benefit ratio
Implementation difficulty evaluation	Technical complexity	intermediate	Technical implementation difficulty
	Time requirement	high	Time required for technology implementation
	Resource demand	intermediate	Resources required for implementation
	D_{index}	Calculated value	Comprehensive implementation difficulty index
Risk assessment	Operational risk	intermediate	Operational risks during implementation
	Data security risk	high	Potential data security issues
	R_{level}	Calculated value	Comprehensive risk level

The total cost, difficulty and potential risk of implementing the new technology are calculated. As shown in Figure 3 below:

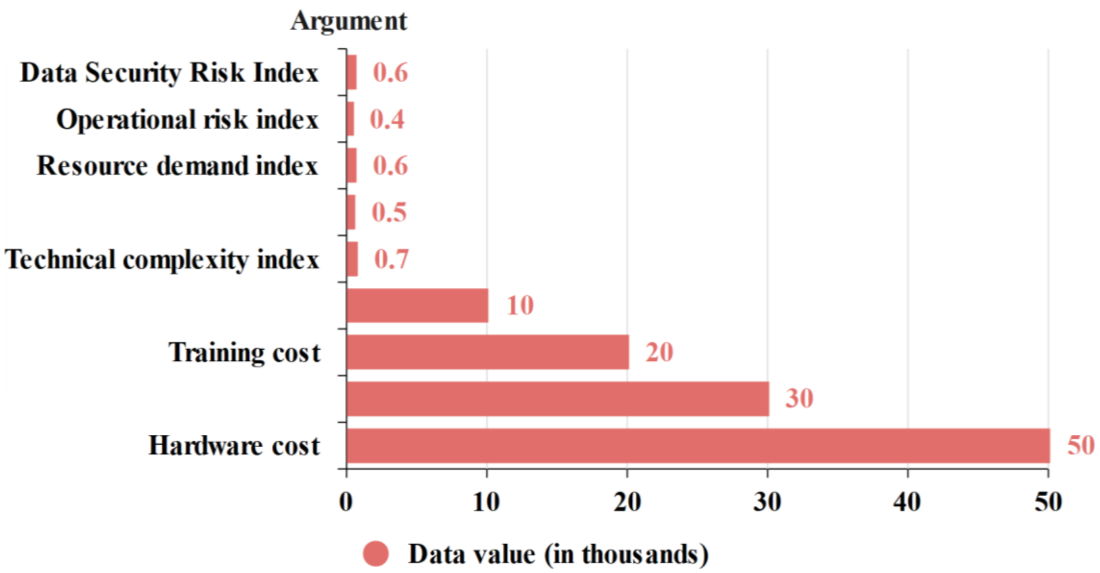

Fig. 3. Feasibility analysis

Through such feasibility analysis, the feasibility of technical solutions in specific logistics scenarios can be comprehensively evaluated. This not only helps to ensure that the program can achieve the desired goal, but also helps to effectively control the cost and risk. This comprehensive evaluation provides reliable data support for decision-making in the field of logistics.

5.2 Cost-benefit analysis of the strategy

When conducting the cost-benefit analysis of the strategy, the key is to evaluate the economic benefits that the proposed optimization strategy can bring compared with the existing methods. This includes a comparison between the cost of implementing the optimization strategy and its expected savings in operating costs.

Cost-benefit analysis model:

The purpose is to evaluate the economic benefits after the implementation of the new strategy and ensure the rationality of investment. The process includes calculating the total cost of implementing the policy and the expected savings in operating costs. The cost-benefit ratio (CER) is calculated as follows Eq. (11):

$$CER = \frac{S_{save}}{C_{impl}} \tag{11}$$

Where S_{save} indicates the expected operating cost savings, and C_{impl} indicates the policy implementation cost.

Let the policy implementation cost (including technical input, training, etc.) be $C_{impl} = 200,000$ unit. The expected annual operating cost savings through optimized delivery routes are $S_{save} = 300,000$ units.

Calculate $CER = \frac{300,000}{200,000} = 1.5$.

