Erasmus University Rotterdam

MSc in Maritime Economics and Logistics

2022/2023

Research on banana cold chain transportation network and route optimization based on transportation time and cargo loss constraints

by

Xiaowen Li

Copyright © [Xiaowen Li]

Acknowledgements

It was a wonderful thing to meet MEL, from a professional point of view, it made me more professional and precise in the logistics industry that I love, and it also made me realize the magic of sea freight, which I had never encountered before. At the same time, it has brought me a lot of interesting partners, where I have met good friends in life, good partners in the profession, and leaders in the field. Not only did I learn about the classes, but I also benefited a lot from attending many career lectures at MEL.

First of all, I would like to thank the supervisor of my Thesis, Professor Rommert Dekker, who is a very knowledgeable scholar and a very patient and professional lecturer. I could see the depth of his expertise in the field and his love for the subject, both in his classes and in the meetings where I communicated my thesis, and his lectures were always very lively and interesting. I learned a lot about the methods and skills of thesis writing, as well as research methods, and I am very grateful to him for his support.

In addition, I would like to thank MEL office and all the workers for escorting our learning and providing high-quality guarantee for all our study life, they will always answer our questions and solve the difficulties encountered in our learning, and they are the ones who ensure the brilliance of MEL.

Secondly, I would like to thank my family for supporting me in everything I do, and supporting me to come to the Netherlands to start my new life. I would also like to thank my lover Star, a worker in the logistics industry, who gave me confidence at all times during my dissertation, and who always discussed my study life with me, my future career path, and provided me with great moral support. Finally, I would like to thank my best friend, Huiming, who I received the news of her death during the writing of my dissertation, which made me very sad, it always reminds me of the fact that I have been with her every time I encounter difficulties and setbacks, and I have taken the trouble to listen to me tell me about my troubles, and it has become a star that continues to accompany me in the present and future, I hope you all well in heaven.

Life is like a box of chocolate, you never know what the next piece will taste like, thank you to all of you for your company and support, and wish everyone a better future.

Abstract

Refrigerated containers have many advantages such as convenient operation, good temperature control and high cleanliness, and are widely used in cold chain logistics. With the continuous rise of refrigerated container shipping volume, the scientific and reasonable design of refrigerated container shipping network to meet the transportation needs of refrigerated containers has become one of the urgent problems to be solved by container liner companies. In addition, the transportation efficiency and preservation of fresh goods will directly determine the revenue level and market share of cargo owners, and how to reasonably formulate the optimal refrigerated container shipping route according to the existing shipping network has become the most concerned issue for cargo owners. Transit time is the most important indicator for evaluating the efficiency of cold chain logistics, and it is also the main consideration for container liner companies to design maritime networks and cargo owners to develop transportation plans. Therefore, according to the transportation requirements and characteristics of refrigerated containers, this research considers the transportation time constraints, and studies the optimization of refrigerated container shipping network and the selection of maritime routes. Firstly, the concept and characteristics of container shipping network are clarified, and the role of ports, container liner companies, cargo owners and other factors in container shipping network is summarized. The transportation conditions and quality changes of fresh goods were analyzed, and the transportation time composition of refrigerated containers was analyzed based on the shipping process of refrigerated containers. Secondly, considering that the total cost of cargo owners is the smallest, and the transportation time, supply and demand balance and the reefer container capacity of the route are the main constraints, the optimization model of the reefer container shipping route is constructed, and the optimal shipping route of refrigerated container based on fixed shipping network is solved. Taking banana transportation from Ecuador as an example, the practicality of the optimization model is verified.

The reefer container shipping network optimization model proposed in this research can provide a theoretical basis for container liner companies to design routes, the reefer container shipping route optimization model can provide technical support for cargo owners to formulate reefer container shipping routes, and the research results of this research can also provide reference for the cold chain infrastructure construction of ports.

Content

List of figure

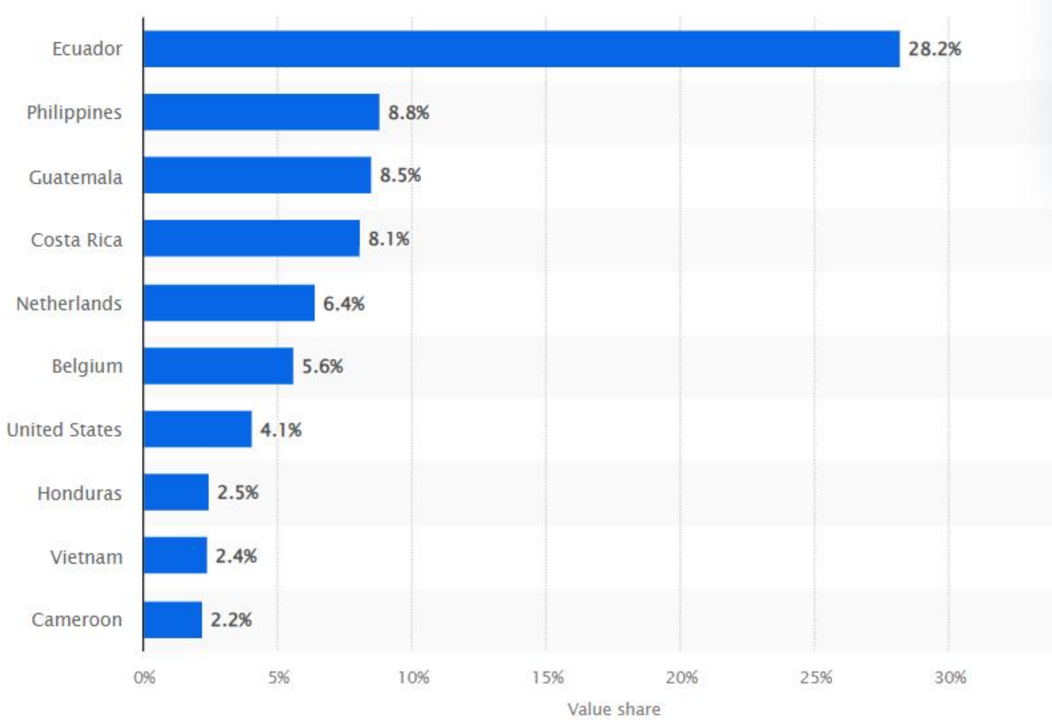
List of table

Chapter 1 Introduction

1.1 Background

Ecuador is a major banana grower and exporter worldwide. As shown in Figure 1, Ecuador ranked first in the world with 28.2% of the value share of the world's major banana exporters in 2022. According to the statistics of the National Banana Programme of Ecuador in 1998, there are 4,941 banana plantations in Ecuador, which are basically operated by 100% domestic capital, and the proportion of foreign capital in Ecuador's banana cultivation industry is negligible. Of these, the vast majority of plantations are between 1 hectare and 30 hectares in size. The banana industry in Ecuador, n.d.)
The traditional export markets for Ecuadorian bananas for a long time are the United States and European Union countries, and bananas exported to these two regions have always accounted for about 1/2 to 2/3 of Ecuador's total banana exports, and in recent years, the main growth in exports has been reflected in the European Union, whose export volume is 247.96 million boxes, an increase of 22.41%, which is due to the increase in purchases from the main market of the Netherlands, which increased by 14.25%, an increase of 18,034.821 million boxes, and a 32.17% increase in Germany to 10,603,598 million containers, Italy increased by 12.29 percent to 8,907,225 million containers, and Belgium increased by 2.86 percent to 7,574,903 million containers.(Crecen Las Exportaciones de Banano de Ecuador a La Unión Europea – Acorbanec, n.d.)

Figure1 Value share of banana exports worldwide in 2022, by country



Source: (WTEx. (August 3, 2023).)

The European Union, as the main export region of Ecuador's bananas, has been facing transportation challenges. This is closely related to the characteristics of the banana product itself, the transportation requirements and the storage technology.

1.2 Industry Overview

This part first introduces the background of the product being transported, that is bananas, including its own characteristics and as well as those in transport, and then analyzes the storage technology. Then, the background characteristics of cold chain transportation are introduced to create conditions and constraints for the establishment of a model. Finally, the characteristics of refrigerated ships and reefer containers and the economic benefits of ordinary containers are compared, which provides necessary variables for the model.

Product background (features and storage and transportation profile)

Bananas are one of the most traded and consumed agricultural commodity worldwide and therefore. Bananas are very delicate fruits as their temperature should be maintained between 13.6°C and 16°C for the entire duration of the transportation chain in order to avoid them freezing or maturating beforehand. Hence, this cold chain needs to be managed with extreme care by all the suppliers involved at each stage, from the time of production until their arrival at the supermarkets.(Evans ,2020)

Although bananas are grown commercially in more than 130 countries, production is highly concentrated in the top 10 producing countries, India is by far the largest producer, accounting for 26.8% of the total world production in 2017, followed by China (9.8%) and Indonesia (6.3%). (FAO 2019a). The biggest 5 exporters of bananas (Ecuador, Costa Rica, Philippines, Colombia and Guatemala) accounted for almost three-fifths (58.3%) of all banana sales on international markets(Bananas Exports by Country 2021, n.d.).Most of Europe's bananas and pineapples come from Latin American countries, such as Ecuador, the world's largest banana exporter, Costa Rica and Colombia, the world's largest pineapple exporter('All About Bananas | Producers, Where They're Grown & Why They Matter', n.d.).

Market structure

In terms of market structure, the supply side of the banana market has changed noticeably from when it once was an oligopoly, where a few vertically integrated multinational companies controlled the trade. For instance, the top five multinational banana companies, Chiquita, Del Monte, Dole, Fyffes, and Noboa, went from controlling 65.3% of the global banana exports in 1980 to 44.4% by 2013 (FAO 2014). Several factors are responsible for the observable structural change; chief among them was the conscious decision on the part of the traditional multinational companies to reduce their level of risk exposure by moving from primary production to focusing their attention more on the transportation and distribution aspects of the value chain. This decision opened the door for the rise in the number of national companies better placed to minimize some of the production risks and to guarantee supply. Due to the way they operate, national companies sell the fruit to the big multinational companies or directly to supermarket chains and food retailers.

Storage technologies

To ensure high quality of ripe banana, it is essential that green bananas during transportation to maturity chambers are maintained at optimum temperature, relative humidity, and air circulation.

Immediately after harvest, fruits should be rapidly cooled to the storage temperature using cold air (room cooling, forced air cooling), cold water (hydro‐cooling), or evaporating the water from the fruit (evaporative cooling, vacuum cooling). Plantain and banana are usually cooled with cold air to prevent temperatures becoming too low, which can cause chilling injury.

High humidity reduces water loss and increases storage life. A relative humidity of 90% provides the best compromise for storing plantain and banana. Humidity can be raised in a container or room by spraying water in a fine mist. Nevertheless, excessive wetting leads to fruit splitting and reduces market quality.

Air circulation is an effective method used to reduce temperature in storage rooms. However, ventilation also increases water loss from fruit by removing the saturated layer of air that surrounds the fruit.

Cold-chain transportation

A complete and effective cold chain system must keep perishable food within the desired temperature and humidity range, from the point of collection to the final point of consumption. Fresh produce cold chain logistics refers to the use of refrigeration technology to continuously maintain a suitable temperature and humidity environment for fruits, vegetables, dairy products, meat, fish, and other perishable products. (Mercier et al., 2017)The entire cold chain will be useless if there is even one link that breaks. To prevent food loss and waste, cold chain logistics must be maintained in their integrity. The effectiveness of cold chain logistics for fresh produce mostly depends on its performance, infrastructure upkeep and modernization, and management practices(Goedhals-Gerber & Khumalo, 2020) (such as chilling techniques, standardization, packaging materials, and production packaging layouts).

Cold chains need a lot of energy

Fresh food consumes a lot of electricity, which is the main financial burden for cold chain stakeholders (manufacturers, suppliers, and retailers) during the duration of the cold chain. This environment must be acceptable, stable, and low in temperature and humidity (Han et al., 2018),FAO (2020) estimates that 70% of the energy needed by the food system occurs after the food leaves the farm, such as during transportation, processing, packaging, transportation, storage, marketing, etc. According to estimates, one-third of the food produced each year is lost or wasted, accounting for 38% of the energy used by the food system(FAO,2020). The pre-cooling, warehouse refrigeration, refrigerated transportation, and sales systems—four interlocking systems that differ in order and timing—compose the cold chain. Since each link in the cold chain is interconnected and dependent upon the others, any malfunction at any one of them will have a negative impact on the rest of the chain by increasing food loss and waste as well as the associated loss of human and material resources. Upstream and downstream connections in the cold chain are connected by refrigeration transport. The best refrigeration transport modality depends on the shelf life, economic value, cost, and customer needs.

1.3 Problem Context

1.3.1 Research Domain

The study of maritime route optimization encompasses many branches, including route planning and design, ship scheduling and scheduling, port equipment optimization, cargo loading optimization, information technology applications, environmental and sustainability considerations, risk management, international law and policy, economic and market analysis, etc.

(Ksciuk et al., 2023; Tran et al., 2023)The main research areas in this article focus on route planning and design, as well as market analysis. Among them, the planning and design of routes studies how to design and plan the optimal routes to minimize transportation costs and maximize transportation efficiency. This includes considering factors such as the type of cargo, the type of vessel, the flow of cargo, and more. Market analysis mainly studies the global economy and market trends to adjust and optimize sea freight routes to adapt to changing market conditions. At the same time, we study the market situation of bananas, the main force of the fresh transportation market, and select the transportation market situation from Ecuador to EU countries so that we can establish a route planning model in the future.

Due to the rapid changes in the market, we learned in the previous research that refrigerated containers have gradually replaced refrigerated ships as the main force of cold chain transportation, and their price, speed and market adaptability are different, we study the advantages and disadvantages of refrigerated ships and refrigerated containers, lock our main transportation carriers in route planning, and study how to establish a new transportation network in the existing shipping network nodes under the constraints of time and capacity. In the context of this transportation network, a linear optimization model is established to calculate the optimal route.

1.3.2 Impact of problem

The shipping industry benefits from the optimization of maritime routes in a number of ways, including but not restricted to the following:

Cost-effectiveness: Shipping companies can lower their transportation expenses by streamlining their routes. For shipping companies, optimal route planning can lower operating costs by consuming less fuel and requiring shorter voyages and transit times.

Enhanced effectiveness in the transportation of cargo: Route optimization contributes to the augmentation of cargo transportation efficiency. Goods can reach their destination faster by minimizing stops and selecting the most direct route, which lowers lead times across the supply chain.

