



Air China Cargo route optimization

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Abstract

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<p>For cargo airlines, in the face of large and complicated air cargo demands, determining appropriate air cargo hub airports, allocating existing cargo planes to different flight segments, and allocating cargo flow to different transport routes and modes can reduce transport costs and improve transport efficiency. Therefore, it is of great practical significance to study the related problems in air cargo route optimization.</p> <p>This paper first puts forward the main problems existing in the air transport route of the enterprise air express: unreasonable route selection leads to high cost. In order to solve this problem, an in-depth analysis is made on the influencing factors of air cargo air transportation route selection. Finally, an air cargo air transportation route optimization model considering transshipment under the fully connected network is established, aiming at the optimal cost and reducing the route with low cargo volume, and taking the volume demand and cost as constraints. The effectiveness of the model and algorithm is proved by using genetic algorithm to compare and analyse the solution results before and after optimization in terms of cost and low cargo routes.</p> <p>Through the above research, the writing of this paper and the optimization process have proved the effectiveness of the optimization method, and put forward a beneficial scheme to solve the current Air China Cargo air transport route selection problem, and put forward a beneficial scheme to solve the current Air China cargo air transport Route selection problem, the results were compared before and after the optimization, in which the air transportation cost was reduced by 11% and the cost per kilogram was reduced by 3%, low-cargo routes down by 7 percentage points. Finally, some suggestions for Air China cargo management and the conclusion of this thesis are given.</p>
Key words Air Cargo, Route optimization, genetic algorithm

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1 Introduction

Air cargo is a very important part of modern logistics transportation. Compared with other modes of cargo transportation, air cargo has the main characteristics of fast transportation speed, large space span, high transportation safety, not restricted by the ground, etc. These characteristics make it very suitable for the transportation of some fragile, valuable, perishable, high time value items. Such as precision instruments, valuables, fresh perishables, emergency items, etc. Before the war between Russia and Ukraine, the volume of global air freight will continue to rise. Air freight rates have fallen as war, high energy prices, inflation, high retail inventories and a renewed focus on the services sector have sapped demand for goods in the consumer market. In addition, reduced capacity in China's manufacturing centers due to COVID-19 policies has also curbed exports. In addition, reduced capacity in China's manufacturing hubs due to COVID-19 policies has also curbed exports by air and sea carriers. Capacity is still low, about 8 percent below 2019 levels, according to carnoc.com(2023), as passenger aviation has yet to resume all pre-pandemic flights.

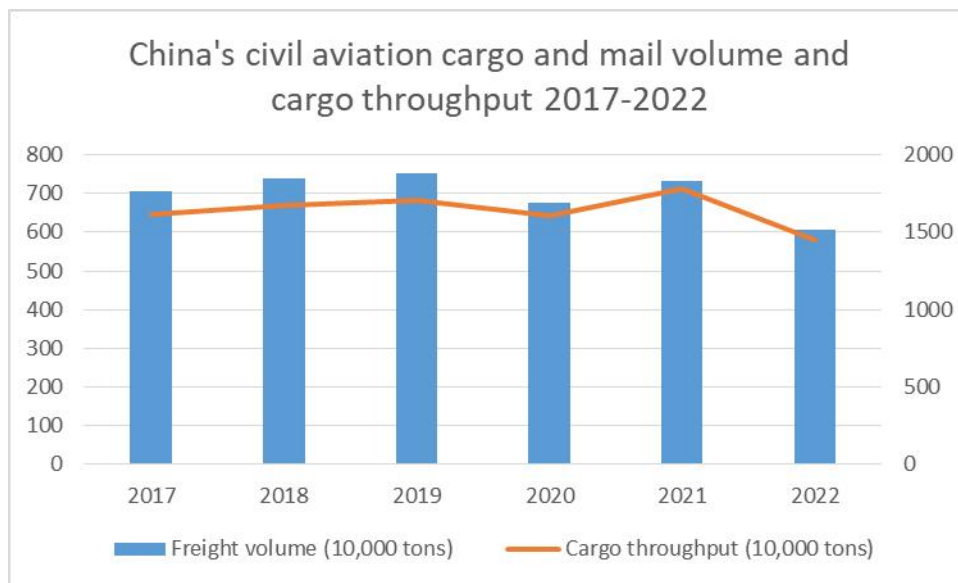


Figure 1 China's civil aviation cargo and mail volume and

cargo throughput 2017-2022 (Adapted from the Civil Aviation Industry Development Statistical Bulletin from 2017 to 2022)

According to Civil Aviation Resource (NetCARNOC.com) (2023), 2023 begins with a challenging business environment, continuing uncertainties including the Russia-Ukraine conflict, inflation and Labour shortages. But it is still possible to be cautiously optimistic about air cargo, with yields higher than before the pandemic. Production in the largest market for air cargo has been stabilised as China has moved much faster than expected to exit its dynamic quarantine policy. As companies do more business with China, much-needed demand will pick up. Air cargo volume in March 2023 was 7.3% lower than in the same month in 2022. It was down slightly from February (down 5.4%). The drop in demand shows that air cargo demand in the region has yet to stabilise following the reopening of China in January. The region's available capacity (ACTK) increased 23.6% year on year, with strong capacity growth associated with the continued recovery of the passenger market and increased belly capacity. This also represents that the whole cargo plane transport is still facing the problem of high transport cost caused by the small amount of goods.

1.1 Research significance

In view of the high cost and insufficient utilization of all-cargo aircraft in Air China Cargo transport route selection, this paper proposes solutions through the optimization of cargo hub airport location and transport capacity allocation. The optimization problem of air cargo transportation route selection for Air China Cargo Corporation is studied. First of all, the research further enriched the air cargo transport route selection related research. Most of the current researches on air express air transport route selection focus on the optimization of air cargo transport network and the traffic flow allocation of various routes. Most of them belong to the research on future air cargo business and network development planning based on current data, rather than the actual aviation network of air cargo enterprises. This paper takes air freight as the main body of research to optimize the transport route, and reduces the operating cost on the basis of considering the actual demand for goods in the model, so as to select a lower cost route for air express air transport, which is of great significance to the development of the enterprise at the current stage, and also provides reference and reference for the operation of similar enterprises.

1.2 Research question

The purpose of this paper is to improve the current problems of high operating costs and timeliness faced by most air cargo services. Air cargo route optimization is a highly complex and nonlinear mathematical planning problem, which needs to be solved by modern computer technology and modern optimization methods (Ren Juanjuan 2019, 17-20.). At present, genetic algorithm and

particle swarm optimization are common optimization algorithms for air logistics distribution route optimization (Jin Wenzhou, ZHU Zixuan, Wu Wei-Tiao, et al. 2020, 89-97.). Taking Air China Cargo company as an example, this paper analyzes the existing air freight routes of the company, establishes the route optimization model considering transit under the fully connected network based on the theory of multiple commodity flows, and then uses the genetic algorithm to solve the problem - on the basis of ensuring the timeliness of air transport links, the transportation path with lower cost and shorter route is selected for Air China Cargo company's air freight business. Finally achieve the purpose of reducing the cost.

1.3 Research methods

On the basis of the existing research results, the paper uses the methods of literature, field research and mathematical model to study the problem to be solved.

(1) Literature data method: The problem studied in this paper is the transportation route optimization of air cargo companies. Therefore, air cargo, air cargo network and air cargo transportation path optimization are selected as keywords, and relevant literature is summarized and analyzed, finally concluding the research status and necessity of air cargo transportation path optimization.

(2) Field investigation method: Collect relevant information of Air China Cargo company through field investigation, analyze the enterprise's existing routes, cargo volume of each navigation point, existing fleet and its information, and the costs of various links such as take-off and transfer.

(3) Mathematical model method: On the basis of the research of relevant literature and basic theories, the optimization model of air cargo transport route considering transit for Air China Cargo Company is established. The genetic algorithm is improved to solve the problem, and the corresponding comparative analysis process is designed to prove the effectiveness of the model.

1.4 Structure of the research

This paper will put forward solutions to the above problems, and the specific solutions are shown in the figure. The structure of the paper is as follows:

Chapter One, introduction. This paper introduces the research background, purpose and significance, as well as the question of the research and the solutions and ideas.

Chapter Two is literature review and theoretical basis. This chapter reviews and summarizes air express, express transportation path optimization and air express transportation path optimization from three perspectives. At the same time, relevant theoretical basis is introduced, and all previous studies are summarized to provide ideas and methods for subsequent studies, also the algorithm selection. Then draw a conclusion

Chapter Three: Theories related to air cargo. Introduction, air cargo concept and characteristics, air cargo operation process, air cargo network analysis, and hub location method introduction.

Chapter Four: Present situation of Air China Cargo. Analyze the operation situation, as well as the existing routes, air cargo transport mode, summarize the existing problems of all cargo aircraft transport.