As shown in Figure 4 below:

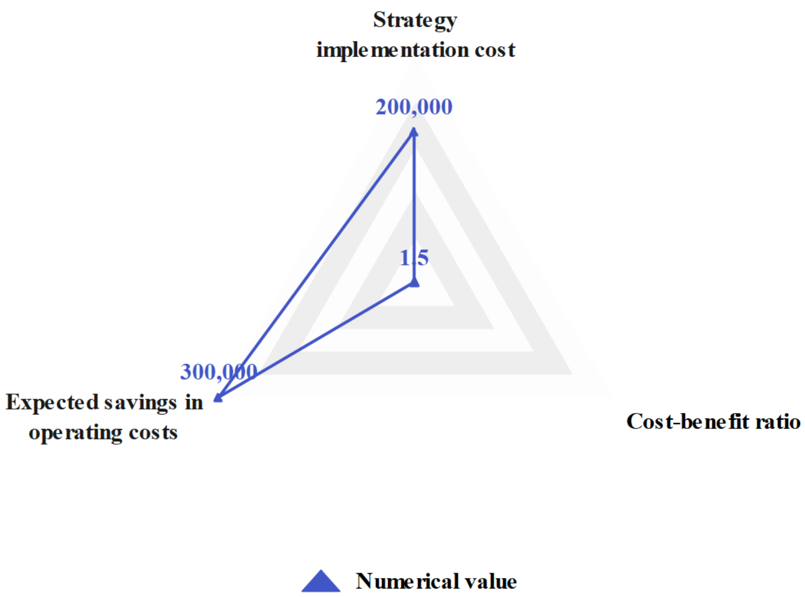

Fig. 4. Cost-benefit analysis

This cost-benefit analysis aims to demonstrate the economic viability of the new strategy. In this example, a value of CER greater than 1 indicates that the expected savings in operating costs exceed the total cost of implementing the new strategy, indicating that the strategy is economically viable. However, it is important to note that this analysis should consider all relevant costs and benefits, both direct and indirect, as well as possible long-term effects. In addition, the cost-benefit analysis should also take into account any non-financial benefits or costs, such as increased customer satisfaction, enhanced brand value, etc.

Long-term cost-benefit projections:

Objective: To assess the economic viability of the project in the next few years.

Methods: The net present value (NPV) for the coming years was calculated using the discounted cash flow analysis method.

Case application: Assuming the same annual operating cost savings over the next 5 years, discount using an appropriate discount rate, taking into account the time value of the funds. The calculated NPV will provide an assessment of the long-term economic benefits of the project.

5.3 Challenges and potential solutions

In the process of research, there are many challenges. The following are detailed descriptions of these challenges and potential solutions:

(1) Quality and integrity of data

In-depth analysis: Inaccurate or incomplete data can lead to biases in the analysis results, affecting the effectiveness of the optimization model. Especially in the dynamic logistics environment, real-time updates and accuracy of data are crucial.

Specific solution strategy: Implement regular data quality audit and monitoring procedures to ensure the reliability of data sources. Introduce automated data cleaning tools, such as missing value filling and outlier detection using machine learning algorithms, as well as regular data quality reporting.

(2) Complexity of technology implementation

In-depth analysis: For semes with limited resources, building and implementing a complex system that incorporates AI and IoT can be very challenging.

Specific solution strategy: Adopt modular design, so that the system can be implemented in stages. Provide customized technology solutions for semes to reduce the complexity of implementation. Establish training courses and technical support to improve the technical capabilities of the enterprise.

(3) Cost and budget constraints

In-depth analysis: Even if the strategy is economically viable, high initial investment and operating costs can be a barrier to implementation.

Specific solutions: Explore multiple funding channels, such as government funding, co-investment or crowdfunding. Implement cost control measures such as reducing operating costs by automating and optimizing processes.

(4) Technical update and maintenance

In-depth analysis: The rapid development of technology requires constant updates and maintenance to maintain the advanced nature and security of the system.

Specific solution strategy: Establish a multidisciplinary technical team responsible for the continuous monitoring and updating of the system. Communicate regularly with external experts and suppliers to keep abreast of the latest technology trends and best practices.

(5) User acceptance and training needs

In-depth analysis: The implementation of new technologies can meet resistance from employees and management, especially when it requires new operational skills and ways of working.