Decreased environmental impact: Reducing carbon emissions and other environmental impacts can be achieved through route optimization. Shorter, more cost-effective routes can help achieve environmental sustainability objectives by using less fuel and emitting fewer greenhouse gases.

Enhanced cargo throughput: Ships can use their cargo capacity more effectively and achieve maximum cargo throughput by optimizing route planning. This lowers the cost of transportation per unit of cargo and increases the economic efficiency of shipping.

All things considered, the optimization of sea routes benefits the environment and the entire supply chain in addition to the economy. Improving the shipping industry's competitiveness and sustainability is greatly impacted by this.

1.3.3 Problem statement

Fresh agricultural and sideline products must be transported and distributed using cold chain logistics technology at all stages, because they are different from general products, they are perishable, difficult to preserve, and have a relatively high rate of damage to goods. Due to these differences, fresh agricultural and sideline products have some special logistics characteristics. However, problems such as high cold chain transportation costs and high cargo loss rates need to be addressed immediately. Therefore, it is still very important to study the related areas of cold chain logistics. At the same time, some large fruit and vegetable dealers usually choose to hire container liner companies for cargo transportation, how to choose the best transportation route for refrigerated containers in the shipping network of container liner companies, so as to minimize transportation costs, has become the most concerned issue for cargo owners.

1.4Research objective and research question

1.4.1 Objective

On the basis of summarizing the research results, this research analyzes the demand for transportation time and the loss of cargo quality of bananas during transportation according to the transportation characteristics of refrigerated containers. From the perspective of container liner companies and cargo owners, an optimization model of banana refrigerated container transportation route was established, and the route design and transportation route of refrigerated containers were quantitatively analyzed. An optimization algorithm is designed to solve the model, and the practicability of the optimization model and the solution algorithm is verified by case analysis. It is designed to minimize the total cost of the vessel, the cost of the port, and the cost of refrigerated container consumption. Taking the transmission time, port life capacity and refrigerated container storage capacity as the main constraints, the route design and ship configuration of container liner companies were optimized through the refrigerated container shipping network optimization model.

1.4.2 Main research question：

In what way can organization optimize banana maritime transportation routes to minimize total costs within transit time and capacity constraints?

1.4.3 Sub-questions

1. What is the past, present and future status of banana reefer container transportation?
2. How to choose between bulk reefer and reefer containers, and what are the trends?
3. What modes can be selected for the optimization of banana cold chain transportation routes?
4. How will the self-ripening properties of bananas affect the model?
5. In what ways are banana transport routes optimized, and what is the impact on the company's economy and emissions?
6. How can the optimization model be applied to real-world scenarios?

The first, second, and third issues will be addressed by the author using the data from the study and qualitative analysis of the relevant literature review. For the fourth and fifth questions, the author will use quantitative analysis to develop a series of algorithms. Afterward, the author will evaluate and solve the problems using algorithm solutions. Lastly, the author will utilize examples to validate the algorithms to solve the sixth question.

1.5 Thesis Structure

In the first chapter, the background of the problem and the industry background are described, and the research content and problem are defined and scoped, as well as the impact of the problem. After that, the second chapter mainly conducts literature review research, which includes the research status of cold chain transportation, the development trend of banana cold chain transportation, and the research status of previous research on the optimization of maritime road strength, to help us to deepen our research questions, find practical research routes, and create a theoretical basis for research methods and model construction. In the third chapter, we explore sub-question 2 through a targeted study, and determine the choice of transportation themes and variables to be used in our model through a comparative analysis of the advantages and disadvantages of refrigerated and refrigerated containers, as well as a summary of the cold chain transportation market environment. In Chapter 4, we provide a theoretical description of the maritime network, and fully define and explain the variables and descriptions in the model construction. Chapter 5 is Research Methods and Data, which includes a summary of our research strategies and routes, as well as data collection and analysis methods. In the sixth chapter, the model is constructed, and the linear optimization model is selected for the path optimization model construction, the model takes the minimum cost as the goal, and the transportation time and capacity are the constraints, and the theoretical assumptions, variable definitions, and constraint interpretation processes are carried out respectively. In Chapter 7 for analysis and results, we use actual scenarios to verify the model, and use the latest market data for data input and result output, which are output and compared with different constraints. Chapter 8 is a summary, summarizing the research in the previous article, answering the six-word research question and the main research question, and describing the limitations of the research process and the future prospects.

Chapter 2 Literature Review

In the previous research, we mainly introduced the research background and problem definition of this research, and this chapter mainly solves two research sub-questions through literature research, namely, what is the past, present and future status of banana refrigerated container transportation, and what modes can be selected for the optimization of banana cold chain transportation routes, which two questions have laid the foundation for our subsequent model establishment. In this part, the author reads a large number of literatures to help the author explore the existing cold chain transportation and its route planning, potential problems and feasible solutions.

2.1. Research on cold chain transportation

In terms of cold chain transportation research, Flick proposed a method to evaluate the quality change of food during cold chain transportation, which quantified the influence of temperature, moisture content, microorganisms, and other factors, and proposed a Monte Carlo algorithm to calculate (Flick et al., 2012). Laguerre pointed out that the unevenness of temperature and humidity is the most important factor leading to the degradation of food quality in cold chain logistics, and he proposed a food quality evolution model that takes into account the initial characteristics of food and transportation conditions to evaluate the efficiency of cold chain logistics(Laguerre et al., 2013). Oliva established a food cold chain transportation simulation model to identify the main factors affecting meat quality during transportation, and compared the effects and differences of DFID, TTI and other technologies for food quality control (Oliva & Revetria, 2008). Eden examines the role of new technologies in upgrading cold chain logistics, pointing out that DSS technology can be used to predict risks in food transportation to make optimal decisions, GIS technology can provide the geographical location of products in real time and set transportation conditions according to the external environment(Eden & Colmer, 2010). Joshi established a cold chain logistics efficiency evaluation system to explore the advantages and disadvantages of each cold chain enterprise, conducted an empirical analysis on a food company, and finally proposed the company's countermeasures to improve the efficiency of cold chain logistics from the aspects of warehousing and sales(Joshi & Banwet, 2011). Yahia et al. pointed out that the application level of cold chain logistics in developing countries is still relatively low, the infrastructure construction of cold storage, refrigerated containers, special testing instruments is not perfect, and the number of cold chain professional and technical personnel is also very limited, which affects the efficiency of cold chain logistics (Yahia, 2010). Reddy et al. proposed that cold chain logistics management should include cargo quality supervision, control of transportation conditions, risk assessment and resource scheduling, and enterprises need to establish a scientific cold chain management system to ensure the level of cold chain transportation (Good Cold Chain Management Practices - Google Scholar, n.d.). Kim et al. have established a cold chain logistics risk management system, which provides functions such as risk perception, risk detection, risk assessment and behavior response by collecting and analyzing various types of information involved in cold chain logistics (Kim et al., 2015). Sharma et al. applied Bayesian network to establish an evaluation model of influencing factors of cold chain logistics, analyzed the interdependence between various influencing factors and the impact of these factors on the service level of cold chain logistics, and conducted an empirical analysis based on the cold chain logistics system in a certain region (Sharma & Pai, 2015). Raab has established a general model to calculate the remaining shelf life of meat products in cold chain logistics, which comprehensively considers the shelf life of goods, cold chain transportation conditions and quality changes of goods, and can be classified according to the organizational characteristics of different supply chains (Generic Model for the Prediction of Remaining Shelf Life in Support of Cold Chain Management in Pork and Poultry Supply Chains | Journal on Chain and Network Science, n.d.).

2.3 Status of reefer container transportation with bananas

The transportation of bananas using reefer containers has a rich history, a thriving current status, and a promising future outlook:

Past Status (Historical Context):
Early Shipping: The transportation of bananas using reefer containers dates back to the late 19th and early 20th centuries when the banana trade industry began to develop. Initially, bananas were transported on traditional cargo vessels with limited temperature control, which often led to spoilage and losses during transit.
Innovation with Reefers: The introduction of refrigerated containers (reefers) revolutionized the banana industry. This innovation allowed for precise temperature control, reducing spoilage and ensuring that bananas arrived at their destination in good condition.

Current Status (Present-Day):
Efficient Transport: Reefer container transportation of bananas has become the standard in the industry. Bananas are harvested, packaged, and loaded into refrigerated containers in producing countries (such as Ecuador, the Philippines, and Costa Rica). These containers are then transported by sea to consumer markets around the world, including North America and Europe.

Global Supply Chain: The current status reflects a highly efficient and globalized supply chain for bananas. Reefer containers ensure that bananas maintain their quality and freshness during long-distance shipping, allowing consumers to enjoy the fruit year-round.
Market Dominance: Major fruit companies like Chiquita, Dole, and Del Monte have well-established supply chains that heavily rely on reefer container transportation to meet global demand for bananas.

Future Outlook (Trends and Projections):
Sustainable Practices: As sustainability becomes a more significant concern in the shipping industry, there is a growing focus on reducing the environmental impact of reefer container transportation. This includes using more energy-efficient refrigeration systems and exploring alternative fuels.
Supply Chain Resilience: Recent disruptions in global supply chains, such as the COVID-19 pandemic, have highlighted the need for supply chain resilience. In the future, there may be efforts to diversify transportation routes and reduce dependencies on specific regions for banana production.
Market Expansion: The global demand for bananas continues to grow, driven by population growth and changing dietary preferences. As a result, the use of reefer containers for banana transportation is expected to expand, with new markets opening up in regions that were previously underserved.
Technological Advances: Ongoing advancements in refrigeration technology and container design will likely improve the efficiency and reliability of reefer container transportation for bananas.

In summary, the past saw the transformation of banana transportation with the introduction of reefer containers, which revolutionized the industry. The current status reflects a highly efficient global supply chain, and the future outlook points toward continued growth, sustainability initiatives, and technological advancements in reefer container transportation for bananas.

2.3. Research on container transportation path optimization

The existing research on container transportation network optimization mainly focuses on two aspects, the first is to establish optimization models from different angles to solve specific problems in container transportation, and the second is to design targeted solution algorithms according to the characteristics of optimization models.

Wang Shuaian et al. established a linear optimization model for container liner shipping network, and evaluated its service level by taking the transportation time as the main index, and considering the restrictions of the coastal trade law on the transportation route, the optimal container transportation route was solved to minimize the transportation cost(Wang et al., 2013). Meng Qiang took the weekly short-term transportation as the research object, considering the transportation time and ship configuration, established an optimization model to solve the route design problem of container liner company, and conducted an empirical analysis based on the data of a large shipping company(Meng & Wang, 2012). Wang Shuaian et al. established a mixed integer nonlinear optimization model to solve the container route design problem under a fixed delivery time, and designed a heuristic algorithm to solve it, and finally proved the practicability of the model by taking the maritime transportation system from Asia to Africa as an example (Wang & Meng, 2014). ManWo considers the influence of the uncertainty of container shipping demand on container liner transportation, and uses a stochastic optimization model to solve the optimal route design scheme and corresponding ship configuration of container liner companies under uncertain demand (Ng, 2015). Dong et al. proposed a two-stage stochastic programming model to solve the problem of container optimal shipping route under the conditions of container liner route joint service capacity planning and random transportation demand, and developed an improved stepwise hedging algorithm to solve the model(Dong et al., 2015). Taking cargo transportation time, transportation cost and cargo quality as the main considerations, Hao et al. established a container multimodal motion state optimization model, and solved the optimal transportation mode combination strategy to achieve generalized minimum transportation cost (Hao & Yue, 2016). He et al. established a multi-level container supply chain network optimization model with the goal of minimizing the total cost of the supply chain, and proposed a new simulation-based heuristic algorithm to solve the optimization model (He et al., 2015). Chou et al. proposed a mathematical programming model combining fuzzy multi-criteria decision-making and network optimization to solve the problem of container transportation demand segmentation, and verified the model by taking Taiwan ports as an example (Chou et al., 2010). Maurizio et al. proposed a linear programming model to solve the problem of volume allocation of container multimodal transport, and adopted a frequency-based approach to solve the problem of time difference between maritime transport and inland transport (Arnone et al., 2014). Maučec et al. believe that the optimization problem of container traffic flow is closely related to the development speed of container ports, and use the secondary statistical data analysis and modified distribution method to solve the container traffic flow optimization model, which proves that the development speed of container ports has a great impact on its attractiveness level(Optimizing Overseas Container Transportation: A Case Involving Transatlantic Ports - Hugo Maučec, Anton Ogorelc, Ratko Zelenika, Drago Sever, 2015, n.d.).

2.4. Literature Review Summary

The above review of container transportation network optimization and cold chain logistics shows that most of the results in the existing research on container transportation network optimization are based on ordinary containers, and the transportation time requirements of refrigerated containers and the changes in cargo quality during transportation should be further considered. In the existing research on cold chain logistics, there are many studies on the optimization of cold chain distribution routes and the evaluation of cold chain logistics efficiency, and the factors of port and sea transportation should be further considered.

2.4.1 Further research on the optimization of the maritime network of refrigerated containers

Compared with ordinary containers, refrigerated containers have higher requirements for transportation time, and the existing research rarely considers the constraints of refrigerated containers on transportation time when designing maritime networks. In addition, the goods in reefer containers experience quality loss during transportation, which in turn incurs additional costs. Therefore, container liner companies need to control the transit time of refrigerated containers by optimizing route design and ship configuration to reduce the cargo quality loss of refrigerated containers, improve the competitiveness of enterprises and attract more customers.

2.4.2 Further research on the optimization of the shipping route of refrigerated containers

The maritime transportation of refrigerated containers is affected by many factors such as ports and shipping enterprises, and the existing research on cold chain logistics mostly focuses on the cargo itself, transportation management, cold chain distribution and other levels, and there are still relatively few studies on the impact of shipping networks and port service levels. Based on the fixed shipping network and port service level, this research studies the optimization problem of the sea route of refrigerated containers under the constraint of transportation time, and determines the best of refrigerated containers under different transportation time constraints Excellent sea path.