In Chapter Five, the optimization model is constructed and solved. Combined with the specific situation, the cost and low cargo routes and cargo demand function are analyzed and unified dimensional processing is carried out to construct the model. The model is solved, and the effectiveness of the solution results, problem solving and result analysis are proved by comparing the results of the optimization scheme and the actual operation results.

Chapter Six: Conclusion and prospect. This paper summarizes the content of the paper and draws a conclusion, and puts forward future research prospects for air freight air transport route optimization.

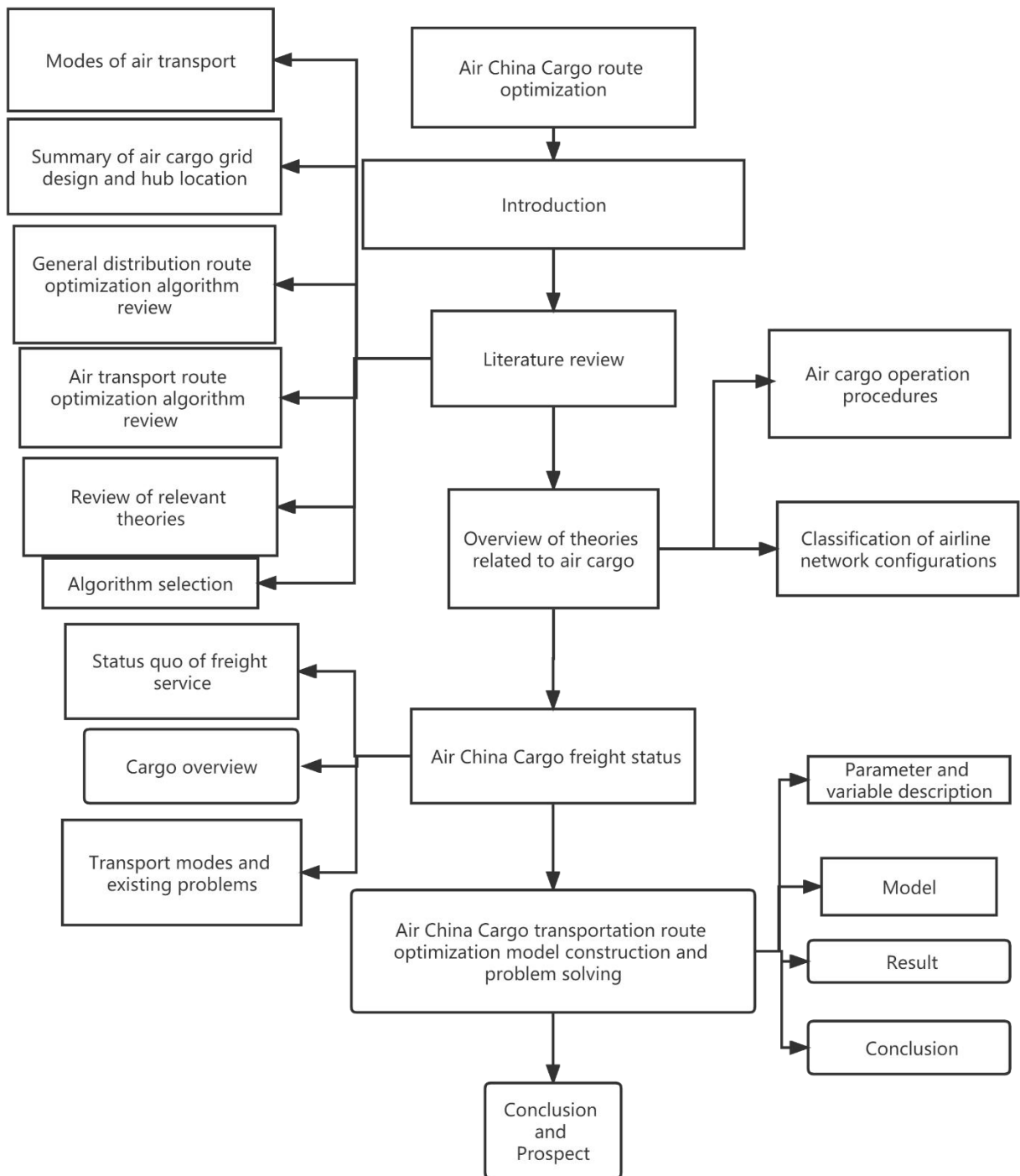


Figure 2 structure of the thesis

2 Literature review

This chapter focuses on the literature review, and summarizes the routing optimization, aviation grid, and model algorithm, and finally gives the conclusion.

2.1. Modes of air transport

Hiroshi Ohashi, Tae-Seung Kim (2005, 149-159) et al. analyzed the influencing factors in air cargo route selection by establishing logit model. Based on the air cargo data in Northeast Asia, the paper discusses the influence of monetary cost and time cost on the selection of transshipment airport. The results show that carriers are more sensitive to airport time cost. Yonghwa Park, Jung Kyu Choi, Anming Zhang (2009, 321 - 334) made a comparative study of FedEx, TNT and EMS in South Korea by using analytic hierarchy process. And UPS four air express companies in the accuracy, security, agility, economy and reliability of five aspects of the service status, and proved that the accuracy and agility of express service is the most critical element. Lacquer Chunhua (2013, 45-49.) analyzes the feasibility of development of air rail combined transportation mode in China based on the theory of concurrency-game, and proposes that the "soft connection" of air rail can be tried first, and that after mature development, "hard connection" will be gradually tried. Tian Zhenzhong (2014, 88-90) sorted out the current operating status of aviation logistics of Zhengzhou Airport, analyzed and concluded that the development of aviation logistics has advantages in policy, location, industry and service, and proposed relevant suggestions for the development direction and strategy of aviation logistics of Zhengzhou Airport through horizontal comparison with other foreign airports. Jiang Li (2015, 40-45) pointed out that at present, there is a "heavy passenger and light cargo" phenomenon in Chinese air transportation, and the demand for freight transportation is declining, but from the perspective of market opportunities, the air cargo has great potential for development. This paper builds a competitive advantage model of air cargo, and analyzes the problems existing in the development process of air cargo from four factors: market demand, industry competition, supply chain cooperation and enterprise resource input. Zhang (2016, 195-210.) et al. Studied the integration of flight scheduling and aircraft assignment based on discrete choice model, and proposed two mixed integer programming models: the first model solves the integration of flight scheduling and aircraft assignment, and the second model further considers travel price elasticity. Schmitt D and Gollnick V (2016) studied the air transport management system.

2.2. Summary of air cargo grid design and hub location

Zhang Wenbin (2015) chose the multi-hub axle network to plan the air express network. Based on this, he built a model for the location of transit centers and the planning of air routes, and verified it through case analysis. Wang Jing (2015) optimized the air express trunk network by referring to the characteristics of scale effect of the central axis of the axle-spoke network, taking into account such factors as inter-node transportation time, flight interval time, transportation cost, transfer cost and flight number, and established an optimization model of air express trunk network based on scale effect, and solved it by greedy algorithm. Niu Huanhuan (2016,167-168.) established a mathematical model to select aviation pivot points with the method of center of gravity and proposed a solution method. Through qualitative analysis of SF Express Company's existing aviation network, and take STO Express Company as an example to put forward the aviation hub proposal. Yang Zhongzhen et al. (2016,103-114.) built a two-layer optimization model to optimize the air cargo network by comprehensively considering the belly capacity of passenger aircraft and the cargo capacity of all-cargo aircraft. The objective function of the upper layer model was to minimize the total cost of the transport enterprise, designed the structure of the cargo network and distributed the cargo capacity. Zhang (2017,158-173) et al. studied the integration problem of hub positioning and aircraft type assignment in the context of air cargo, established two mixed integer programming models respectively according to the number of hub airports allowed to pass through, and then adopted a two-stage hybrid algorithm to solve large-scale problems. He Zhenggang et al. (2018, 34-41) established an air cargo mode selection model based on the background of the hub-and-spoke cargo route network, considering the time ceiling required by customers. The model assumed that there were three cargo modes, namely, the direct mode of loose air, the transfer mode of loose air and the transfer mode of all-cargo aircraft, and proposed a hybrid heuristic algorithm combining greedy algorithm and genetic algorithm to solve the above model. However, this paper only considers the demand of a single origin-destination pair and a single full-cargo aircraft, without considering the split of goods, which is far from the reality. Liu Xinyu (2021) proposed that in the context of hub-and-spoke route network structure, the selection of hub airport has an important impact on the results of cargo route optimization of airlines.