Specific solutions: Implement a comprehensive training program covering the operation and application of the new technology. Improve employee awareness and acceptance of technology through internal communication and training. Win management support through case studies and performance demonstrations.

Through these specific analyses and strategies, the challenges encountered in the implementation of AI and IoT technologies can be more effectively addressed, the logistics distribution path can be optimized, and the successful implementation of the project can be ensured.

6. Conclusions

Through the comprehensive application of the latest technology and theory, a set of optimization scheme and method is proposed. The research results show that the use of artificial intelligence and iot technology can significantly improve the efficiency and accuracy of logistics distribution routes. Through the collection, pre-processing and analysis of a large amount of data, as well as the construction and testing of optimization models, this study not only verified the effectiveness of the proposed scheme in theory, but also demonstrated its feasibility and value in practical application through cost-benefit analysis and discussion of challenge coping strategies.

For industry practice, this study provides a new perspective: integrating advanced technologies to solve traditional problems in logistics distribution. It shows how AI and iot can be leveraged to make data-driven decisions, optimize operational efficiency and cost control. At the same time, this study also reveals the challenges of implementing new technologies and provides a reference for the industry to implement new technology strategies. The future development of the logistics industry will be more dependent on the innovation and application of technology. For example, by further merging machine learning and IoT technologies, we can expect greater advances in automation, intelligent route planning, and real-time data processing. At the same time, I believe that with the continuous development of technology, the future logistics system will be more flexible and adaptable, and better able to cope with the rapid changes and uncertainties in the market.

Explore more applications of artificial intelligence algorithms in logistics data analysis, especially in improving prediction accuracy and decision-making efficiency. The innovative application of Internet of Things technology in real-time data acquisition and processing is further studied to enhance the dynamic response capability of the system. Take into account the impact of technology iterations and market changes, and conduct ongoing cost-benefit analysis and technology evaluation to keep the strategy forward-looking and adaptable.

In summary, this study not only provides a set of practical technical solutions for the optimization of logistics distribution routes, but also provides a valuable reference for technological innovation in the logistics industry, and points out the direction for future research and practice.

Funding
This research received no external funding.

Data Availability Statement
The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Conflicts of Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement
This research was not funded by any grant.

References

[1] Bhalotia, N., Kumar, M., Alameen, A., Mohapatra, H., & Kolhar, M. (2023). A Helping Hand to the Elderly: Securing Their Freedom through the HAIE Framework. Applied Sciences, 13(11), 6797. https://doi.org/10.3390/app13116797

[2] Xin, L., Xu, P., & Manyi, G. (2022). Logistics distribution route optimization based on genetic algorithm. Computational Intelligence and Neuroscience, 2022, ID 8468438. https://doi.org/10.1155/2022/8468438

[3] Gan, Q. (2022). A logistics distribution route optimization model based on hybrid intelligent algorithm and its application. Annals of Operations Research, 1-13. https://doi.org/10.1007/s10479-022-04854-6

[4] Ma, X., & Wang, F. (2022). Logistic Distribution Route Optimization Based on RFID and Sensor Technology. Wireless Communications and Mobile Computing, 2022, ID 7599539. https://doi.org/10.1155/2022/7599539

[5] Wu, D., Zhu, Z., Hu, D., & Mansour, R. F. (2022). Optimizing Fresh Logistics Distribution Route Based on Improved Ant Colony Algorithm. Computers, Materials & Continua, 73(1), 2079-2095. https://doi.org/10.32604/cmc.2022.027794

[6] Liu, W. (2020). Route optimization for last-mile distribution of rural e-commerce logistics based on ant colony optimization. IEEE Access, 8, 12179-12187. https://doi.org/10.1109/ACCESS.2020.2964328

[7] Stopka, O. (2022). Modelling Distribution Routes in City Logistics by Applying Operations Research Methods. Promet-Traffic&Transportation, 34(5), 739-754. https://doi.org/10.7307/ptt.v34i5.4103

[8] Yu, L. (2021). A route optimization model based on cold chain logistics distribution for fresh agricultural products from a low-carbon perspective. Fresenius Environmental Bulletin, 30(2), 1112-1124.