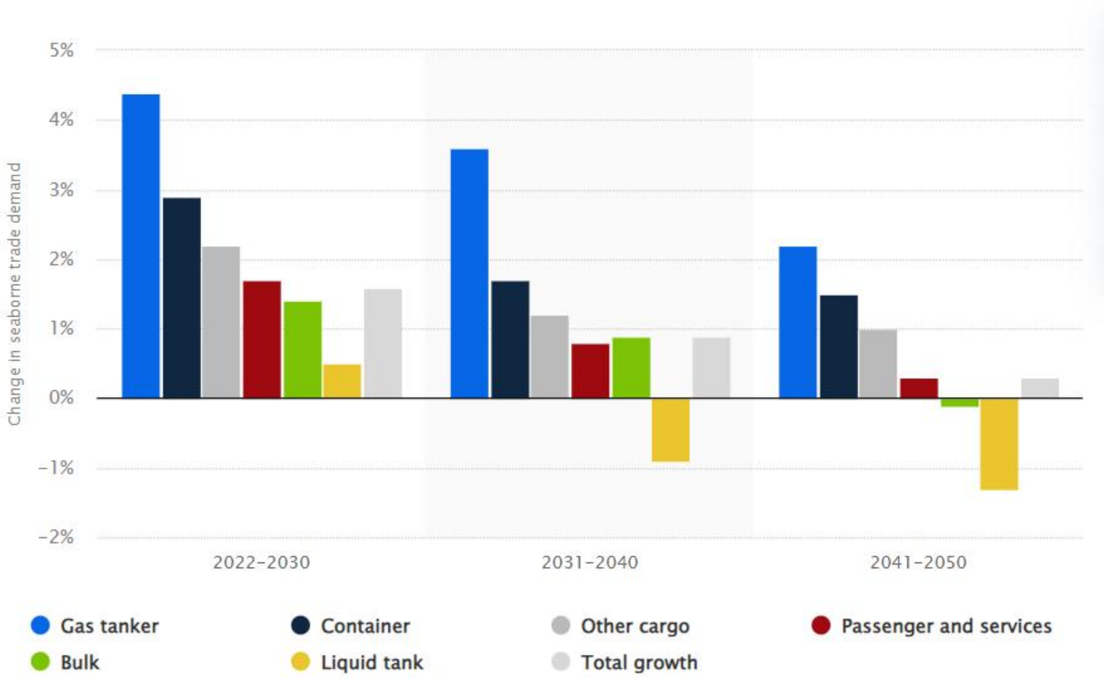
In summary, the optimization of the shipping network and route of refrigerated containers has not been studied considering the transportation time requirements of refrigerated containers and the changes in cargo quality. Therefore, this research focuses on the optimization of refrigerated container shipping network under transportation time constraints, and studies the optimization of refrigerated container shipping network under transportation time constraints from the perspective of container liner companies, so as to provide reference for container liner companies to design routes and configure ships. From the perspective of cargo owners, the optimization of the sea route of refrigerated containers under the constraint of transportation time is studied, which provides reference for cargo owners to formulate transportation plans.

Chapter 3 Bulk reefer ships versus reefer containers

3.1 Introduction

A reefer ship is a type of refrigerated cargo ship that is commonly used to transport perishable goods that require temperature-controlled handling, such as fruits, meat, vegetables, dairy products, and similar items. Refrigerated ships are not usually described in terms of the usual tonnage value. The size of the reefer ship is more suitable for describing the capacity in terms of cubes. Each cargo transport space is lined with a layer of insulation, which effectively reduces its cargo capacity,due to the nature of its trade, insulation is necessary.(Reefer Vessels., n.d.)

Figure2:Projected growth of seaborne trade between 2022 and 2050, by cargo type and decade



Source：DNV. (September 30, 2022).
According to DVN's forecast, the demand for seaborne trade is expected to increase in the coming decades, but the growth rate of seaborne trade has declined for different types of transportation. The growth rate of Bulk's maritime trade sector will decline from 1.4% in the 2022-2030 period to -0.1% in the period 2041-2050, that is, in the next 30 years, Bulk's maritime trade sector will decline to negative growth. In the area of container maritime trade, demand for containers is expected to grow by 2.9% between 2022 and 2030, 1.7% between 2031 and 2040, and 1.5% from 2041 to 2050. It can be seen

that the demand growth of container has a slow downward trend, but its demand growth is positive in the next 30 years.

Comparison of reefer container and ordinary container cost
The service life of reefer containers is about 10 to 12 years, and the average life of standard containers is 15 to 20 years, and their purchase price is visible in the table, from which the average annual cost can be calculated.

Table 1:
Price comparison table of ordinary containers and refrigerated containers of different specifications

Container type	Purchase Range	average annual cost
20-foot shipping container cost	$2,800 to $6,500	$186 to $433
40-foot shipping container cost	$4,000 to $8,300	$266 to $691
20ft refrigerated containers	$5,600 and $7,000	$560 to $700
40ft refrigerated containers	$10,000and $12,000	$1000 to $1200

Source:(How Much Do Shipping Containers Cost?, 2023)

We can see that the price of a reefer container is about twice that of an ordinary container, but it has the advantage that ordinary containers do not have, and can transport bananas from Latin America to Europe intact, and ordinary containers may cause greater losses in this transportation, according to the World Bank. The import price of European bananas in 2023 is $1.14 per kilogram (Banana price (Europe), April, 2023 - data, chart, n.d.), and it has been calculated that a 40-inch reefer container can carry bananas worth $25,080. The difference between ordinary containers and refrigerated containers is much smaller than the price of goods, so refrigerated containers still occupy a great advantage in banana transportation. Therefore, in the scenario of this article, refrigerated container cargo ships have more economic value and are analyzed as the main body of this article.

3.2 Reefer ship

Reefer ship Pros
1. Reefer ship fast
The transportation duration of professional reefer ships is significantly less than that of tanker ships (13–15 KNOTS), bulk carrier ships (13–15 KNOTS), and regular container ships (16–22 KNOTS). This is a significant benefit. The

10,000-ton multipurpose reefer ship can travel at more than 20 knots per hour. A dedicated reefer ship may arrive in Rotterdam from South America in roughly 18 days, compared to approximately 29 days for a container ship. ThenThe rapidity of delivery is a major benefit, particularly for a commodity like bananas, whose limited shelf life limits the sales time. (How Fast Does a Cargo Ship Go?, n.d.)

2. Better refrigeration system

refrigerated cabins, generally separated into many cabins, are located in the cargo hold of refrigerated ships. A closed, separate loading area exists for every cabin. To ensure that heat does not transfer from one neighboring cabin to another, the doors and bulkheads are sealed and covered in insulating materials such foam plastics and aluminum plate polymers. Reefer containers are limited to maintaining the temperature within the container; this is where reefer ships differ from one another. Large volumes of commodities, like bananas, are better suited for the temperature-controlled shipping of reefer ships, which offer more temperature control possibilities.

(Automotive Observer Network, n.d.)

3. Large capacity in reefer cargo transportation space

Large-volume cargoes like bananas are better suited for whole-batch shipping by conventional reefer ships, however certain container ship operators have an edge when it comes to small-volume packaging of appropriate container goods.

Reefer ship Cons：

1. The ships are old and the number of ships is small

The managing director of Seatrade, Yntze Buitenwerf, stated that some businesses were choosing to forgo developing reefer ships in favor of other boats that may generate more revenue. Furthermore, the cost of building a reefer ship might take twenty years to recover, therefore many businesses decide to ship in other directions rather than using specialized refrigerated ships, which has resulted in a sharp fall in the number of conventional reefer ships. The age of ships is rising, and not many reefers have been built in recent years. This indicates a decline in the quantity of ships. (The restricted number of ships is caused by the high cost of shipbuilding and the sluggish return on expenses; also, the limited availability of reefer ships will limit the flexibility of cargo transportation arrangements.)(Reefer Ships versus Containers, 2013)

2. Decline in market share

On the other hand, conventional cargo operations with open-top hatches and reefer ships have lost market share. Dynarm's 2018 REEFER Analysis - Market Structure, Conventional, Containers states that the percentage of reefer perishable cargo transported by legacy carriers has decreased from over 55% in 2000 to over 18% at now.(Conventional reefer ships further lose market share, n.d.)

3. Temperature control quality
Banana shelf life should be between 13.6 and 16°C, even if the refrigeration system on the reefer ship can regulate the temperature to the needed temperature of the cargo. In general, the refrigeration device can manage the temperature of the reefer cabin to 15°C to 25°C.

4. Goods damage
Most storage heights are still higher than the height of a single container, even though the height difference between the reefer cabin's deck and bilge or between its upper and lower decks is less than that of other cargo ships. Compared to the container, there is a higher chance of the goods being piled too high and crushing the lower cargo.

5. It is difficult to make a claim and the insurance claim amount is large
A reefer ship's claim amount might be higher than its claim amount for the whole loss of its container cargo if there is an issue with the refrigeration system. Reefer ships are crucial for cold chain transit for many container shipping firms, but their financial significance is lower, according to Peter Haagen of RaetsMarine, a division of MS Amlin. Haagen believes that if one specialist reefer ship has a problem, everything goes wrong.(The best of both worlds for fruit transport, 2017)

3.3 Reefer Container

Pros

1. Easy to ensure the quality of goods
At the shipping point, perishable items can be put into containers and delivered straight to the receiving unit. Even if the items go via several different modes of transportation, there is no need to load and unload them (such as vehicles, railroads, sea transportation, etc.). When perishable commodities are moved from one mode of transportation to another without the use of reefer containers, they will unavoidably be exposed to high temperatures, which will quickly raise the temperature of the items and improve their respiration. impacts on the growth of microbes, which has an impact on the products' quality. (Advantages of Refrigerated Containers for Refrigerated Transportation equipment_Engineering Technology_Refrigeration Information, n.d.)

2. Itinerary tracking

The ability to trace a travel is another benefit of reefer containers thanks to the black box within. For the cargo to be securely safeguarded during handling and transit, this feature establishes who is responsible for freezing or maturing ahead of time during transportation (Maersk Line, 2009). In light of current trade conditions, this research will focus on the route optimization of reefer container transportation by banana shipping, since market trends and refrigerated containers are somewhat more appropriate.

3. Can reduce loading and unloading costs

It makes loading and unloading processes more automated and mechanized. Typically, a range of transportation techniques are required to get perishable items from their point of origin to the market. The cost of loading and unloading will surely rise as a result of numerous loading and unloading operations along the route. The items within the boxes do not need to be reversed when reefer containers are utilized for intermodal transit between various modes of transportation; just the containers themselves need to be reloaded. Pallets can be used to load containers, improving the automation of the loading and unloading process.(Advantages of Refrigerated Containers for Refrigerated Transportation equipment_Engineering Technology_Refrigeration Information, n.d.)

4. Independence

Reefer container ships are not limited by the number of reefer containers they can carry, unlike other container ships that may be limited by the number of reefer exports or insufficient generator capacity. The refrigeration system is connected to the rear end of the reefer container. While on board, these containers plug into the electrical outlet associated with the ship's power generation (usually 440 VAC). Each reefer container unit is usually designed with individual circuits and has its own circuit breaker switch that can be connected and disconnected as needed. In principle, each individual unit can be repaired while the ship is still underway.

5. Applicable to international transport

Specialized, large-scale, automated, and robotic loading and unloading is becoming the norm in ship transportation due to the growth of the global shipping industry. Ships that transport reefer containers have cargo holds specifically designed for that purpose. Reefer container electricity is supplied by power outlets aboard some ships. A cold storage capacity is provided to the containers by refrigeration equipment aboard some ships. Because of this, international marine transportation finds great utility in the import and export of perishable products using reefer containers.

(Advantages of Refrigerated Containers for Refrigerated Transportation equipment_Engineering Technology_Refrigeration Information, n.d.)

6. Convenience
While the total cost of shipping bananas in a reefer container is about the same as bulk reefer shipment, there is no real economic advantage to using a reefer container instead of bulk reefer shipment of bananas. An important technical and operational advantage of using reefer containers is related to the convenience of transporting bananas by container ship (Arduino et al., 2015).

In summary, its main advantages are that it can meet different transportation requirements, realize mutual conversion between different operations, reduce transportation time, increase transportation rate, reduce collisions between transportation, and improve the quality of transported food. At the same time, the continued shrinkage of the traditional reefer fleet industry has given the reefer container industry more development opportunities. Because ships in the container industry usually have a large number of reefer spaces, they can not only provide professional reefer services, but have also become an important part of the contemporary food and perishables supply chain.

Cons：

1. High rental costs
The equipment, maintenance and transportation costs of container cold storage are relatively expensive. Although the biggest advantage of container cold storage is that it reduces construction costs compared with traditional storage methods, its rental costs are still higher than ordinary containers.
(Advantages of Refrigerated Containers for Refrigerated Transportation equipment_Engineering Technology_Refrigeration Information, n.d.)

2. Requires professional operation
Container cold storage requires professional personnel to operate and maintain. Therefore, when companies use container cold storage, they also need to train and educate their employees, which increases the company's management costs.

3. Rely on external power supply
Container cold storage relies on external power supply to support its operation. If the power supply is unstable or interrupted during transportation, it may cause the goods to be lost or even exceed the expected storage time, causing losses.

4. Limited space utilization
Compared with traditional storage methods such as cold storage, container cold storage has limited storage space. If the size of the container cold storage rented by the enterprise is too small, it will not be able to meet the needs of cargo storage. If the size is too large, part of the storage space and cost will be wasted.

Table2:Reefer ship versus Reefer container comparison table

	Reefer ships	Reefer containers
Pros	1.Fast (20 KNOTS) 2.Better refrigeration system 3.Large capacity & space	1.Easy to ensure the quality of goods 2.Itinerary tracking 3.Reduce loading and unloading costs 4.Independence 5.Applicable to international transport 6.Convenience
Cons	1.Ships are old and the amount is small 2.Decline in market share 3.Temperature control quality 4.Goods damage 5.It is difficult to make a claim & the insurance claim amount is large	1.High rental costs 2.Requires professional operation 3.Rely on external power supply 4.Limited space utilization

To sum up, the logistics sector has demonstrated significant benefits from the introduction of reefer containers as a novel form of storage equipment. By regulating the right temperature and humidity, it successfully ensures the security of the cargo; clever management techniques increase the effectiveness of storage and transportation. and safety; adaptability, economy, pragmatism, and changeability are appropriate for typical freight and logistical demands. As it grows more and more mature, its high protection performance and strong flexibility have made it the driving force of cold chain transportation, despite certain restrictions in terms of cost and usage. The main benefit of employing reefer ships is their speed and timeliness, which is advantageous for items like bananas that need to be transported with a high degree of timeliness. Therefore, in order to combine the logistics advantages of containers with the speed advantages of specialized refrigerated ships, the author believes that reducing transportation time through path planning and optimization can make up for the pain points of reefer containers that are not as fast as reefer ships in transportation speed, thereby obtaining an optimal banana transportation method.