2.3 General distribution route optimization algorithm review

At present, most transportation path optimization problems are those with vehicles as the research subject, while those with air cargo transportation as the research subject are few. Wei Zhen (2013, 110-114) incorporated the risk characteristics into the path optimization model, took into

account the two objectives of cost and risk to obtain the optimization results, and analyzed the final results. Wen Xuhong, Lin Boliang, Wang Long, Chen Lei, Ji Lijun (2013, 117-121) also considered the constraint of reasonable detour when solving the route optimization problem of railway traffic flow. Liu (2019, 1-19.) studied the optimization of container distribution organization of China-Europe freight trains. Currently, most China-Europe freight trains are direct round-trip transportation, that is, empty containers are directly loaded onto the returning outbound train after they arrive at the station and unload. The paper proposes that after the inbound cargo containers arrive at the station and unload, the empty containers can be stored in the container yard of the station, and the containers can be organized to arrange the transportation frequency of the empty containers on their return trip. Taking Alashankou Station as an example, this paper establishes a distribution organization optimization model with the goal of minimizing the storage time of incoming China-Europe freight trains in the storage yard, and then solves the model based on the idea of genetic algorithm to obtain the result of the combined container return transportation. Zhao (2019, 1-16.) et al. Pointed out that the China-Europe freight trains are often transported point-to-point without cargo integration, resulting in low load rate and low profit rate. In order to solve these problems, the paper analyzed the selection of potential integration centers and the optimization of integration routes from the perspective of complex network evolution. Zhang Pengfei (20220,95-96) et al. studied cold chain logistics distribution route based on immune optimization algorithm, and realized logistics distribution optimization from the aspects of safety and cost by intelligent hybrid algorithm based on genetic algorithm and particle swarm optimization algorithm. Wang Xingtong (2021, 13-16.) et al. studied the application of fast simulated annealing algorithm in path planning to provide a further solution to the path optimization problem.

2.4 Air transport route optimization algorithm review

Zhang Peiwen et al. (2020, 1432-1446) combined airline capacity allocation with network design, established a joint decision optimization model and designed genetic algorithm to solve it. The results showed that the joint decision model saved 9.39% of the cost compared with the traditional network model. Xian Mengyu (2020,101-105), aiming at the demand of accurate route calculation in aviation logistics field to reduce distribution cost, abstracting the route optimization problem into the hub location problem (HLP) in mathematics through modeling analysis, and then improving and solving the genetic algorithm. Wang Y studied the application of ant colony algorithms in route optimization of air logistics. In response to the limitations of traditional ant colony algorithms, Wang Yu proposed improved strategies. However, the path optimization results obtained were greatly influenced by the weight coefficients of transportation time and transportation cost, and more appropriate weight coefficients (2021, 76-80) sufficient was needed to be

selected later. Yang Xiaokang and Song Xiufeng (2022, 109-112) optimized the traditional genetic algorithm and proposed an adaptive variation method to solve the problem of single population of aviation logistics which has fallen into the local optimal solution.

2.5 Review of relevant theories

Multi-commodity Flow Problem refers to the transmission of various commodities between the start node and the target node in a transport network composed of different transport nodes and different types of transport modes. It is necessary to select a more cost friendly transport route for the transmission of goods through more efficient allocation of the internal transport resources. Xu Wei (2018, 436-449) et al. used mathematical model method to solve the problem of multiple commodity flows. Yao Chengyuan (2018) pointed out that the aviation business of express enterprises is generated between different cities, and different air waybills are circulated and transported between several originating airports and destination airports, i.e., between airport pairs. Therefore, express products constitute multi-commodity flows in this network, and the optimization of the transportation path of air express products belongs to the path planning problem of multi-commodity flows

2.6 Algorithm selection

The essence of air cargo transportation path optimization is an optimization problem, which belongs to NP-hard problem. There are two solutions to this problem. First, it is an accurate algorithm represented by Dijkstra algorithm and Floyd algorithm. Its advantage is that it can efficiently ensure the effectiveness and accuracy of the solution, and the quality of the solution is high. However, the disadvantage is that as the complexity of solving the problem increases (1975), the computational difficulty and transportation time also increase exponentially. Therefore, this kind of accurate algorithm is not suitable for air cargo transportation path optimization under large-scale network nodes.

The other is the heuristic algorithm, which consists of two parts. The first part is the classical heuristic algorithm, which is suitable for solving simple and easy to solve small problems, while the modern optimization algorithm is based on the previous experience of scientists to solve optimization problems. This kind of algorithm has the advantages of simplicity, improving the efficiency of solving large-scale problems and avoiding falling into the local optimal.

Genetic algorithm (GA) is to use the "survival of the fittest" biological law to find the best solution. This algorithm has high global optimization ability and is suitable for solving multi-objective optimization problems.

Particle swarm optimization (PSO) was first proposed by Eberhart and Kennedy (1995, 39-43). The idea behind particle swarm optimization comes from the foraging behavior of birds. The algorithm has the advantages of fast convergence speed and simple operation. The disadvantage is that it is easy to be premature and fall into local optimum. In the field of path optimization problem, particle swarm optimization algorithm is mainly used in the path optimization problem of field robots and transport vehicles with loading function, but it is not suitable for the express transportation path optimization problem to be studied in this paper.

The Simulated Annealing algorithm (SAA) was designed and used by Metropolis (1953) and Kirkpatrick (1983). The algorithm is designed based on the principle of annealing process of metal objects. The solution is optimized by changing the motion mode of particles in the body caused by the change of temperature and internal energy. The calculation process of this algorithm is relatively simple and robust, but it also has some shortcomings, such as slow approximation speed, long execution time, persistent algorithm relative to initial value and sensitive parameter (2006). Li Changmin et al. (2020, 472-480) adopted the improved simulated annealing algorithm to solve the vehicle distribution route optimization model based on the perfect performance degree of terminal distribution, which is often used to solve the vehicle routing problem.

Ant colony Algorithm (ACO) was proposed by Colomni and Dorigo M (1991, 134-142). Ant colony algorithm has strong adaptability and solving ability when combined with other algorithms, but it also has the disadvantage of falling into local optimum.

According to the above comparison, this paper selects genetic algorithm as the basic algorithm of air express air transportation path optimization.

2.7 Conclusion

Therefore, in order to explore the Air China Cargo route optimization scheme, the method of mathematical model construction is selected. At the same time, when designing the Air Cargo route optimization model of Air China Cargo Company, the model should be built based on the existing navigation points to meet the cargo demand and reduce the routes with low cargo volume, so as to explore the optimization of the transport path for the purpose of reducing costs. Finally, genetic algorithm is used to solve the problem.

3. Overview of theories related to air cargo

In a narrow sense, air cargo transport refers to a form of transport that uses aircraft or aircraft to achieve the function of cargo transport. In a broad sense, air cargo transportation refers to the door-to-door express service in which the air cargo service provider uses its own facilities and resources to receive the goods from the consignor and deliver the goods to the designated destination or consignee within the time limit specified by the consignor, and can accurately grasp all the information of the goods in the whole transportation process and provide real-time information query services to the relevant personnel. Based on the basic concept of traditional air cargo transportation, the connotation of air cargo transportation in a broad sense is further expanded. It not only extends "airport to airport" air transportation to "door to door" air transportation plus ground transportation, but also adds additional service content such as timely delivery and searchable information, which is the development and extension of traditional air cargo transportation to modern air logistics. Based on the limitations of the research content of this paper, only the content related to air cargo in the traditional sense is studied. Therefore, the air cargo transport studied in this paper is only limited to the "airport-to-airport" air transport stage, and there is no detailed research on the ground pick-up and delivery.

(1) Classification of air cargo transport

According to different classification methods (2020), air cargo transport can be divided into different categories. For example, according to the type of transportation of goods to divide, can be divided into general cargo transportation, urgent cargo transportation, special cargo transportation and owner escort.

Transport of general goods: refers to transport of general goods other than urgent and special goods;

Urgent cargo transport: refers to the shipper's request to reach the destination by the earliest flight or a limited time, and the carrier agreed to accept a form of transport;

Special cargo transport: according to the special attributes of cargo transport, the carrier adopts a special mode of transport, including animal transport, fresh and perishable goods transport, valuable goods transport, chemical dangerous goods transport, etc.

Shipper escort: A mode of transport in which the carrier permits or requires the shipper to escort the goods randomly, depending on the nature of the goods and the need for special care during transportation.

According to the means of transport used to transport goods, it can be divided into charter transport, container transport and container transport. A form of transport in which cargo is chartered by the shipper for a particular purpose by the aircraft of an air transport enterprise;

Package transport: a mode of transport in which the cargo consigned by the shipper requires a separate portion of the cargo hold of the aircraft for a certain period of time and the carrier requires special measures to guarantee it;

Package board and box transport: It is a contracted mode of transport, that is, the shipper contracts the carrier for a certain number of container boards on the aircraft of a flight line, and the carrier gives the shipper a certain preferential price.

According to the main body to undertake the transportation task, can be divided into independent transportation and outsourcing transportation.

Autonomous transport: it means that the air transport enterprise transports the goods consigned by the shipper from the starting point to the corresponding destination according to the requirements through its own equipment (full cargo aircraft or passenger aircraft belly).