[9] Yan, L., Grifoll, M., & Zheng, P. (2020). Model and algorithm of two-stage distribution location routing with hard time window for city cold-chain logistics. Applied sciences, 10(7), 2564. https://doi.org/10.3390/app10072564

[10] Liu, B. B. (2021). Logistics distribution route optimization model based on recursive fuzzy neural network algorithm. Computational Intelligence and Neuroscience, 2021, ID 3338840. https://doi.org/10.1155/2021/3338840

[11] Zhao, J., Xiang, H., Li, J., Liu, J., & Guo, L. (2020). Research on logistics distribution route based on multi-objective sorting genetic algorithm. International Journal on Artificial Intelligence Tools, 29(7-8), ID 2040020. https://doi.org/10.1142/S0218213020400205

[12] Li, X. (2022). Multiparty coordinated logistics distribution route optimization based on data analysis and intelligent algorithm. Journal of Sensors, 2022, ID 6053332. https://doi.org/10.1155/2022/6053332

[13] Liu, D., Hu, X. L., & Jiang, Q. (2023). Design and optimization of logistics distribution route based on improved ant colony algorithm. Optik, 273, ID 170405. https://doi.org/10.1016/j.ijleo.2022.170405

[14] Sun, Q., Zhang, H., & Dang, J. (2022). Two-stage vehicle routing optimization for logistics distribution based on HSA-HGBS algorithm. IEEE Access, 10, 99646-99660. https://doi.org/10.1109/ACCESS.2022.3206947

[15] Xiong, H. (2021). Research on cold chain logistics distribution route based on ant colony optimization algorithm. Discrete Dynamics in Nature and Society, 2021, ID 6623563. https://doi.org/10.1155/2021/6623563

[16] Ouyang, F. (2020). Research on port logistics distribution route planning based on artificial fish swarm algorithm. Journal of Coastal Research, Special Issue 115, 78-80. https://doi.org/10.2112/JCR-SI115-023.1

[17] Cui, H. X., Qiu, J. L., Cao, J. D., Guo, M., Chen, X. Y., & Gorbachev, S. (2023). Route optimization in township logistics distribution considering customer satisfaction based on adaptive genetic algorithm. Mathematics and Computers in Simulation, 204, 28-42. https://doi.org/10.1016/j.matcom.2022.05.020

[18] Yu, X. S. (2019). On-line ship route planning of cold-chain logistics distribution based on cloud computing. Journal of Coastal Research, Special Issue 93, 1132-1137. https://doi.org/10.2112/SI93-164.1

[19] Zheng, H. Y., Gao, J., Xiong, J. X., Yao, G. L., Cui, H. J., & Zhang, L. R. (2022). An enhanced artificial electric field algorithm with sine cosine mechanism for logistics distribution vehicle Routing. Applied Sciences-Basel, 12(12), 6240. https://doi.org/10.3390/app12126240

[20] Luo, L. L., & Chen, F. (2022). Multi-objective optimization of logistics distribution route for industry 4.0 using the hybrid genetic algorithm. IETE Journal of Research. https://doi.org/10.1080/03772063.2022.2054869

[21] Cai, L. Y. (2023). Decision-making of transportation vehicle routing based on particle swarm optimization algorithm in logistics distribution management. Cluster Computing-The Journal of Networks Software Tools and Applications, 26(6), 3707-3718. https://doi.org/10.1007/s10586-022-03730-z

[22] Li, S., Zhang, H. H., Li, Z. L., & Liu, H. (2021). An air route network planning model of logistics UAV terminal distribution in urban low altitude airspace. Sustainability, 13(23), 13079. https://doi.org/10.3390/su132313079

[23] Liu, L., Su, B., & Liu, Y. (2021). Distribution route optimization model based on multi-objective for food cold chain logistics from a low-carbon perspective. Fresenius Environmental Bulletin, 30(2), 1538-1549.

[24] Zhao, Z. X., Li, X. M., Zhou, X. C. (2020). Distribution route optimization for electric vehicles in urban cold chain logistics for fresh products under time-varying traffic conditions. Mathematical Problems in Engineering, 2020, ID 9864935. https://doi.org/10.1155/2020/9864935