Chapter 4 Refrigerated container shipping network

4.1 Transportation characteristics of refrigerated containers

Refrigerated container refers to a special container with good heat insulation and it can maintain certain low temperature requirements, suitable for the transportation and storage of all kinds of perishable food. With the strong growth of cold chain transportation demand, refrigerated containers stand out among many cold chain transportation tools with unique transportation advantages, compared with other cold chain transportation tools, refrigerated containers have the following aspects of transportation characteristics.
(1) There is no need to open the box during the whole process, which is convenient for transfer
(2) Transportation and special service facilities for transshipment must be used
(3) It can be used for the transportation of multiple cargo types.

4.2 Maritime network structure

A container shipping network is a complex system, including ports, shipping enterprises, cargo owners, customs and regulatory units, etc., of which the port, shipping enterprises and cargo owners are the most important factors determining the structure and characteristics of container shipping networks. Hereafter we discuss them in detail.

(1) Ports
The port is an important node in the maritime transportation system, undertaking the task of connecting water transportation and land transportation, and is the hub of cargo distribution, storage and transshipment. At the same time, the port is also a key fulcrum of economic development of various countries, playing an important role in international trade, transportation services and urban construction, and making great contributions to national economic development and social progress. In this context, modern ports are also actively undergoing transformation and upgrading, and on the basis of retaining the traditional cargo loading and unloading, storage and transit operations, vigorously developing cargo processing and sales, port landscape construction, financial and trade services and other businesses, providing a strong guarantee for international logistics development and urban economic construction.

(2) Shipping enterprises
Shipping enterprises undertake the task of maritime transportation in the container shipping network, and shipping enterprises design routes connecting port nodes according to the cargo transportation needs between each port, configure corresponding transport ships for each route, and carry

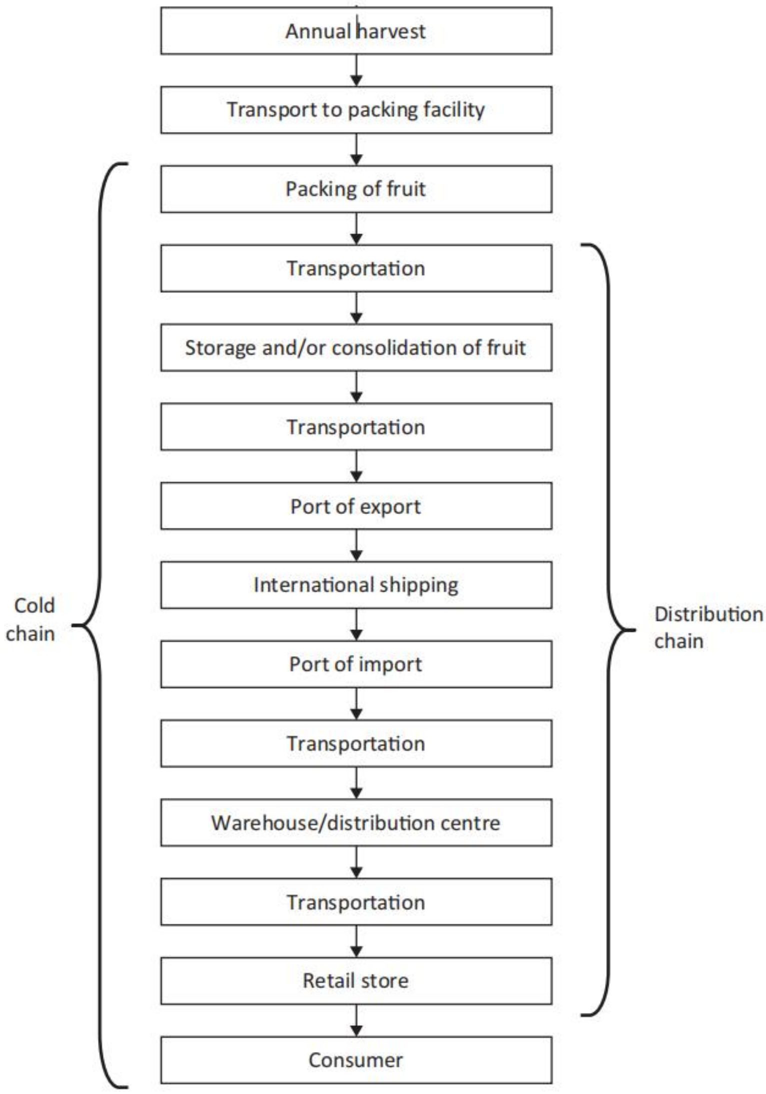
out transportation in a certain cycle. Shipping enterprises are capital-intensive enterprises, so they need to carry out scientific design and planning of routes and ships to reduce the cost of enterprises and improve the efficiency of ship use.

(3) Cargo owners
Cargo owner refers to the owner of the goods, in the container shipping network, the main role of the cargo owner is to put forward transportation requirements. The transportation requirements here include the start and end points of container transportation, which is commonly known as the concept of OD, as well as the container volume between groups of ODs, transit time requirements, and so on. Cargo owners in container shipping networks can be divided into two categories, one is self-employed and the other is large enterprises, for self-employed people, the amount of goods owned is relatively small, so their transportation needs have little impact on the overall shipping network. For large enterprises, there are generally subsidiaries in many parts of the world, so there are multiple combinations of supply and demand for goods. At present, large enterprises mainly rely on hiring container liner companies to carry out the maritime transportation of containers, and cargo owners need to determine the shipping route of containers according to the shipping network provided by container liner companies and the actual transportation needs of goods, so as to save transportation costs as much as possible under the premise of meeting transportation requirements.

(4) Banana container cold chain network
A Supply Chain is defined as a global network responsible for delivering products and services to end customers from the point of extraction of raw materials through organized financial flows, information, and physical distribution activities ((12) APICS Dictionary 13th Ed | Frank g - Academia.Edu, n.d.). Various transformational activities or processes and stakeholders to produce the final product or service and deliver it to the consumer. Figure 1 shows some important activities in banana SC and depicts the extent of the cold chain. The cold chain is similar to SC, but refers to the temperature control part of SC (Aung & Chang, 2014); Therefore, it is a segment or part of the SC, during which perishable products are refrigerated. For fresh fruit SC, the cold chain starts at the packaging facility where the harvest is refrigerated and ends with the consumer who consumes it after refrigeration.

The distribution chain is a collection of physical activities, such as transportation, handling, storage, and administrative activities, usually in the form of finished products from the manufacturer to the customer or the return of defective goods to the manufacturer As can be seen from Figure 1, the distribution chain of fresh fruit starts from the first shipment of the finished packaged fruit and ends with the fruit arriving at the retail store.

Figure 3: A fresh fruit supply chain depicting supply chain activities and the cold and distribution chains.



Source:(Dyk & Maspero, 2004)

The problem of sea freight optimization for reefer containers has two levels. The first level is to design the reefer container shipping network from the perspective of container liner companies, according to the flow of reefer containers between various ports and the requirements of cargo owners for transit time. The second level is to find the optimal shipping route for refrigerated containers in the existing shipping network according to the actual transportation requirements of fresh goods from the perspective of cargo owners, so as to minimize transportation costs. This thesis will mainly study the optimization of the shipping route of refrigerated containers from the perspective of cargo owners, based on the fixed shipping network and port service level.

Chapter 5 Research Methodology and Data

5.1 Introduction

This chapter describes the research methods and data in this research, including research strategies, data collection methods, and data analysis methods.
Based on the sub-question mentioned in Chapter 1, we will use the problem description and qualitative analysis to solve the first and second problems in the previous article, we will design algorithms for quantitative analysis and solution of the third to fifth problems, and finally use example verification algorithms to solve the sixth problem.

5.2 Research Design

In this thesis, qualitative and quantitative methods were used.
Qualitative research is the process of collecting, analyzing, and interpreting non-numerical data, such as language. Qualitative research can be used to understand how individuals subjectively perceive social reality and give it meaning.(Qualitative vs Quantitative Research, 2023)

Here we use qualitative research to analyze the problems in our sub-questions
Q1: What is the past, current and future status of reefer container transportation with bananas?Q 2:How to choose between bulk reefer and reefer containers, and what are the trends?And Q 3: What modes can be selected for the optimization of banana cold chain transportation routes?

For the first question, we used literature research to study the current research status of previous people in cold chain transportation, and explored practical solutions for our subsequent model construction. At the same time, we studied the market for banana cold chain transportation, using time as a clue. Study the development history of banana cold chain transportation, the total price in the past, the current development stage and current situation, as well as the predictions of various companies and researchers on its future development.

For the second question, through theoretical analysis and literature summary, we summarized and compared the advantages and disadvantages of refrigerated ships and refrigerated containers respectively. At the same time, we integrated their costs and compared prices under the same unit variable. Secondly, we study the current situation and market environment in the market, analyze which kind of transport ship is more suitable for today's enterprise transportation options, and also lay the theoretical foundation for our subsequent model construction and data selection.

For the third question, the author used a literature review to conduct research, studying the cold chain transportation route model and the path optimization model respectively, exploring the depth of the research problem and looking for potential solutions and models.

Quantitative research involves the process of objectively collecting and analyzing numerical data to describe, predict, or control variables of interest. The goals of quantitative research are to test causal relationships between variables, make predictions, and generalize results to the broader population.(Qualitative vs Quantitative Research, 2023)

In this thesis, quantitative research methods are used to solve the remaining three sub-questions.
In question 4: How will the self-ripening properties of bananas affect the model? In, we first studied the literature to collect data. There is often a specific coefficient for the biological ripeness of banana self-ripening. We defined the coefficient variable into the model establishment, constructed a linear function for calculation, and linked it with the transportation time. The calculation results and analyze.

Question 5: How to optimize banana transportation routes and what impact will it have on the company's economy? In this problem, we model the problem using linear optimization, a mathematical modeling technique that involves maximizing or minimizing a linear function while taking into account various constraints. Linear programming, also known as linear optimization.(avcontentteam, 2017)

The specific method is as follows: We collect the following data variables mentioned later, namely time, cost, route distance, supply and demand, port throughput, banana self-ripening coefficient and other variables, and construct an objective function with the goal of minimizing cost, and use other Variables construct a linear function model for constraints.

In question 6: How is the optimization model applied to actual scenarios? In this question, we will use the linear optimization model in the previous question to calculate the data and use the open solver in excel to perform modeling and calculation to obtain the results. The data sources are described in detail below. We mainly collect the latest data in 23 years to ensure the validity of the model and analysis results. After the calculation results are completed we evaluate the effectiveness of the model through benchmark calculations.

5.3 Research Process

Using the principle of network optimization and the existing relevant research results, this research proposes an optimization method for the sea route of refrigerated containers under the constraint of transportation time.The specific research methods are as follows:

1) The existing research results, we analyze the structure and characteristics of reefer container shipping network. At the same time, we used the literature to study the research status of path optimization,and provide a theoretical basis for the establishment of optimization model.

2) We summarize the transportation conditions of bananas and the quality changes during transportation, and the differences between refrigerated containers and refrigerated ships are qualitatively analyzed

3) Considering the transportation costs of container liner companies, we establish the optimization model of refrigerated container shipping network. To provide a theoretical basis and network attachment for the subsequent model establishment of routine strength optimization.

4) Considering the transportation costs of cargo owners, we establish a refrigerated container shipping route optimization model. The case analysis of banana transportation imported from South America to the EU was carried out to verify the feasibility of the optimization model.

5) After the model calculation, we use the benchmark calculation method to compare the results in the model and evaluate the effectiveness of the model.

6) The last one answers the main research question and sub-questions and gives suggestions and limitations analysis.

5.4 Data Collection

5.4.1 Supply and demand data

This type of data is mainly concerned with the balance between the supply of the starting point and the demand of the end point in the model. We have chosen to use secondary data as our master data, which is the use of existing data generated by large government agencies, healthcare facilities, etc., as part of an organization's recordkeeping. The data is then extracted from more different data files. It has the characteristics of interrupted acquisition time and simple data processing process.(Wagh, n.d.)

5.4.2 Port data

This type of data is mainly related to the port selection in the model, including the location of the port, the throughput, and whether it is suitable for the passage of refrigerated vessels. The data mainly comes from the port website and government website data, which is characterized by data authority, high accuracy and timely update.

5.4.3 Shipping distance data

Maritime distance data is mainly obtained through data input from the shipping website. The peculiarity of this data is that the shipping route is not a straight-line distance, and it is difficult to measure its data directly on the map. And our main problem is also to use time as the main constraint, so we convert distance to time units for calculation. We check the shipping website directly to get the usual required transit time between its different nodes.

5.4.4 Cost data

The objective function in our model is built to minimize the total cost, so the cost data is the main data in our model, which includes transportation expenses, storage expenses, handling costs, and goods costs. The cost factor of the loss of goods in the above costs cannot be directly obtained, so we build it in the model and calculate it in the form of a coefficient.

5.4.5 Banana self-ripening coefficient

As mentioned above, the biggest transportation feature of the goods studied in this article is that they have the characteristics of self-ripening during transportation, which will directly lead to a certain proportion of cargo loss and increased costs. Since this characteristic is a biological property, we will not go into it here, but we have obtained a self-maturation coefficient through literature research, which represents the quality of the goods lost according to a certain time ratio, which we attribute to the cost according to the price of the goods.

5.5 Data Analyse Method

Among the data required in the above-mentioned models, we mainly pre-process and transform the supply and demand data, sea freight distance and its unit cost data, and other data not mentioned below are directly referenced.