Outsourcing transport: it means that air transport enterprises will separate the transport business and entrust the third party logistics enterprises to realize the transport of goods.

This paper only considers the transport mode of all-cargo aircraft autonomous transport to study the relevant issues of air cargo transport. It is assumed that the goods transported are general goods, and the transport form is not considered. In this way, the goods of different shippers can be reasonably arranged according to their own transport capacity, and they can be combined and transported by the same aircraft.

(2) Characteristics of air cargo

There are five major modern transportation modes: railway transportation, highway transportation, water transportation, air transportation and pipeline transportation. With the continuous development of economy, air transport is also developing rapidly. Especially in recent years, due to the rapid development of e-commerce, air cargo occupies an important position in the market with its unique advantages. Compared with other modes of transport, air cargo transport has the following characteristics:

(1) Fast transportation speed

Compared with other modes of freight transport, the main advantage of air freight is its fast transport speed. This is because air freight is carried by aircraft, which has a fast flight speed. The

airspeed of modern passenger aircraft is generally about 0.8 Mach, and B747 has even exceeded 0.9 Mach, that is, the speed exceeds 1000 km/h. About 20-30 times faster than a ship, 7-15 times faster than a car, 6-11 times faster than a train, and 2-4 times faster than a high-speed train. For some items requiring high timeliness, such as flowers, seafood and other fresh perishable goods or urgent items, air transport is undoubtedly the most appropriate way. And with the continuous progress of science and technology, aircraft technology will continue to improve, the operation speed will naturally continue to improve, in the future air freight will be able to better reflect its high-speed characteristics.

(2) High security

Besides speed, another feature of air transport is safety. From the perspective of accident rate, the probability of major accidents occurring in the process of air transport is only less than one in a million, which is far less than the probability of major accidents occurring in other modes of transport such as road and railway transport. From the point of view of cargo loss rate, due to the high cost of air transport, extra care will be taken in handling goods. The handling, loading and unloading and other links on the ground are strictly regulated, which greatly reduces the probability of cargo damage in the process of operation. However, in the process of air transport, due to the high performance of aircraft, In addition, the flight route has clear regulations and guidance. Under normal circumstances, there is less interference from external environment, so the flight is relatively stable, and the probability of cargo extrusion is small, so the cargo damage rate is low. Therefore, for some valuable and fragile items, such as precision instruments, porcelain and other goods, air transport is a relatively safe choice.

(3) Small implementation difficulty

For other modes of transport, more infrastructure needs to be built before the implementation of transport. For example, trains and automobiles need to build roads, while ships rely on water areas, and pipeline transport needs pipelines laid along the way. Compared with these modes, air transport is much simpler. No matter whether there are mountains, oceans or deserts between them. Therefore, in some places where geographical conditions are not suitable for the implementation of infrastructure construction along the transport route, air transport is more appropriate. For example, in mountainous areas, disaster areas, deserts and other areas, rescue operations and supplies are implemented by air transport.

(4) High transportation price

Compared with other modes of transport, the price of air freight is high. This is because the cost of air freight itself is very high. On the one hand, the price of hardware facilities such as airports and

aircraft is high, which needs to be distributed among consumers, so the price of transportation is high. On the other hand, due to the advantages of speed and safety mentioned above, the added value of air transport services is high, so the charges are higher.

(5) Low controllability

Since air transport is greatly affected by the weather, when it encounters rain, snow, fog, lightning and other weather, flights will be delayed or even cancelled, which may make the cargo cannot be delivered to the designated place within the specified time. This uncontrollable factor has a great negative impact on those goods with high time value. For example, the aircraft loaded with fresh and perishable goods cannot take off on time due to weather reasons before takeoff, or it is diverted to other airports due to weather influence on the way, which eventually causes the goods to rot, bringing great losses.

(Fengling education net, 2018)

3.1 Air cargo operation procedures

The process of air cargo transportation mainly includes consignee, air cargo agent, Airline Company and consignee. The operation process of air cargo transportation mainly includes receiving, inbound, transportation, outbound and distribution. The basic operation process is shown in the figure below:

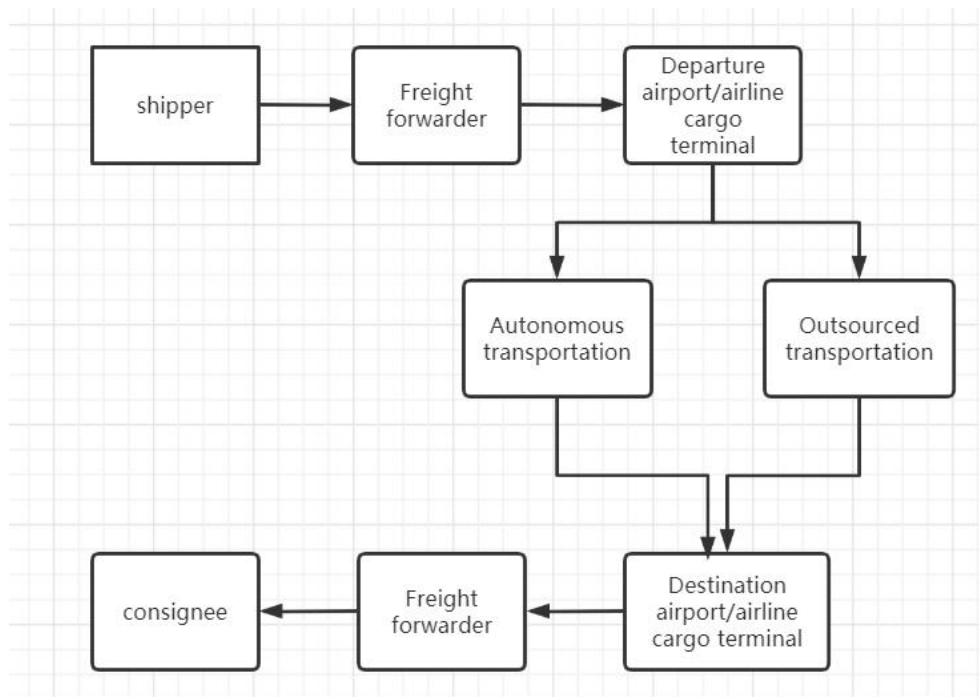


Figure 3 Air cargo flow chart

- (1) Receiving goods: there are two ways to receive goods. The first is that the consignor will send the goods to the freight agency spontaneously. The second is that the freight agency will pick up the goods according to the specific information left by the consignor.
- (2) Inbound: After receiving the cargo of the cargo owner, the air cargo agent books the space to the airline, and then sends the cargo to the cargo station of the airline or the corresponding airport.
- (3) Transportation: After receiving the goods, the airlines carry out sorting, cargo tally, storage, installation and other operations, and then transport the goods from the start airport to the destination airport.
- (4) Outbound: when the goods arrive at the destination airport of the airline cargo terminal, the air cargo agent will take out the cargo from the terminal.

Delivery: According to the consignee's information on the manifest, send the goods to the designated consignee.

From the perspective of airlines, this paper selects the air transport process in the air cargo operation process as the research object. Autonomous transport means that airlines use their own route network, aircraft and other resources to transport goods from the starting point to the destination. Autonomous transport is generally divided into passenger aircraft belly transport and cargo aircraft transport. Since passenger aircraft transport routes and frequencies are relatively fixed, there is not much room for regulation. The airline company can arrange the cargo storage according to the actual situation and arrange the appropriate transportation path, so as to achieve the goal of the lowest cost. Outsourcing transportation means that the airline company enforces the transportation business to the third-party logistics company and pays the transportation fee according to the weight of the cargo. In this sense, how airlines arrange their own cargo planes on various routes and how to arrange different cargo transportation modes and routes are of vital significance for airlines to control costs and improve resource utilization.

3.2 Classification of airline network configurations

According to different Airline structure forms, Airline Network can be divided into two types: Point-to-Point Airline Network (PPAW) and Hub-and-Spoke airline network (HSAW). City-to-city Airline routes can be developed into Linear Airline Network (LAW), that is, planes pass one or more stops on the way from the origin to the destination, and linear airline routes can be developed into spider web airline Network (SWAN). The axle-spoke route network refers to the route network mode

including hub airport and non-hub airport. The route between hub airport and hub airport is trunk, and other routes are branch routes.

(1) Hub-and-spoke route network classification

According to the different connection modes between non-hub airports and hub airports, it can be divided into single distribution and multi-distribution route network. The so-called single allocation means that a non-hub airport can only connect with the only hub airport, and the passenger/cargo flow into/out of the non-hub airport must pass through the only hub airport connected to it for transfer transportation. The so-called multi-allocation means that a non-hub airport can be connected with multiple hub airports, and the passenger/cargo flow into/out of the hub airport can be transshipped through different hub airports.

According to whether the direct connection between non-hub airports is allowed, it can be divided into strict axle-spoke route network and non-strict axle-spoke route network. The strict hub-and-spoke route network requires that there is no direct connection between non-hub airports, and the passenger/cargo flow between non-hub airports should pass through hub airports for transit transportation. A flexible hub-and-spoke route network allows direct connections between non-hub airports.

(2) Advantages of hub-and-spoke route network

Compared with the "point-to-point" network structure of direct transportation, the hub-and-spoke network has the following obvious advantages: First, transit can improve the service density of each route. Although the hub-and-spoke network structure does not change the number of airport nodes and all overall freight traffic, it can reduce unnecessary route flights in the network and increase the traffic density of each connecting route. Secondly, through the centralized allocation of resources, airlines can not only improve the interest rate efficiency of infrastructure, so that people can fulfill their responsibilities and make the best use of materials, but also obtain high economic benefits and reduce operating costs by taking advantage of the large amount of network traffic brought by hub-and-spoke network. It is found that in the operation mode of hub-and-spoke network, the aircraft passenger load rate can be increased by 5% to 10%, which improves the service quality and air carrying rate.

The economy of hub-and-spoke network is embodied in the structural economy brought by the flow of each airline connection, the benefit return of hub airport, the reorganization of airport connection path and the adjustment of network traffic. The economic benefits associated with network layout, referred to here as network structure, refer primarily to the performance of producing service costs by reducing the ability to provide the same service at different connection points within the same

network. For network-based services, the output of the network system can be enhanced by providing different services to the nodes in the network. For example, in the figure below, a company produces structural economy of a network if it can implement the exchange and sharing of people or devices on a particular node and multiple connections in a network.

As shown, there are two paths, AC and BC. When the peak demand of AC connection and the peak demand of BC connection are not displayed in the same time period, that is, when there is no conflict between the two, the service will be issued from point A, after arriving at C, C will provide equipment, personnel and other resources, and put on CB, which improves the enterprise's utilization efficiency of equipment, reduces the marginal cost of AC connection, and increases the income of BC connection. The economic characteristics of the network structure reflect the cost compensation of different network connections, which means that improving the service level of one connection will reduce the marginal cost of another connection.

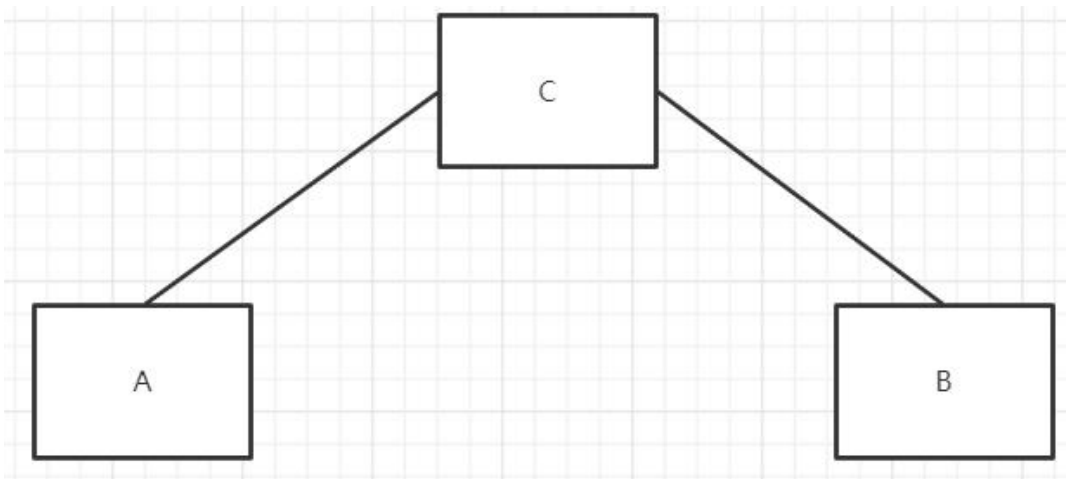


Figure 4 Three-point route connection diagram

The hub-and-spoke network allows airlines to internally convert the call of route resources between different connections, instead of the resource exchange between operators. In this way, the conflict of network users in switching between different airline networks is solved, which enables airlines to make service plans more effectively and increase the total revenue of route operation. By rationally organizing the passengers and goods entering and leaving the hub, the passengers and goods transferred from non-hub nodes can be reorganized and then transferred to other pivot points. However, the capacity of hub nodes is limited, and the technical level is also an important factor, so the economy of the network structure cannot be played indefinitely.

In the hub-and-spoke network structure, the starting point and destination location and quantity of goods flow can produce synergistic effect. In the air transport network, the hub-and-spoke service network transport goods from the starting point to the destination through the hub, so most cities can enjoy due services in the coverage area, and the air traffic coordination between non-hubs and hub nodes between urban areas can also be improved. At present, almost major airlines regard facility construction as the strategic focus of establishing service network, and the former air hub cities have been gradually transformed into multi-modal transport and air route concentrated aviation centers. For example, Chicago, Dallas, and Atlanta and so on, the number of aircraft takeoff and landing sorties has increased significantly. Flight routes and transfers between hub airports and non-hub airports are established between the same airlines, rather than between different airlines, which can save the time of transit. The hub-and-spoke network can not only bring economic benefits to airlines and customers, but also reduce inconvenient costs such as freight transfer.

(Weng Kerui 2007)

(3) Configuration selection of air cargo network

Compared with other route networks, the hub-spoke route network has good economy and can improve resource utilization. Therefore, the hub-spoke route network is chosen as the network configuration studied in this paper. Due to the difference between air cargo and air passenger transport, the optional routes are very flexible, so non-hub airports are allowed to be directly connected, and non-hub airports can be allocated to more than two hub airports at the same time. In other words, the specific route network configuration studied in this paper is a non-strict multi-distribution axle-spoke route network. In addition, in previous studies on air cargo network, scholars assumed that only hub airports could complete the transfer, just like the research on passenger transport network. But in fact, due to the flexibility of cargo transport, non-hub airports often also implement cargo transfer. Therefore, in this study, it was assumed that both hub airports and non-hub airports could transfer cargo. The difference between the two lies in the fact that the hub airport, due to its advanced facilities and concentrated resources, can transfer the maximum capacity of cargo larger than that of non-hub airports.

4. Air China Cargo freight status

Air China Cargo is a professional international cargo air transport and logistics services company. Founded in 1997, the company has become an important player in the field of international cargo air transport in China. Air China Cargo has a fleet of 15 freighters, including Boeing 747-400, 777-200F and 757-200F. The company has been expanding its global cargo network, launching new routes and increasing flight frequencies, particularly in response to growing demand for air cargo services in the Asia-Pacific region. Due to the epidemic, resulting in Zaragoza, Tokyo Narita all-cargo flight points canceled, existing routes 21. Like other airlines, China International Cargo Airlines is also facing ongoing challenges related to the COVID-19 pandemic, including travel restrictions and reduced passenger flights, which have affected air cargo capacity and rates. The company has been adapting to these challenges by optimizing its freight business and adopting new technologies, such as e-commerce platforms and blockchain-based systems, to improve the efficiency and transparency of the freight supply chain. The company's goal is to become one of the world's leading cargo airlines.

4.1. Status quo of freight service

Air China Cargo has developed into one of the major aviation logistics service providers in China. Its main business can be divided into three parts: air cargo service, air cargo terminal service and integrated logistics solution. Among them, air cargo service revenue accounts for about 70 to 80 percent. In 2020, 2021 and 2022, Air China's air cargo service revenue was 15.034 billion yuan, 18.678 billion yuan and 16.698 billion yuan, respectively. Data show that in the past three years, the number of all-cargo aircraft has remained unchanged, while the number of passenger aircraft belly cabins has increased, and the overall level of aviation capacity has remained stable. However, the turnover volume and freight volume of goods increased first and then decreased, which was mainly influenced by downstream demand changes and different types of goods transported. Among them, in 2020 and 2021, Air China Cargo ranks second only to China Southern Logistics in the market share of freight and mail turnover. In terms of freight and mail turnover, Air China Cargo ranked second only to China Southern Logistics in 2020 and third in 2021. (Yangtse Evening Post

2023)