5.5.1 Supply and demand data processing

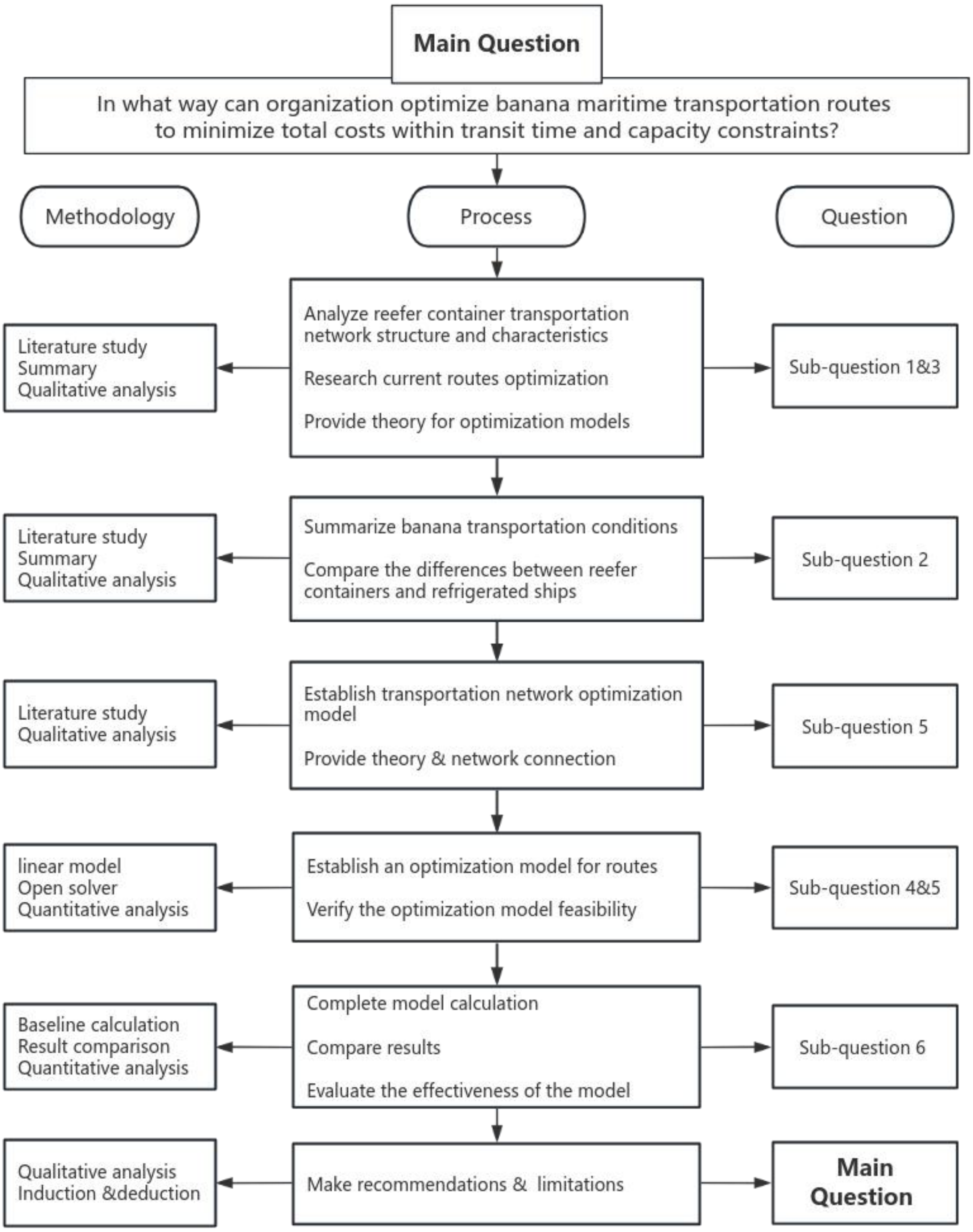
Collecting annual banana export import data from Ecuador to EU countries from the website as supply and demand data, because the website data only collected data from January to July 23. We use the smoothing data method for processing, which is the smoothing technique that can be used in the absence of a significant trend in the time series. They eliminate random variations in historical demand. It helps to identify patterns and levels of demand to estimate future demand. (Bhat, 2019)The method we use is the simple moving average method in the smoothing technique.

5.5.2 Shipping distance data and cost data processing

As mentioned above, the author converts the shipping distance data into shipping time data, and choose a more authoritative shipping website to seek quotations, which includes the shipping time data from the starting point to the transit point and the transit point to the end point and its total cost data. It is also more referential in reality.

5.6. Research Framework

Figure4: Research Framework



As indicated in the research framework image below, the author created six sub-questions to address the study's primary questions. We also integrated the study's research methodology and using a variety of research techniques to provide clear, comprehensive answers to these issues.

Using a review of the literature, a summary, and a qualitative analysis, the author first looked at the composition and features of the network of refrigerated container transportation as well as the state of cold chain shipping path optimization research. The aim of this study is to address sub-questions 1 and 3 and give a theoretical foundation for the development of an optimization model for the shipping path of bananas.

Using a review of the literature, a summary, and a qualitative analysis, the author examined how banana quality changed as they were transported under various circumstances in the second stage. In order to determine which technique would be better for transporting bananas, he also contrasted the benefits and drawbacks of chilled ship transportation versus refrigerated container shipping. This section responds to sub-question 2.

The author creates a refrigerated container transportation network optimization model in the third step using methods from qualitative analysis and literature study in an effort to reduce transportation costs for the container liner company. This model also establishes network connections for further research. and provided a response to sub-question 5.

In the fourth phase, the author created an optimization model for the transportation route of refrigerated containers based on the transportation costs incurred by the cargo owner, and then used the export of bananas from Ecuador to the EU as an example to confirm the model's viability; Mainly employed quantitative analytical research methodologies to develop linear optimization models, and used Open solver to solve the data. Sub-questions 4 and 5 are mostly addressed in this section.

In order to compare the outcomes and assess the viability of the model, the author uses quantitative analytic techniques to perform benchmark calculations on the pooled data in the fifth stage. The author employs qualitative analysis in the sixth phase to condense and extract all study materials in order to address the primary issues and constraints, make recommendations, and put those recommendations into practice.

Chapter6 Linear programming model building

In this chapter we present our research methodology and data. We start with listing our basic assumptions, next we build mathematical models and detailed explanations are given.

6.1 Basic Assumptions

To make the modeling process more convenient, combined with the actual operation of refrigerated container transportation, this article focuses on refrigerated containers.
We container sea freight network makes the following assumptions:
(1) A reefer container is transferred at most twice during transportation, that is, the sea between each group of ODs.The route consists of up to four ports.
(2) We assume that all containers in the model are loaded with goods, and do not consider the impact of empty container transfer and rental boxes..
(3) It is assumed that the temperature in the reefer container remains unchanged during the whole process of transportation, and the temperature is the cargo in the containers.
Corresponding optimal transport temperature.
(4) The cargo quality loss of a single reefer container is calculated based on the average mass loss of all goods in the container.
(5) The reefer container shipping network is relatively stable, and random emergencies such as natural disasters and wars are not considered
Impact of line networks.
(6) Only one container ship type is configured on each route, and multiple ship types are not considered to be used together in the same route
situation.
(7) All containers in the model are 20-foot TEU type, excluding other container types.
(8) Each route in the maritime network is a fixed operation, that is, the transit time and port of call of the route are fixed.

6.2 Objective function

The goal of reefer container sea route optimization minimizes the total cost under the condition of satisfying constraints and basic assumptions, including transportation cost, cargo loss cost, loading and unloading handling cost and storage cost.
According to the cost composition of the reefer container shipping network analyzed below, a mathematical optimization model is established to minimize the total cost of the reefer container shipping network, and the objective function is shown in the following equation:

$$\mathrm{MinZ} = C_t + C_l + C_h + C_s \tag{6.1}$$

Z: The total cost of the reefer container shipping network
C_t: The total cost of transportation in the reefer container shipping network
C_l: Total cost of cargo loss in reefer container shipping networks
C_h: The total cost of loading and unloading of reefer container shipping networks
C_s: Total cost of stockpiling in reefer container shipping networks

6.2.1 Shipping Costs
Transportation cost is the sum of transportation costs between all OD pairs in the more maritime route determined by the total cost of transportation.
The formula

$$C_t = \sum_{o \in O} \sum_{d \in D} \sum_{r \in R_{od}} \sum_{(i,j) \in A} \sum_{h \in H_{ij}} q_{od}^r y_{ij}^r x_{ij}^h C_{ij}^h \tag{6.2}$$

C_t: The total cost of transportation in a reefer container shipping network
N: The set of all port nodes in the maritime network, O is the set of origin port nodes, T is the set of pure transit port nodes, D is the set of terminal port nodes.
R_{od}: Main reefer container path from either origin port node O to any end port node D.
Collection, if a group of ODs cannot be connected through existing routes, the corresponding R_{od} of the group ODs is an empty set;
A: A collection of arcs between port nodes in a maritime network.

H_{ij}: A selectable set of routes on the arc from port node i to port node j, where $(i, j) \in A$.

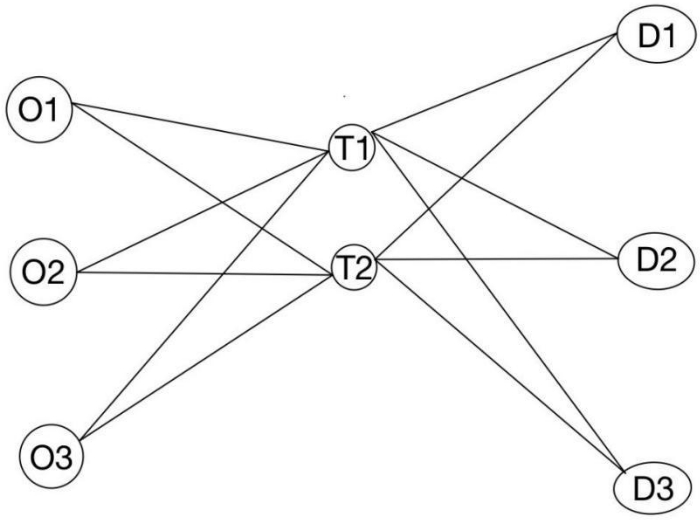
C_{ij}^h: Select the unit transportation cost for route h from port node i to port node j, where $(i, j) \in A$, $h \in H_{ij}$

Decision variables, meaning as follows:
q_{od}^r : Number of refrigerated container traffic (TEU) transported from Origin Port Node O to Terminal Port Node D via sea route r,$r \in R_{od}$

y_{ij}^r: Sea Route Selection variable, 0-1 variable, 1 if Sea Route r includes arcs from node i to node J, otherwise $0 (i, j) \in A, r \in R_{od}$.

x_{ij}^h: Route selection variable, 0−1 variable, 1 if route h is selected from node i to node j for transportation, otherwise 0, where $(i, j) \in A$, $h \in H_{ij}$.

Figure 5: Simplified shipping route



6.2.2 Cost of loss of goods

Cargo loss is calculated by the rate of mass loss and transit time of goods in refrigerated containers, as follows

$$C_l = \sum_{o\in O}\sum_{d\in D}\sum_{r\in R_{od}} q_{od}^r \varphi TP \quad (6.3)$$

$$C_{t1} = \sum_{(i,j)\in A} y_{ij}^r \sum_{h\in H_{ij}} x_{ij}^h t_{ij}^h \quad (6.4)$$

$$C_{t2} = \sum_{\substack{(i,j),(k,j)\in A \\ h_1\in H_{ij}, h_2\in H_{ki}}} y_{ij}^r x_{ij}^{h1} y_{ki}^r x_{ki}^{h2}\, t_i^{h1,h2} \quad (6.5)$$

In the formula:

C_l:Total cost of loss of cargo quality in reefer container shipping networks

φ :The rate of mass loss of goods is determined by the proportion of quality loss of goods converted into hourly goods

P :The value of the goods inside the reefer container

The transportation time can be divided into two parts, namely the sea transportation time and the port operation time.

C_{t1}: Sea transportation time

t_{ij}^h: Select the transit time of the route h from node i to node j (h), where $(i, j) \in A$, $h \in H_{ij}$

C_{t2}: Port operation time;

$t_i^{h1,h2}$: The port operation time (h) generated by the transshipment of the reefer container from route $h1$ to route $h2$at node i, $h1$ is the route on which the reefer container travels from port i to port j, and h2 is the route taken by the reefer container from port k to port i, which is calculated from the moment when route h2 leaves port i minus the time when route h1 arrives at port i.

The mass loss rate of the cargo is 0.00376% per hour (Yang D,2014).

6.2.3 Loading and unloading costs

Loading and unloading costs are determined by the port and volume of reefer containers, as follows

$$C_h = \sum_{o \in O} \sum_{d \in D} \sum_{r \in R_{od}} \sum_{(i,j) \in A} q_{od}^r y_{ij}^r (Z_i + Z_j) \quad (6.6)$$

C_h: Total cost of handling in reefer container shipping networks

Z_i: The cost of loading a reefer container per container at port node i

Z_j: The cost of unloading a reefer container per container at port node j

Here for transportation between any two ports, the cost of one loading and one unloading is calculated, that is, for direct transportation, only the loading cost of the origin port and the unloading cost of the terminal port are calculated, and for transit transportation, the transit port needs to calculate the unloading and loading costs.

6.2.4 Storage Costs

$$C_s = \sum_{o \in O} \sum_{d \in D} \sum_{r \in R_{od}} \sum_{(i,j) \in A, k \in A} T_k B_k q_{od}^r y_{ij}^r \quad (6.7)$$

C_s: Total cost of stockpiling in reefer container shipping networks.

B_k: The unit cost of stacking reefer containers at transfer port node k.

T_k:Storage time at Transit port k.

6.3 Constraints

6.3.1 Transit Time Constraints

For any set of ODs, the reefer container shipping path selected must meet the corresponding transit time constraints.

The details are as follows:

$$\forall r = R_{od}, [C_{t1} + C_{t2}] \leq T_{od} \quad (6.8)$$

In the formula:

C_{t1}: Sea transportation time

C_{t2}: Port operation time

T_{od} :The maximum transit time of reefer containers from Node o at the port of origin to Node d at the port of destination. Where $o \in O, d \in D$.

6.3.2 Supply and demand balance constraints

The sum of the reefer container supply of all origin ports in the reefer container shipping network should be equal to the sum of the reefer container demand of all terminal ports, and for any one origin port, the total outflow of refrigerated containers should be equal to the refrigerated container supply of the port, and for any terminal port, the total outflow of its reefer containers should be equal to the refrigerated container demand of the port, as follows:

$$\sum_{o \in O} G_o = \sum_{d \in D} G_d \quad (6.9)$$

$$\sum_{d \in D} \sum_{r \in R_{od}} q_{od}^r = G_o, \forall o \in O \quad (6.10)$$

$$\sum_{d \in D} \sum_{r \in R_{od}} q_{od}^r = G_d, \forall d \in D \quad (6.11)$$

Go : reefer container supply (TEU) at the origin port node o, where $o \in O$.

Gd : Reefer container demand (TEU) at the terminal port node d, where $d \in D$.