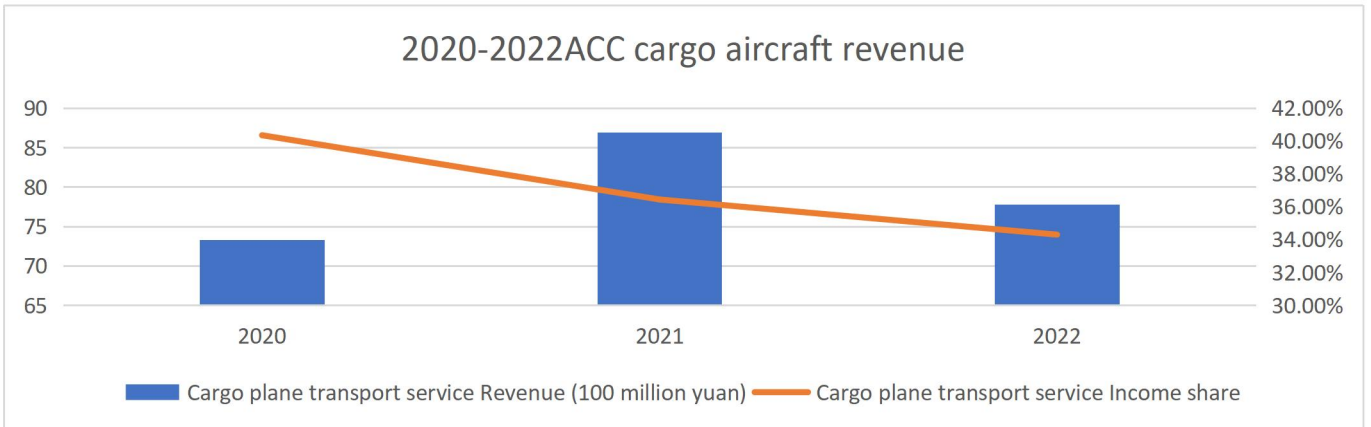


Table 1 2020-2022 Air China Cargo Ltd cargo aircraft revenue

cargo throughput 2020-2022 (Adapted from the Yangtse Evening Post 2023)

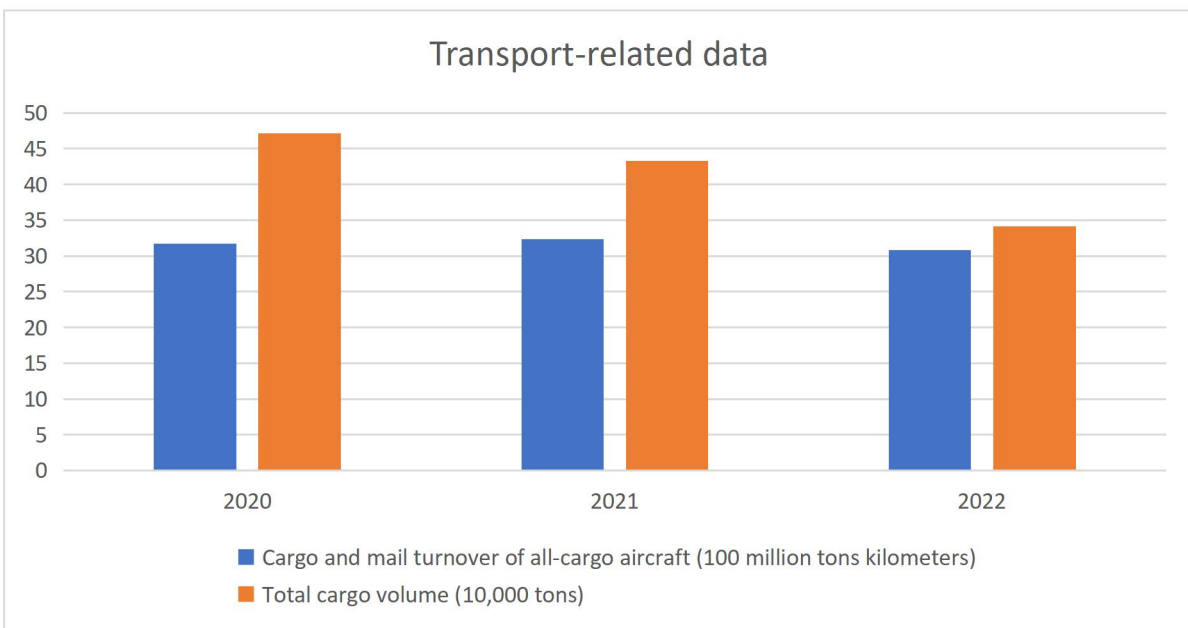


table 2 2020-2022 Air China Cargo Ltd cargo Transport-related data(Adapted from the Yangtse Evening Post 2023)

4.2 Cargo overview

Air China Cargo has a total fleet of 15 freighters, including three B747-400Fs, four B757-200SF and nine B777Fs. The B757-200SF freighter has a maximum cargo capacity of 30 tons, a maximum daily utilization rate of 15h, a maximum take-off weight of 115 tons, a maximum fuel capacity of 42,680 liters, a maximum range of 6,320 kilometers, and a maximum deadweight of 28 tons. The B777F freighter has a maximum cargo capacity of 106.5 tons, a maximum daily

utilization rate of 13h, a maximum take-off weight of 34.7 tons, a fuel carrying capacity of 117,000 liters, and a maximum range of 9,045 kilometers. The 747-400f has a maximum deadweight of 11.3 tons, a maximum daily rate of 14 hours, a maximum range of 8,240 kilometers and a maximum fuel capacity of 216,840 liters

According to the statistical annual report of Air Cargo China, the fixed cost of a takeoff of B757-200SF cargo aircraft, B747-400f and B777F cargo aircraft is 5,000 yuan, 5,000 yuan and 20,000 yuan respectively, and the variable cost is 2.42 yuan/tonnage km, 2.42 yuan/tonnage km and 0.84 yuan/tonnage km respectively.

Transportation cost cargo volume interval (kg) [0, 45) 20 yuan/kg [45,100] 12 yuan/kg [100,300) 8 yuan/kg [300,500) 5 yuan/kg [500, 1000) 3 yuan/kg [1000, ∞) 2 yuan/kg

4.3 Transport modes and existing problems

Air China Cargo company's transport modes include loose air and all-cargo aircraft. Among them, loose flight is the mode of using the belly compartment of corporate passenger aircraft to ship goods, which has the characteristics of relatively low cost, large number of flights, but the aging and loading capacity is unstable. Full-cargo aircraft is a full-cargo aircraft route fixed by enterprises with fixed weekly shifts. It is a transport mode with absolute dominance over the use of full-cargo aircraft, featuring strong disposability, large stowage capacity, relatively stable aging, but high cost, difficult access to resources and long preparation period.

The cost per kilogram of cargo in the current air cargo transport link has a great relationship with the quantity of cargo shipped on the current route, and has obvious scale effect. The larger the quantity of cargo, the lower the unit rate. According to the company's report for January and February 2023, the total cargo load rate (%) was only 22.4% and 19.9%, respectively. Since 2020, the average purchase price of jet fuel is 2937.66 yuan/ton, 4214.3 yuan/ton, and 7379.22 yuan/ton. As a comprehensive logistics service provider with air transport service as the core, jet fuel cost is one of the most important cost expenditures, and low freight rate will lead to higher costs.

At the same time, too dense scheduling leads to frequent flights with low cargo volume. Taking the section from Chongqing to Frankfurt as an example(Appendix 4), the cargo volume of flight CA643 in January this year was zero. Low cargo volume route refers to the route where cargo volume is less than 30% of the maximum deadweight among the routes where cargo volume is less than 30% of the maximum deadweight, and the proportion of low cargo volume route refers to the proportion of the routes where total cargo volume is less than 30% of the maximum deadweight in the total shipping routes. The calculation formula is the routes where total cargo volume is less than 30% of the maximum deadweight/the total shipping routes of the enterprise. The index of the

proportion of routes with low cargo volume is a major index to measure the operating status of air express business of aviation enterprises, which can effectively reflect the merits and demerits of air express transport route selection.

Air route	Weekly shift
Nanchang - Liege - Nanchang	3
Pudong -- Frankfurt -- Beijing -- Pudong	4
Pudong -- Frankfurt -- Pudong	2
Pudong -- Chongqing -- Frankfurt -- Capital -- Pudong	2
Pudong -- Amsterdam -- Pudong	3
Pudong -- Amsterdam -- Tianjin -- Pudong	1
Pudong -- Chongqing -- Amsterdam -- Pudong	2
Pudong - Amsterdam - Liege - Pudong	1
Pudong -- Amsterdam -- Zaragoza -- Tianjin -- Pudong	1
Beijing - Pudong - Los Angeles - Pudong	4
Pudong - Anchorage - Dallas - New York Kennedy - Capital - Pudong	1
Pudong -- Anchorage -- Dallas -- New York Kennedy -- Pudong	2
Pudong -- Anchorage -- Kennedy, New York -- Capital -- Pudong	1
Pudong -- Anchorage -- Kennedy -- Pudong, New York	7
Pudong -- Anchorage -- Chicago -- Capital -- Pudong	4
Pudong -- Anchorage -- Chicago -- Pudong	4
Pudong -- Chengdu -- Anchorage -- Chicago -- Pudong	2
Pudong -- Los Angeles -- Capital -- Pudong	4
Pudong -- Los Angeles -- Pudong	7
Beijing - Pudong - Osaka Kansai - Pudong	6
Pudong -- Tokyo Narita -- Pudong	6

figure 5 Air route

5. Air China Cargo transportation route optimization model construction and problem solving

Compared with air passenger transport, air freight transport is flexible as long as the goods are transported to the specified destination within a specified time. At present, only a few cargo airlines have their own passenger aircraft belly compartment for use, so this paper does not consider the self-owned passenger aircraft belly compartment transportation, air cargo flow can use its own cargo aircraft transportation or the cargo demand outsourcing to the third party enterprise transportation. In the few previous studies that considered cargo aircraft and passenger aircraft transportation to construct cargo network, it was stipulated that cargo aircraft could only be transported between hub airports, which is inconsistent with the reality. Therefore, the cargo capacity should be allocated according to the demand and capacity situation, and the global cost should be the lowest to construct the air cargo network. In addition, in order to reduce the complexity of the problem, previous studies usually stipulate that the air cargo demand of the same origin-destination pair can only be transported in one time by one way, which is also inconsistent with reality. In order to achieve the goal of the lowest total cost, airlines should fully consider the cost and capacity of various modes of transportation to allocate cargo flow. The freight demand of the same origin-destination pair can be divided into different modes of transportation, and can also be transported through different paths, allowing the split and reorganization is more conducive to achieve the goal of lower global transportation cost.

This chapter establishes a model for the problems existing in Air China Cargo transportation route selection. Firstly, the model is established based on the existing navigation points of the enterprise to select a better air transport route for air freight. Under the condition of satisfying the constraint conditions such as the volume and cargo space of each navigation point, the model minimizes the air transportation cost of air express by selecting the optimal path.

The problem of air cargo transportation route selection originates from the actual operation situation of Air China Cargo enterprises. To a large extent, reasonable and necessary model assumptions can simplify the complexity of the model and reduce the calculation amount of model solution. Therefore, the following assumptions are made in this paper for the establishment of a mathematical model for the transportation route optimization of air express air transportation links considering transit under the fully connected network:

(1) In order to ignore the labor and time cost of unpacking the air waybill, the goods of the same waybill cannot be split or LCL in the link of air transport;

- (2) Information related to the air waybill is known, including the weight of the air waybill and the start and destination;
- (3) No accidents such as lost or damaged cargo shall occur in the link of air transport;
- (4) The chargeable weight ratio of all air waybills is the same, and whether the cargo can be loaded into the aircraft is only affected by its weight;
- (5) The cargo demand of each airport does not change due to seasonal products

5.1 Parameter and variable description

OD: origin-destination, hereinafter referred to as OD

N : Set of airport nodes, index symbol is i, j, k, m, O, D .

L : Model set, model index symbol is $l, O = (1, 2, 3, \dots, 0)$, the collection of all waybills from where they originated,

U^l : Maximum capacity per Type l cargo aircraft

n_l : indicates the number of cargo aircraft of type l .

d^{OD} : The quantity required to transport goods from node o to node D .

s_{ij} : The flight distance from Airport i to Airport j .

f_l : The fixed cost for each l freighter to operate on each segment, the unit is thousand yuan.

v_l : Variable cost of operating a cargo aircraft of model l on each route segment, unit is thousand yuan/ton - kilometer.

T_l : The maximum utilization rate of each l freighter in the assigned period.

M : A very large number

y_{ij}^l : The number of flights of cargo aircraft of type l from Airport i to Airport j .

w_{ij}^l : Cargo volume carried by cargo aircraft of type l on segment $i - j$.

5.2 Model

$$\min Z = \sum_{l \in L} f_l \left(\sum_{i \in N} \sum_{j \in N} y_{ij}^l \right) + \sum_{l \in L} v_l \left(\sum_{i \in N} \sum_{j \in N} s_{ij} w_{ij}^l \right) \quad (5-1)$$

$$\sum_{i \in N} \sum_{j \in N} x_{ij}^{OD} = d^{OD} \quad \forall O, D \in N \quad (5-2)$$

$$w_{ij}^l \leq U^l y_{ij}^l \quad \forall l \in L, j \in N \quad (5-3)$$

$$\sum_{i \in N} \sum_{j \in N} y_{ij}^l t_{ij}^l \leq n_l T_l \quad \forall l \in L \quad (5-4)$$

$$x_{io}^{OD} = 0 \quad \forall O, D, i \in N \quad (5-5)$$

$$\sum_{j \in N} x_{Oj}^{OD} = x_{OD}^{OD} \quad \forall O, D \in N \quad (5-6)$$

$$x_{Dj}^{OD} = 0 \quad \forall O, D, j \in N \quad (5-7)$$

$$\sum_{j \in N} x_{iD}^{OD} = x_{OD}^{OD} \quad \forall O, D \in N \quad (5-8)$$

$$\sum_{l \in L} w_{ij}^l = \sum_{k \in N} \sum_{m \in N} x_{ij}^{km} i + \sum_{k \in N} \sum_{m \in N} (x_{jk}^{im} + x_{mi}^{kj}) \quad \forall i, j \in N, i \neq j \quad (5-9)$$

$$y_{ij}^l \in Z^+ \quad \forall i, j \in N, l \in L \quad (5-10)$$

$$x_{ij}^{OD}, w_{ij}^l \geq 0 \quad \forall i, j \in N, l \in L \quad (5-11)$$

The objective function (5-1) is to minimize the total cost; Constraint condition (5-2) indicates that origin-destination pair demand is transported by cargo plane. Constraints (5-3) mean that the cargo transport of each type of freighter on any segment shall not exceed the total transport capacity of the type; Constraint condition; Constraints (5-4) mean that the total flight time of each type of freighter shall not exceed the total maximum utilization rate of this type of aircraft; The constraint conditions (5-5) - (4-8) specify the variable form that must be 0; The constraint conditions (5-9) are the equation relation of total cargo transport volume. Constraints (5-10)-(5-11) define the value range of decision variables.

5.3 Result

MATLAB software was used to compile an algorithm to solve the model. Through calculation, it can be seen from the optimization and convergence of the objective function in the following figure that the algorithm is effective

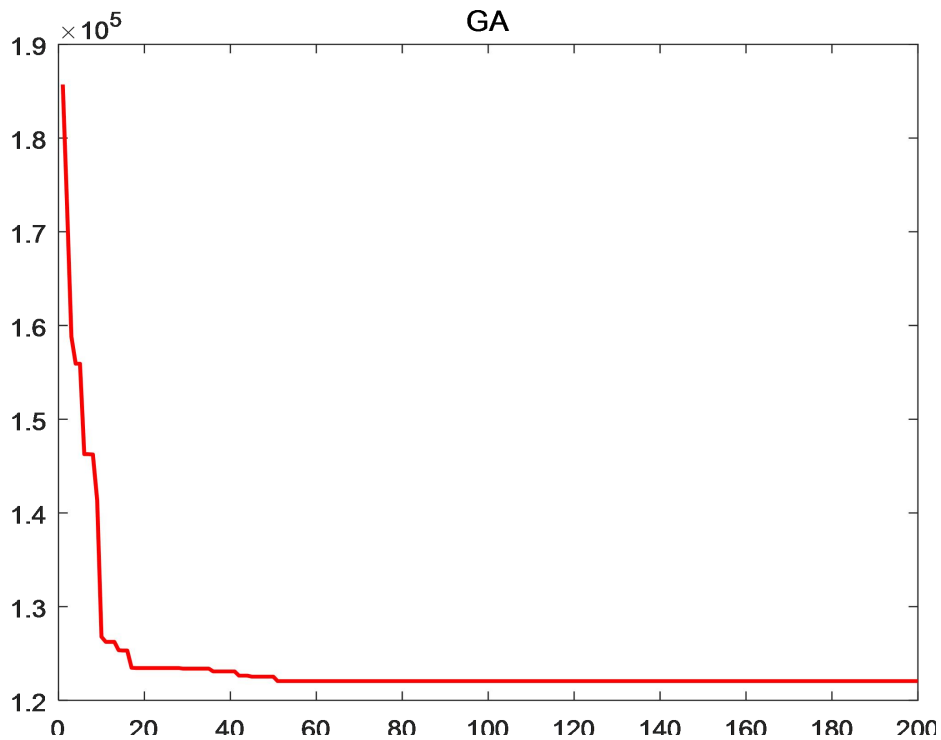


Figure 6 Objective function optimization process

Firstly, the model optimization results were compared from the perspective of cost composition. Compared with direct air transportation, the transportation cost after the optimization of the new plan was reduced by 11%, the transit operation cost increased by 33,147 yuan, and the total transportation cost was reduced by 3%. On the whole, the new transportation route realizes the scale effect of transportation and can effectively optimize the original scheme.

Cost per kilogram refers to the average price per kilogram of goods shipped by an enterprise, calculated by the formula of total cost/total cargo volume. This index is the most commonly used index to measure the operating cost of an enterprise, which can reflect the average operating cost of the enterprise and measure the advantages and disadvantages of scheduling and air express route selection. Before optimization, the cost per kilogram of the whole network is 7.82 yuan; After optimization, the cost per kilogram of the whole network is 7.59 yuan, which is reduced by 3% after optimization.