6.3.3 Maximum load constraint of reefer containers in ports

For any port node in the reefer container shipping network, the reefer container flow at that node cannot exceed the port's reefer container storage capacity, as follows：

$$\sum_{o \in O} \sum_{d \in D} \sum_{r \in R_{od}} \sum_{(i,j) \in A} q_{od}^r y_{ij}^r \leq L_i, \forall i \in N \quad (6.12)$$

In formula： L_i: Refrigerated Container Storage Capacity (TEU) at Port Node i

6.3.4 Constraints on the number of transfers

According to the basic assumption of the model, the reefer container undergoes up to two transit times during transportation, which means that the sea route of the reefer container includes up to three routes, and the direct transportation is one route, so the following formula is obtained.

$$1 \leq \sum_{(i,j) \in A} y_{ij}^r \leq 3, \forall r \in R_{od} \quad (6.13)$$

6.3.5 Shipping Capacity Constraints

For each leg of the route, the volume of reefer containers transported through the route shall not exceed the reefer container capacity of the route, as follows:

$$\sum_{o \in O} \sum_{d \in D} \sum_{r \in R_{od}} q_{od}^r y_{ij}^r x_{ij}^h \leq L_{ij}^h, \forall (i,j) \in A \quad (6.14)$$

In formula： L_{ij}^{h}: Reefer container capacity for route h on the arc from port node i to port node j（TEU）, where $(i,j) \in A$， $h \in H_{ij}$.

6.3.6 The variable is not a negative constraint

For any set of ODs, the volume of reefer containers on any sea route is obviously non-negative,
The details are as follows:

$$q_{od}^{r} \geq 0, \forall o \in O, d \in D, r \in R_{od} \tag{6.15}$$

According to the optimization model proposed in Equation (6.1) and the constraints proposed in Equation (6.8) to Equation (6.15), the optimization model of reefer container shipping network in this research is constituted.

Chapter 7 Analysis and Results

In the previous chapter, we completed the construction of our linear optimization model, and in this chapter we mainly solved the last problem in the sub-problem: how can the optimization model be applied to the actual scenario? We take Ecuador, the largest banana importer in Europe, as an example, and select the three European countries with the highest import volume, namely the Netherlands, Germany and Belgium as the importing countries, and select the ports of these three countries for data input and analysis.

7.1 Model input parameters

7.1.1 Port data

Most of Europe's bananas come from Latin American countries, such as Ecuador, the world's largest banana exporter ('All About Bananas | Producers, Where They're Grown & Why They Matter', n.d.-b). And most bananas are transported by sea in refrigerated containers. At 2021,there had 4,700,000 tons bananas export from Latin America to EU('EU Bananas and Plantains Ask for Equal Treatment', n.d.),This is fed into our model as a supply and demand constraint. According to the port construction situation of various countries and the import and export volume of bananas, this research selects 9 major container ports to form a collection of port nodes. These include 3 ports of origin, In Latin America, bananas can leave from three different ports: Port of Callao, Puerto de Guayaquil or Puerto de Posorja.(patricia, 2022),The three destination ports are the ports of Antwerp, Rotterdam, Hamburg, and the two pure transit ports Port of Cristobal and Bilbao (Search a schedule - MSC EN Shipping Schedules, n.d.), Since bananas in Europe are in a state of continuous imports, the calculation in this research chooses a one-year cycle. There are a total of 24 paths that can be selected, not all of which are listed below.

Figure 6: Sketch map of shipping network of EU's import of banana in Ecuador

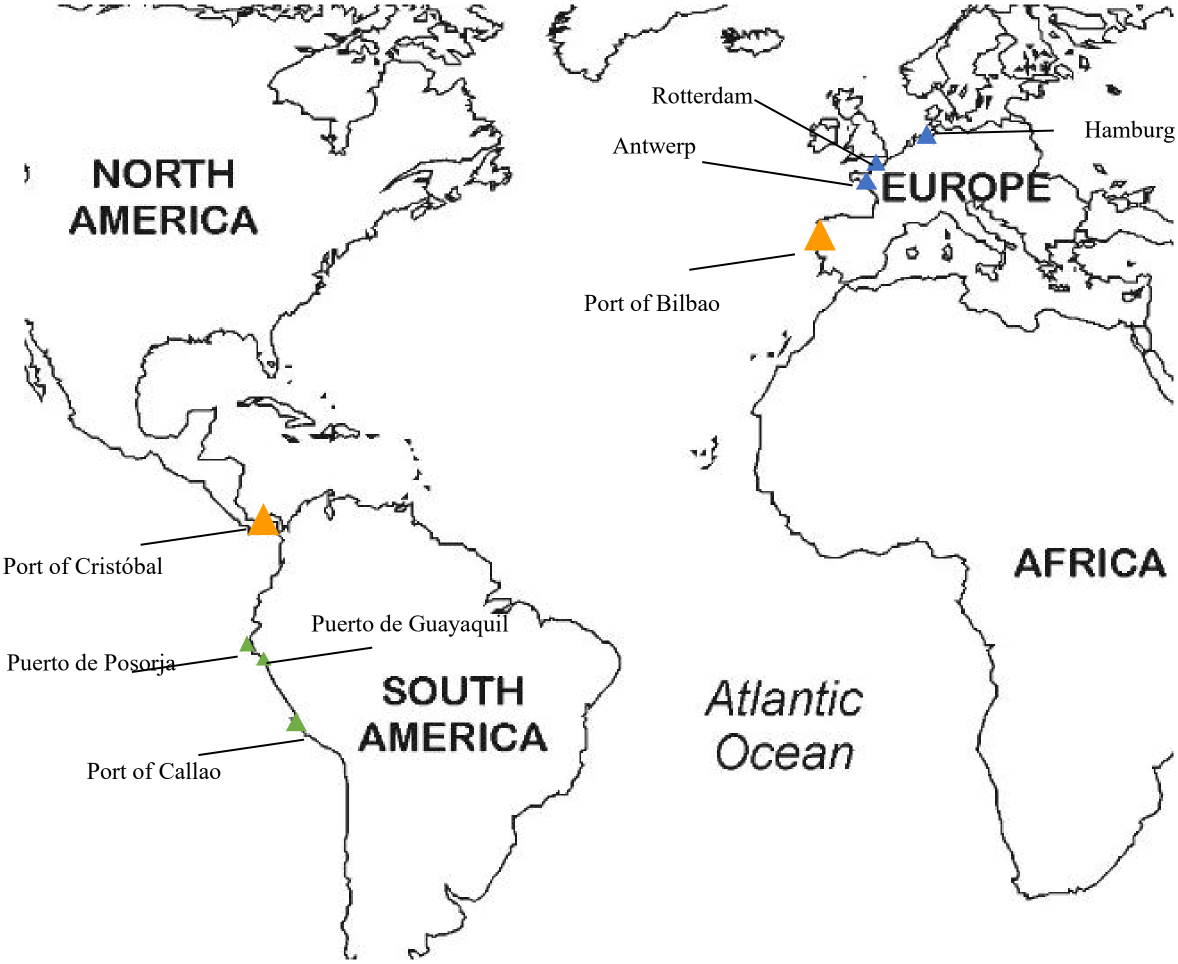


Table3: Port node of the container shipping network

Name of origin port	**O1**	**O2**	**O3**
Number of origin port	Port of Callao	Puerto de Guayaquil	Puerto de Posorja
Name of destination port	**D1**	**D2**	**D3**
Number of destination port	Antwerp	Rotterdam	Hamburg
Name of transit port	**T1**	**T2**	
Number of transit port	Cristóbal	Port of Bilbao	

7.1.2 Transport time data / unit cost data

In order to calculate the cost per kilometer of sea freight, we need to enter the time data for different routes, as well as transit time data.
The freight rates between ports are shown in Table 3.

As for the cost data, due to the large changes in market prices, we have sought quotations per unit of container between different nodes on the official website of the shipping company for inquiry, and the unit of measurement here is calculated as per 20-foot-tall container. The cost quotation includes transportation costs, port handling costs, withdrawal fees and all other miscellaneous charges, which is in line with the market inquiry rules and is easy to calculate.

Regarding the transportation time data, the straight-line distance is quite different from the real shipping company's transportation distance, and the relationship between the transportation distance and time is greatly affected by the transportation speed. Therefore, we will make an inquiry directly in the same way as the above cost data, and the shipping time data will be given directly on the shipping company's website.

In order to ensure the validity of our route optimization results, we conducted a multi-party comparison of prices and an inquiry between nodes in addition to the network identified in the previous section, and determined that our transportation routes and transportation times were within a small range to achieve more realistic and effective results.

The following are the transportation distance and cost from each O point to T point and the transportation distance and cost from each T point to D point. The final cost and transportation distance is the cost and distance of OT+TD.

Table4: Shipping cost per 20ft container between port nodes and shipping schedule

Shipping cost(USD)/Transport time			
number of port	O1	O2	O3
T1	1,080.00	810.00	810.00
	6 Days	5 Days	5 Days
T2	2,892.06	2,530.40	2,530.40
	43days	35 Days	38 Days

Shipping cost(USD)//Transport time		
number of port	**T1**	**T2**
D1	1,071.00	1,241.30
	24 Days	2 Days
D2	1,071.00	1,342.19
	23 Days	7 Days
D3	1,071.0	1,470.33
	25 Days	11 Days

Source：(iContainers, n.d.)

7.1.3 Port Capacity data

The following table shows the capacity of reefer containers in each port, using the reefer container plug-in outlets owned by each port as the measurement data.This data represents the maximum refrigerated container capacity that can be passed through each port.

Table 5: Table of connecting capacity of refrigerated containers in each port

Reefer containers capacity (per 20ft container)								
number of port	O1	O2	O3	T1	T2	D1	D2	D3
capacity	3,510	1,510	3000	1,100	1,143	8,500	18,500	3,100

Source：

(2.1 Ecuador Ports Assessment | Digital Logistics Capacity Assessments, n.d.),(2.1.3 Panama Port of Manzanillo International Terminal | Digital Logistics Capacity Assessments, n.d.),(Reefer container throughput in main European ports., n.d.)

7.1.4 Supply and Demand Data

The most important point in the linear optimization model is that the number of origins and destinations needs to be equal, in this model, this means that the number of bananas exported by Ecuador to the Netherlands, Germany, and Belgium needs to be equal to the number of bananas imported from Ecuador by these three countries. We collected data reports on the market. The fastest-growing destination in the first seven months of 2023, driven by an increase in purchases in the Netherlands, which increased by 16.08% to almost 16.2 million banana boxes, Germany, with 9.7 million cases purchased (+39.50%), and Belgium, with 6.9 million cases (up 6.64%). We use the exponential smoothing method to average the seven-month data into how many bananas are imported by Ecuador in each month, so as to predict the total annual imports.(Ecuadorian Banana Exports to the EU-27 up until July Increased by 23.5%, 2023)

Table 6: Annual supply and demand table of European Union bananas in 2023 (unit: box)

Unit:BOX	Port of Callao	Puerto de Guayaquil	Puerto de Posorja	total
Supply	**8434286**	**39360000**	**8434286**	**56228571**
	NL(Rotterdam)	**DE(Hamburg)**	**BE(Antwerp)**	
Demand	**27771429**	**16628571**	**11828571**	

Since our cost data is 1 unit of calculation per container, we convert it into container-based data. The conversion logic is that each container can carry 500 boxes of bananas.(Wild, 2024)

Table 7: Annual supply and demand table of European Union bananas in 2023 (unit: Container)

Unit:container	Port of Callao	Puerto de Guayaquil	Puerto de Posorja	total
SUPPLY	**16869**	**78720**	**16869**	**112457**
	NL(rotterdam	**DE(Hamburg**	**BE(antwerp**	
Demand	**55543**	**33257**	**23657**	

This data corresponds to the model, it is Supply and demand balance constraints.

7.2. Analysis Result

The results were obtained using the open solver in Excel, a high-performance mathematical programming solver for linear programming, mixed integer programming, and quadratic programming.(Guide To Solvers - Open Solver For Excel | PDF | Linear Programming | Nonlinear System, n.d.)
We used the solver to solve two different results, which were to allow them to be imported into one country and then trucked to each country, and to be shipped to each port depending on the demand in each country. This is done because there are tariff-free agreements within the European Union, and there is no positive correlation between the borders of various countries and the distance between their ports and cities in that country.
So we first calculate the route from Ecuador to the same port in the EU, and add the cost of post-port transportation, which ends in each country's capital. Then we constrain the import volume of each country to be different, which is part of the calculation of the cost of eliminating post-port transportation.

7.2.1 Result 1-European imports are not divided into countries.

This section we first uses open solver nonlinear programming to solve the data and model in the previous chapter to obtain results, and then manually calculates the model in the parameter input, compares the masterpiece results as Benchmark with the previous results to verify the results of open solver, and then does a sensitivity analysis, the process is as follows.

Table 8: Route optimizations result 1

	O1	O2	O3
T1	0	1	0
T2	0	0	0
	T1	T2	
D1	0	0	
D2	1	0	
D3	0	0	

Table 9: The cost per TEU is in the route optimization result 1(USD)

	O1	O2	O3
T1	0	810	0
T2	0	0	0
	T1	T2	
D1	0	0	
D2	1071	0	
D3	0	0	

Table 10: Time cost is in the route optimization result 1(Day)

	O1	O2	O3
T1	0	5	0
T2	0	0	0
	T1	T2	
D1	0	0	
D2	23	0	
D3	0	0	

In the table, we use the 01 variable to indicate whether we choose the path or not, and we can see that the optimal path is from O2 to T1, and then from T1 to D2 is the optimal route. A single container shipment cost a total of $1881 and took 28 days. The total annual cost of expenses is:$211531617

Table 11: Sensitive analysis in the route optimization result 1

Cell	Name	Final Value	Reduce cost	Objective Coefficirnt	Allowable Increase	Allowable Decrease
H20	D1 T1	0	99	3453	99	99
I20	D1 T2	0	2928	1448	2928	2928
H21	D2 T1	1	0	3354	4660	4660
I21	D2 T2	0	3544	2064	3544	3544
H22	D3 T1	0	199	3553	199	199
I22	D3 T2	0	4085	2605	4085	4085
H13	T1 O1	0	369	1676	369	369
I13	T1 O2	1	0	1306	4660	4660
J13	T1 O3	0	0	1306	0	0
H14	T2 O1	0	1187	7327	1187	1187
I14	T2 O2	0	0	6140	2928	2928
J14	T2 O3	0	309	6450	309	309

From this sensitivity analysis, it is not difficult to see that under the condition of route selection, if the unit cost of transportation of T1-D2 increases by 99 US dollars, the route will change.

7.2.2Result 2-European imports are divided into countries

In this section, we will solve the problem in the same way as in the previous section and change the constraint to divide the import demand data into three ports, and we can get the following results.

Table 12: Route optimizations result 2

	O1	O2	O3
T1	1	1	1
T2	0	0	0
	T1	T2	
D1	1	0	
D2	1	0	
D3	1	0	

Table 13: The cost per TEU is in the route optimization result 2(USD)

	O1	O2	O3
T1	1080	810	810
T2	0	0	0
	T1	T2	
D1	1071	0	
D2	1071	0	
D3	1071	0	

Table 14: Time cost is in the route optimization result 2(Day)

	O1	O2	O3
T1	6	5	5
T2	0	0	0
	T1	T2	
D1	24	0	
D2	23	0	
D3	25	0	

In the table, we use the 01 variable to indicate whether we have selected the path or not.

Here are the results:

D1: O3-T1-D1, the total cost is 29 days, the total cost is $40,526 per container, and the total annual cost is $958,722,612.2.

D2: O3-T1-D3, the total cost is 28 days, the total cost is 72411 US dollars per container, and the total annual cost is 4021937633 US dollars.

D3: O3-T1-D3, the total cost is 30 days, the total cost is $50125 per container, and the total annual cost is 1667038041 USD.

The total cost on this shipping route is $303,689,124.71.

7.2.3 Comparison of result 1 and result 2

From result1, D2, the Port of Rotterdam, is the best destination, so we calculate the post-port transportation costs from the Netherlands to Germany and Belgium respectively and compare them with Outcome 2. Post-port transportation is generally quoted on pallets or boxes, and we obtain data based on 20 boxes of bananas per container.
Rotterdam to Antwerp: $158 per 20 boxes of bananas(‘Container Shipping Cost Calculator , 2024.)Total annual cost was $8,775,771.
Rotterdam to Hamburg: $726 per 20 boxes of bananas(‘Container Shipping Cost Calculator , 2024.),The annual total cost was $2,4,171,291.43.

Therefore, we calculate that the total cost in result 1 is 244,478,679.9 US dollars, and the total cost in result 2 is 303,689,124. Compared with result 1, result 2 saves 19.5%.

Based on the above results, we can see that the best route is O2-T1-D2, which is the sea route from Puerto de Guayaquil to the port of Cristóbal for transit to Rotterdam, plus the route of trucking is the best solution, with a cost of 2173 USD per container and a transit time of 28 days. We calculated in the above description that the total cost in 2023 in Result 1 is US$244,478,679.92, and the annual demand is 112457 containers. We can calculate that the cost of each container on this route is US$2173.

7.2.3Benchmark Calculation
We enter and calculate the shipping cost and transit time of each container transportation in the existing model, and the result is as follows, where the optimal route is two, which are O2-T1-D2, from Puerto de Guayaquil, transfer at Cristóbal,arrive at Port of Rotterdam. And O3-T1-D2, from Puerto de Posorja,transfer at Cristóbal,arrive at Port of Rotterdam. These two routes have achieved better advantages in cost and time, with shipping cost 31% less than average and transit time 25% less than average.In this scenario, the two optimal paths are generated because the origin ports we chose are close in distance, and the transit port and arrival port play a key role in this scenario. It cost 3354USD from the port of origin to the transit port and $1306 from the transit port to the arrival port.

At the same time, we verify the correlation between shipping cost and transit time, and the correlation coefficient is 0.98, which is close to 1, so we consider that the correlation between shipping cost and transportation time in this model is highly relevant.

Table 15: Benchmark Calculation

Route	Shipping cost(USD)	Transport time/day
O1-T1-D1	5129	30
O1-T1-D2	5030	29
O1-T1-D3	5228	31
O2-T1-D1	4760	29
O2-T1-D2	4660	28
O2-T1-D3	4859	30
O3-T1-D1	4760	29
O3-T1-D2	4660	28
O3-T1-D3	4859	30
O1-T2-D1	8775	45
O1-T2-D2	9391	50
O1-T2-D3	9932	54
O2-T2-D1	7588.	37
O2-T2-D2	8205	42
O2-T2-D3	8745	46
O3-T2-D1	7897	40
O3-T2-D2	8514	45
O3-T2-D3	9055	49
Average	**6780**	**37**

Through the above analysis, it can be seen that the transportation time can significantly affect the quality loss of goods in the refrigerated container during transportation, and then determine the choice of the optimal shipping route. Therefore, the choice of transit port is very important for bananas and other self-ripening fresh fruits, and the number and time of transit seriously affect the cost of cargo transportation. Moreover, the increase in cargo quality loss of transit transportation scheme compared with direct transportation scheme is mainly due to the process of refrigerated containers waiting for transshipment at the transit port, so the port can control the quality loss of goods in the port transshipment process by strengthening the temperature control of the reefer container yard and improving the port cold chain service and management level, thereby improving the competitiveness of the port and attracting more refrigerated container transit volume.The average cost in our benchmark calculation is $4,660 and the shipping time is 28 days, so the model works.

Chapter 8 Conclusion

The last chapter aims to summarize the main findings of the study, answering the main question and six sub-questions of the study, and answering how to optimize ocean routes under the constraints of transit time and total capacity with the goal of reducing costs.

8.1 Key takeaways

This part mainly answers the six sub-questions in the research, deepens the research of the dissertation, and further answers the main questions of the dissertation research. Based on the existing research on container shipping optimization, this research considers the transportation characteristics and transportation needs of refrigerated containers, and adds cargo quality loss cost and transportation time constraints. From the perspective of cargo owners, the optimization model of refrigerated container shipping route is established, the optimal shipping route of refrigerated containers under the conditions of fixed route network and port service level is solved, and the refrigerated container shipping network including eight port nodes is selected for case analysis. An example of banana shipments from Ecuador to the European Union was carried out. The main conclusions of this research are as follows:

8.1.1 Key takeaways1: Past, present and future status of banana refrigerated container transportation

Bananas used to be mostly traded internationally by sea. Usually, this entails shipping bananas in regular containers and reefer ships. However, there are issues with traditional shipping methods, like how bananas can ripen more quickly, become discolored, soften, or even rot when exposed to changes in temperature, humidity, and atmosphere. Transportation becomes inefficient as a result, and quality is lost.

As a result of technological advancements, the majority of international banana trade now uses chilled container transportation. Bananas can be kept fresher longer and with less loss when stored in refrigerators, which maintain a consistent temperature and humidity level.

Reefer containers of the future are probably going to be smarter, with IoT and more sophisticated sensors installed. As a result, the shipping company will be able to continuously check on the bananas' condition and modify the shipping environment as necessary.

In addition, future banana transportation is probably going to be more concerned with cutting carbon emissions and environmental impact due to growing concerns about sustainability. Greener transportation options could be used, like energy-efficient ships and cleaner energy sources.

In order to increase transparency, traceability, and compliance in the banana supply chain and enable efficient management of the entire chain from point of origin to point of consumption, digitalization and blockchain technology are probably going to be applied more extensively.

The shipping of banana reefer containers has advanced significantly over the years and is expected to do so in the future with regard to sustainability and technology. In addition to satisfying customer demand for premium food and a sustainable supply chain, this will help increase transportation efficiency and lower losses.

8.1.2 Key takeaways2:How to choose between bulk refrigerated ships and refrigerated containers? What is the trend?

The increasing global trade has led to a rising demand for reefer containers, crucial for transporting temperature-sensitive goods like food and pharmaceuticals over long distances. They ensure the freshness, quality, and safety of perishable items, particularly important in the food industry. Reefer containers can transport a variety of products, and modern refrigeration technology extends shelf life, reducing food waste and improving sustainability. Consumer preferences have shifted towards fresh and frozen foods, and refrigerated containers meet the demand for diverse and convenient food options worldwide.

8.1.3 Key takeaways3: What modes can be selected for the optimization of banana cold chain transportation route?

Temperature, humidity, travel time, cost, safety, and other variables are all included in the cold chain transportation optimization model for bananas. The temperature and humidity control model is designed to optimize the control of the refrigerated environment and guarantee that ideal conditions are maintained during the transportation process. It takes into account the effects of temperature and humidity on the quality of bananas. The transportation path planning model creates a path planning model and chooses the best transportation path to save time and money by taking into account the features of different transportation modes (land, air, and sea), as well as variations in temperature and humidity along different routes In order to optimize cargo capacity utilization, minimize space waste, and guarantee cargo segregation and freshness requirements, an in-cabin load optimization model was developed.

To get the best banana cold chain transport outcomes, these models can be applied singly or in combination, based on the requirements and circumstances. It takes a combination of expertise from several fields, including transportation planning, temperature control technology, and logistics, to build these models.

The goal of banana cold chain path planning is to guarantee that, when transporting fresh food products, such as bananas, the right humidity and temperature levels are maintained throughout the supply chain to preserve the goods' quality. The shortest path algorithm selects the path that takes the least amount of time, travels the shortest distance, and allows for the maintenance of the proper temperature conditions. It does this by taking into account the time, distance, and temperature in the transportation path. Incorporate the idea of time windows into the route planning to guarantee that the cargo reaches its destination on schedule and that the right temperature is maintained the entire way. A model that optimizes the environmental conditions along a path by connecting individual nodes to temperature and humidity levels on the path using a network topology diagram. A variety of goals are considered when planning the route, including reducing the cost of transportation, extending the shelf life of products, minimizing the impact on the environment, etc. In order to guarantee the quality and safety of goods in cold chain transportation, these models can be chosen and applied in accordance with particular requirements and environments. Assuring the quality of goods throughout the transportation process in the quickest amount of time and at the lowest possible cost is the primary objective of cold chain path planning.

8.1.4 Key takeaways4:How will the self-ripening characteristics of a banana affect the model?

The self-ripening characteristics of bananas have many effects on transportation costs, which are mainly related to the freshness of goods, transportation speed and condition control. The following are some of the effects that the self-ripening nature of bananas can have on transportation costs, which requires higher transportation speeds, higher equipment requirements, and the use of refrigeration equipment to control the temperature during transportation in order to delay the ripening process of bananas. Stricter temperature and humidity control requires more advanced cold chain technology and equipment, which increases equipment investment and maintenance costs. To ensure that the bananas arrive at their destination in the best quality conditions, the transportation plan may need to be more compact, reducing the time spent on stopovers and transshipments. This can add complexity and operational costs to shipping.

As a result, the self-ripening nature of bananas often leads to the need for more expensive modes of transportation and a higher level of condition control, which can have an impact on overall transportation costs.
In the linear model in this study, the self-ripening characteristic of bananas is represented as the self-ripening coefficient, which is 0.00376% per hour, i.e., 0.09% per kilogram of bananas per day, which is positively correlated with time, i.e., the longer the transportation time, the more goods are lost and the higher the cost.

8.1.5 Key takeaways5:How to optimize the banana transportation routes, and what is the impact on the company's economy ?

Based on the fixed shipping network and port service level, this thesis establishes a refrigerated container shipping route optimization model with transportation cost, cargo quality loss cost, loading and unloading cost and storage cost as the minimum and transportation time, supply and demand balance, refrigerated container capacity of the route and refrigerated container storage capacity of the port as the main constraints, to determine the optimal shipping route of refrigerated containers. The case analysis results show that the fastest transportation scheme corresponding to the lower limit of the transportation time constraint, the total cost of the reefer container shipping network is the lowest, which is determined by the distance of the route and the loss of cargo quality, and the cargo owner needs to formulate the optimal transportation plan according to the demand of the fruit market and the actual sales value of bananas. For a single set of ODs, the choice of transit port obviously affects the transportation cost and transportation quality, under the same freight rate, the fewer the number of transfers, the less time, the lower the transportation cost.

8.1.6 Key takeaways6: How can the optimization model be applied to the real-world scenario?

In this research, a linear optimization model is used for path planning, and an open solver is used to solve the model, and the results are compared under two different constraints,Under the premise that the total supply and demand remains unchanged, the shipping network remains unchanged, and the unit cost remains unchanged, we divide the analysis process into two parts. In the first part, we do not constrain the country division of the end point. We allow all goods to be transported to one port. , and then distribute it to other countries by truck and calculate its cost. In the second part, we constrain the demand of each EU country, that is, the demand of each country needs to enter from the port of that country, without the cost of truck allocation. The results are as follows.

In Result 1, we found that the optimal route is to start from Puerto de Guayaquil, pass through Cristobal Port, and then arrive at Rotterdam Port for passenger car freight. The unit cost of each container is 244,478,680USD.
In Result 2, we found that the optimal route is to start from Puerto de Posorja, pass through Cristobal, and then ship to various countries according to demand. The unit cost of each container is 303,689,124USD.

The final scheme is a multimodal transportation scheme that transports bananas from Ecuador to the Netherlands, and then uses trucks to transport bananas to Belgium and Germany. The marine route O2-T1-D2 from Puerto de Guayaquil to the port of Cristóbal for transit to Rotterdam is the greatest option, according to the results above. Additionally, trucking is the best option, with a cost of 2173 USD per container and a transit period of 28 days. The model functions since the average cost in our benchmark estimate is $4,660 and the shipment duration is 28 days. With the same amount of time, a total of 53% of transportation costs were saved. It improves the transportation cost of the shipper and ensures the freshness of the banana.

8.2 Recommendation

Bananas must be transported by sea with great care due to their self-ripening qualities and sensitivity to environmental conditions. At the same time, various factors such as technology, sustainability, and changes in the global supply chain may have an impact on the future development of banana maritime transportation. Here are some recommendations to keep bananas in peak condition during sea transport:

Select appropriate shipping vessels and containers: Select ships and reefer containers that are specifically intended to transport temperature-sensitive cargo. To offer a safe transit environment, these gadgets should be outfitted with advanced temperature and humidity control systems.

Use refrigeration equipment: The use of modern refrigeration equipment in refrigerated containers ensures perfect temperature and humidity control. This helps to slow down the self-ripening process of bananas, decreasing the rate of ripening and preserving quality.

Install a temperature monitoring system: Inside the container, install a temperature monitoring system to monitor and record temperature changes in real time. This assists in identifying problems quickly and taking the required steps to maintain good shipping conditions.

Optimize route planning: To save time, use the quickest, most direct route. To avoid potential quality loss, avoid too complex transshipment operations. Create a sensible transportation plan, use the shortest and most direct route, and decrease the number of stopovers and transfers to save time and money on transportation.

Technological innovation: Pioneering advancements in ship and reefer container technology, including the introduction of more sophisticated temperature and humidity control apparatus to enhance accurate regulation of the self-ripening properties of bananas.

Applications for the Internet of Things (IoT) and smart technologies: Expand the use of IoT devices and sensors to track and monitor temperature, humidity, and banana location in real time, as well as to remotely adjust shipping conditions.

Sustainable Transportation: To lessen carbon footprints, encourage more environmentally friendly maritime transportation options with low-emission, more energy-efficient ships. To increase the sustainability of transportation, take into consideration the use of renewable energy, better ship design, and route planning.

Collaboration in the Supply Chain: Encourage the cooperative functioning of the worldwide supply chain and enhance the exchange of information, logistics, and funds among its different links. Boost coordination to increase transportation's dependability and efficiency.

8.3 Limitation

This research considers the transportation needs and characteristics of refrigerated containers and conducts theoretical analysis and applied research on the optimization of refrigerated container shipping network, but there are still many shortcomings. The reefer container shipping network is a very complex system, and there are many problems that need to be further deepened, mainly including the following aspects:

This thesis only studies the maritime transport of refrigerated containers, and in the future, the land transportation and storage of refrigerated containers should be further studied, and the whole process of refrigerated container transportation should be optimized.

There are many differences between refrigerated containers and ordinary containers, and this research considers factors such as cargo quality loss, transportation time constraints, refrigerated container capacity of routes and refrigerated container storage capacity of ports, but it is still not comprehensive enough, such as refrigerated containers have high carbon emissions, etc., follow-up research needs to consider more factors to make the optimization model more comprehensive.

Bibliography

Evans, E. A., Ballen, F. H., & Siddiq, M. (2020). Banana Production, Global Trade, Consumption Trends, Postharvest Handling, and Processing. Handbook of Banana Production, Postharvest Science, Processing Technology, and Nutrition, 1–18. https://doi.org/10.1002/9781119528265.ch1

FAO (2014). Issue Brief: Battling Black Sigatoka Disease in the Banana Industry. Available at http://www.fao.org/3/a-as087e.pdf (accessed 20 December 2018).

Maersk Line. 2009. Cool Facts. Accessed October 5. http://www.maerskline.com

2.1 Ecuador Ports Assessment | Digital Logistics Capacity Assessments. (n.d.). Retrieved 13 August 2023, from https://dlca.logcluster.org/21-ecuador-ports-assessment#id-2.1EcuadorPortsAssessment-PosorjaDeepwaterPort(GuayaquilArea)

2.1.3 Panama Port of Manzanillo International Terminal | Digital Logistics Capacity Assessments. (n.d.). Retrieved 13 August 2023, from https://dlca.logcluster.org/213-panama-port-manzanillo-international-terminal

(12) APICS Dictionary 13th ed | Frank g—Academia.edu. (n.d.). Retrieved 9 May 2023, from https://www.academia.edu/31291212/APICS_Dictionary_13th_ed

Advantages of refrigerated containers for refrigerated transportation equipment_Engineering Technology_Refrigeration Information. (n.d.). Retrieved 12 January 2024, from https://www.zlt.net/mobile/news/476/3/12645.html

All About Bananas | Producers, Where They're Grown & Why They Matter. (n.d.). *Banana Link*. Retrieved 30 May 2023, from https://www.bananalink.org.uk/all-about-bananas/

Arnone, M., Mancini, S., & Rosa, A. (2014). Formulating a Mathematical Model for Container Assignment Optimization on an Intermodal Network. *Procedia - Social and Behavioral Sciences*, *111*, 1063–1072. https://doi.org/10.1016/j.sbspro.2014.01.141

Aung, M. M., & Chang, Y. S. (2014). Temperature management for the quality assurance of a perishable food supply chain. *Food Control*, *40*, 198–207. https://doi.org/10.1016/j.foodcont.2013.11.016

avcontentteam. (2017, February 28). What Is Linear Programming? Definition, Methods and Problems for Data Scientists. *Analytics Vidhya*. https://www.analyticsvidhya.com/blog/2017/02/lintroductory-guide-on-linear-programming-explained-in-simple-english/

Banana price (Europe), April, 2023—Data, chart. (n.d.). TheGlobalEconomy.com. Retrieved 30 May 2023, from https://www.theglobaleconomy.com/World/banana_prices_eu/

Bananas: Export value share by country worldwide 2022. (n.d.). Statista. Retrieved 12 January 2024, from https://www.statista.com/statistics/716154/banana-export-value-share-worldwide/

Bananas Exports by Country 2021. (n.d.). Retrieved 18 April 2023, from https://www.worldstopexports.com/bananas-exports-country/?utm_content=cmp-true

Bhat, A. (2019, June 27). Data Collection Methods: Sources & Examples. *QuestionPro*. https://www.questionpro.com/blog/data-collection-methods/

Chou, C.-C., Kuo, F.-T., Gou, R.-H., Tsai, C.-L., Wong, C.-P., & Tsou, M.-C. (2010). Application of a combined fuzzy multiple criteria decision making and optimization programming model to the container transportation demand split. *Applied Soft Computing*, *10*(4), 1080–1086. https://doi.org/10.1016/j.asoc.2010.05.021

Container Shipping Cost Calculator [2024]. (n.d.). *Freightos*. Retrieved 12 January 2024, from https://www.freightos.com/freight-resources/container-shipping-cost-calculator-free-tool/

Crecen las exportaciones de banano de Ecuador a la Unión Europea – Acorbanec. (n.d.). Retrieved 12 January 2024, from https://acorbanec.com/2023/09/27/crecen-las-exportaciones-de-banano-de-ecuador-a-la-union-europea/

Dong, J.-X., Lee, C.-Y., & Song, D.-P. (2015). Joint service capacity planning and dynamic container routing in shipping network with uncertain demands. *Transportation Research Part B: Methodological*, *78*, 404–421. https://doi.org/10.1016/j.trb.2015.05.005

Dyk, F. van, & Maspero, E. (2004). An analysis of the South African fruit logistics infrastructure. *ORiON*, *20*(1), Article 1. https://doi.org/10.5784/20-1-6

Ecuadorian banana exports to the EU-27 up until July increased by 23.5%. (2023, September 15). https://www.freshplaza.com/north-america/article/9559759/ecuadorian-banana-exports-to-the-eu-27-up-until-july-increased-by-23-5/

Eden, M., & Colmer, C. (2010). Improved cold chain management: Efficiency and food safety through international project results. *Food Science & Technology*, *24*(1), 30–32.

EU Bananas and plantains ask for equal treatment. (n.d.). *FruitToday*. Retrieved 21 August 2023, from https://fruittoday.com/articulos/eu-bananas-and-plantains-ask-for-equal-treatment/

Flick, D., Hoang, H. M., Alvarez, G., & Laguerre, O. (2012). Combined deterministic and stochastic approaches for modeling the evolution of food products along the cold chain. Part I: Methodology. *International Journal of Refrigeration*, *35*(4), 907–914. https://doi.org/10.1016/j.ijrefrig.2011.12.010

Generic model for the prediction of remaining shelf life in support of cold chain management in pork and poultry supply chains | Journal on Chain and Network Science. (n.d.). Retrieved 1 October 2023, from https://www.wageningenacademic.com/doi/10.3920/JCNS2008.x089

Goedhals-Gerber, L. L., & Khumalo, G. (2020). Identifying temperature breaks in the export cold chain of navel oranges: A Western Cape case. *Food Control*, *110*, 107013. https://doi.org/10.1016/j.foodcont.2019.107013

Good Cold Chain Management Practices—Google Scholar. (n.d.). Retrieved 1 October 2023, from https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=+Good+Cold+Chain+Management+Practices&btnG=

Guide To Solvers—OpenSolver For Excel | PDF | Linear Programming | Nonlinear System. (n.d.). Scribd. Retrieved 12 January 2024, from https://www.scribd.com/document/615752235/Guide-to-Solvers-OpenSolver-for-Excel

Han, J.-W., Zhao, C.-J., Qian, J.-P., Ruiz-Garcia, L., & Zhang, X. (2018). Numerical modeling of forced-air cooling of palletized apple: Integral evaluation of cooling efficiency. *International Journal of Refrigeration*, *89*, 131–141. https://doi.org/10.1016/j.ijrefrig.2018.02.012

Hao, C., & Yue, Y. (2016). Optimization on Combination of Transport Routes and Modes on Dynamic Programming for a Container Multimodal Transport System. *Procedia Engineering*, *137*, 382–390. https://doi.org/10.1016/j.proeng.2016.01.272

He, J., Huang, Y., & Chang, D. (2015). Simulation-based heuristic method for container supply chain network optimization. *Advanced Engineering Informatics*, *29*(3), 339–354. https://doi.org/10.1016/j.aei.2014.08.001

How Fast Does a Cargo Ship Go? (n.d.). Retrieved 12 January 2024, from https://www.packsend.com.au/blog/how-fast-does-a-cargo-ship-go/

How Much Do Shipping Containers Cost? 2023 Pricing! (2023, January 7). https://www.containeraddict.com/how-much-does-a-used-shipping-container-cost/

iContainers. (n.d.). Retrieved 21 August 2023, from https://my.icontainers.com/quotes/67939c92-d5a0-4550-bbf6-e6c2d7f9d3fd

Joshi, R., & Banwet, D. (2011). A Delphi-AHP-TOPSIS based benchmarking framework for performance improvement of a cold chain. *Expert Syst. Appl.*, *38*, 10170–10182. https://doi.org/10.1016/j.eswa.2011.02.072

Kim, K., Kim, H., Kim, S.-K., & Jung, J.-Y. (2015). I-RM: An intelligent risk management framework for context-aware ubiquitous cold chain logistics. *Expert Systems with Applications*, *46*. https://doi.org/10.1016/j.eswa.2015.11.005

Ksciuk, J., Kuhlemann, S., Tierney, K., & Koberstein, A. (2023). Uncertainty in maritime ship routing and scheduling: A Literature review. *European Journal of Operational Research*, *308*(2), 499–524. https://doi.org/10.1016/j.ejor.2022.08.006

Laguerre, O., Hoang, H. M., & Flick, D. (2013). Experimental investigation and modelling in the food cold chain: Thermal and quality evolution. *Trends in Food Science & Technology*, *29*(2), 87–97. https://doi.org/10.1016/j.tifs.2012.08.001

Meng, Q., & Wang, S. (2012). Liner ship fleet deployment with week-dependent container shipment demand. *European Journal of Operational Research*, *222*(2), 241–252. https://doi.org/10.1016/j.ejor.2012.05.006

Mercier, S., Villeneuve, S., Mondor, M., & Uysal, I. (2017). Time–Temperature Management Along the Food Cold Chain: A Review of Recent Developments. *Comprehensive Reviews in Food Science and Food Safety*, *16*(4), 647–667. https://doi.org/10.1111/1541-4337.12269

Ng, M. (2015). Container vessel fleet deployment for liner shipping with stochastic dependencies in shipping demand. *Transportation Research Part B: Methodological*, *74*, 79–87. https://doi.org/10.1016/j.trb.2015.01.004

Oliva, F., & Revetria, R. (2008). A system dynamic model to support cold chain management in food supply chain. *Proceedings of the 12th WSEAS International Conference on Systems*, 361–365.
Optimizing overseas container transportation: A case involving transatlantic ports—Hugo Maučec, Anton Ogorelc, Ratko Zelenika, Drago Sever, 2015. (n.d.). Retrieved 1 October 2023, from https://journals.sagepub.com/doi/abs/10.1177/1475090213513249
Qualitative vs Quantitative Research: What's the Difference? (2023, December 18). https://www.simplypsychology.org/qualitative-quantitative.html
Reefer container throughput in main European ports. (n.d.). Retrieved 13 August 2023, from https://iifiir.org/en/news/reefer-container-throughput-in-main-european-ports
Reefer ships versus containers. (2013, June 3). https://www.freshplaza.com/north-america/article/2109657/reefer-ships-versus-containers/
Reefer vessels.pdf. (n.d.). Retrieved 28 March 2023, from https://wayback.archive-it.org/all/20090326013334/http://crosstree.info/Documents/reefer%20vessels.pdf
Sharma, S., & Pai, S. S. (2015). Analysis of operating effectiveness of a cold chain model using Bayesian networks. *Business Process Management Journal*, *21*(4), 722–742. https://doi.org/10.1108/BPMJ-10-2014-0105
Tran, T. T., Browne, T., Veitch, B., Musharraf, M., & Peters, D. (2023). Route optimization for vessels in ice: Investigating operational implications of the carbon intensity indicator regulation. *Marine Policy*, *158*, 105858. https://doi.org/10.1016/j.marpol.2023.105858
Wagh, S. (n.d.). *Research Guides: Public Health Research Guide: Primary & Secondary Data Definitions*. Retrieved 12 January 2024, from https://researchguides.ben.edu/c.php?g=282050&p=4036581
Wang, S., & Meng, Q. (2014). Liner shipping network design with deadlines. *Computers & Operations Research*, *41*, 140–149. https://doi.org/10.1016/j.cor.2013.08.014
Wang, S., Meng, Q., & Sun, Z. (2013). Container routing in liner shipping. *Transportation Research Part E: Logistics and Transportation Review*, *49*(1), 1–7. https://doi.org/10.1016/j.tre.2012.06.009
Wild, R. (2024, January 13). *Is it bananas to try to simplify shipping size?* https://www.thetimes.co.uk/article/is-it-bananas-to-try-to-simplify-shipping-size-3njfwbv8f
Yahia, E. (2010). Cold chain development and challenges in the developing world. *Acta Horticulturae*, *877*, 127–132. https://doi.org/10.17660/ActaHortic.2010.877.9
两全其美的水果运输方法：专门冷藏集装箱船. (2017, October 25). https://www.freshplaza.cn/article/8809191/liang-quan-qi-mei-de-shui-guo-yun-shu-fang-fa-zhuan-men-leng-cang-ji-zhuang-xiang-chuan/
主页 | 能源 | 联合国粮食及农业组织. (n.d.). Retrieved 18 April 2023, from https://www.fao.org/energy/home/en/
冷藏船的怎么样(冷藏船的优缺点)—汽车观察网. (n.d.). Retrieved 12 January 2024, from https://www.autoobserver.net/ycgl/26218.html

厄瓜多尔的香蕉业. (n.d.). Retrieved 12 January 2024, from http://www.mofcom.gov.cn/article/ae/ai/200212/20021200060481.shtml

DNV. (September 30, 2022). Projected growth of seaborne trade between 2022 and 2050, by cargo type and decade [Graph]. In Statista. Retrieved October 01, 2023, from https://www-statista-com.hr.idm.oclc.org/statistics/1364121/growth-demand-seaborne-trade-forecast-decade/