Before optimization, low-cargo routes accounted for 15%, and after optimization, 8%, down by 7 percentage points.

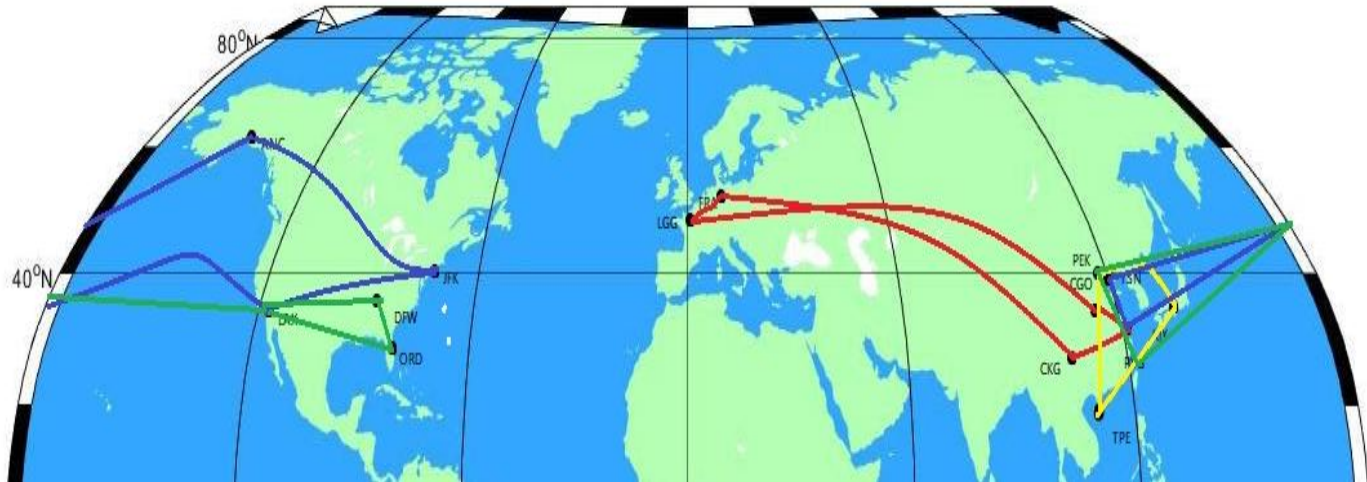


Figure 7 Route diagram

5.4 Conclusion

In this chapter, the algorithm of the model is summarized and selected, and the algorithm is improved according to the actual model. In order to solve the model, the data required by the model are sorted and summarized. The optimized results are obtained by solving the algorithm. By comparing and analysing the results before and after optimization from the cost composition and cost per kilogram, the effectiveness of the model algorithm is proved. The total cost is reduced by 3%, low-cargo routes down by 7 percentage points, which proves the effectiveness of the algorithm.

Based on the analysis of the above results and the applicability of the model, the following management decision-making suggestions are proposed for Air Cargo China in the future:

Through the analysis of the above problems and the exploration of solutions, the fundamental solution to the high cost and low cargo volume of some all-freighter routes is to adjust the all-freighter routes by inputting last week's data into weekly reports. For example, seasonal products (such as fresh goods) can be seized and the number of flights can be appropriately increased according to the sales location. At the same time, belly hold can be selected to replace some low-volume routes of all-cargo aircraft.

6. Conclusion and Prospect

The choice of transport route in air cargo transport links will affect the operation of enterprises to some extent. How to improve the economic benefits of enterprises as much as possible while ensuring the demand of freight volume, making full use of the advantages of all-cargo transport and reducing costs has become a problem faced by many air cargo enterprises in developing air transport business, which has high practical and theoretical research value.

Taking Air China Cargo enterprise as an example, this paper sorts out the problems it is facing in its air cargo business, establishes a route selection model of air cargo considering transit under fully connected network, uses genetic algorithm to solve, and finally obtains the cost optimal solution.

Through the research, the following conclusions are reached:

(1) By analyzing the current operating status of Air Cargo business and the current status of all-cargo air transport route selection of Air China Cargo enterprise, problems existing in air express business of Air China Cargo enterprise are put forward. Through the analysis of the above problems, it proves the importance of air transport route optimization with air cargo as the main research subject, and analyzes the influencing factors related to this problem.

(2) In this paper, an air express air transport route optimization model considering transit is established under the fully connected network, which is constrained by freight demand and cost. The ant colony algorithm was used to solve the above model. After the effectiveness of the algorithm was proved by iterative solution, the results were compared before and after the optimization, in which the air transportation cost was reduced by 11% and the cost per kilogram was reduced by 3%, low-cargo routes down by 7 percentage points, which fully proved the effectiveness of the model and algorithm and achieved the optimization goal.

Based on the analysis of the above results and the applicability of the model, the following management decision-making suggestions are proposed for Air Cargo China in the future:

Through the analysis of the above problems and the exploration of solutions, the way to fundamentally solve the high cost and the low cargo volume of some all-freighter routes is to input last week's data into the model with weekly reports for the adjustment of all-freighter routes. For example, seasonal products (such as fresh goods) can be seized and the number of flights can be appropriately increased according to the sales location. At the same time, belly hold can be selected to replace some low-volume routes of all-cargo aircraft.

In this paper, only total air cost and cargo demand are taken into account when establishing air cargo route selection model. In future studies, factors such as airport service level, freight forwarder service level and consideration of the cooperative relationship among airport, freight forwarder and express enterprise can be included in the model construction of transport route selection.

In order to simplify the model and solving process, only weight is considered in the air cargo loading process, but volume is not considered, that is, the foam weight ratio of the product. In addition, in the actual process of air transport, the price discount of scattered flights of different routes is different. Also the study in this paper is limited to the spatial route optimization, assuming that these routes meet the time requirements in connection and receiving of goods, without further exploring the transport capacity allocation and cargo flow allocation after adding the time factor. Therefore, in the future research, more parameters and data that are more accurate and more in line with the actual situation should be set as much as possible to ensure the reliability and accuracy of the solution results.

In this paper, the collection of data was the most difficult, because Air China Cargo did not publish the data to the public. Therefore, I went to the sales department of Air China Cargo in Chongqing for data collection. I would like to thank the staff there very much. Even so, some of the data still lacks timeliness, so there is a deficiency in building models to consider constraints. At the same time, in this survey, I further deepened my understanding of the air cargo industry and the factors affecting the current air cargo industry, so as to lay a foundation for my future work in this industry. In this process, I consulted a large number of literature materials, which supplemented my ability of mathematical modeling, and I believe it will be helpful for any work involving statistics and optimization in the future.

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Appendices

Appendix 1. Model main code program

```

function obj=updatebest(obj,X)
%% update optimal solution obj original optimal solution X new solution
if obj.BestObjn<X.Objn
obj.BestObjn=X.Objn;
obj.BestObj=X.Obj;
obj.BestSol=X.Sol;
obj.BestResult=X.Result;
end
end

function [routeinf,routedetail]=UL_CVRP(CarSeq,CustSeq,data)
routedetail=cell(0); % Specific line information
routeinf=[0 0 0 0]; % Approximate line information 1 Number of service nodes 2 distance 3 Aircraft
type
nn=0; % Vehicle number
xsol=CustSeq;
CustInf=data.CustInf;
Distall=data.Distall;
CarInf=data.FlightU;
while numel(xsol)>0 % while all tasks are scheduled
nn=nn+1; % Number of lines 1 increased
infS=CarInf(CarSeq(nn),:);
Rinf = [0, 0, infS (1), CarSeq (nn)]; %1 Number of service nodes 2 Distance 3 Aircraft type
route=[1;0;0];
% Initial Line % 1 Node number 2 Load on arrival 3 Load on departure
mm=0; % Whether the line is finished
ss=0;
while numel(xsol)>0 && mm==0 && ss<=data.MaxC

```

```

ss=ss+1;
index=xsol(1); % next node
Flag=0;
Findex=1+index;
%% Indicates whether the calculation constraint is satisfied
if index>0
NewR = [the route, catalog (3, 1)];
newR(1,end)=Findex;
newR(2,end)=route(3,end);
newR(3,end)=newR(2,end)-CustInf(index,4)+CustInf(index,3);
cache=newR(2:3,:);
cache=cache+CustInf(index,4);
newR(2:3,:)=cache;
ditz1=Distall(route(1,end),Findex); % increase distance
% Whether the load is satisfied
if sum(sum(cache>=infS(5)))==0
% %
Flag=1;
end
end
if Flag==1
rinf(1)=rinf(1)+1; % node increment
rinf(2)=rinf(2)+ditz1; % increase distance
route=newR;
xsol(1)=[]; % deleted from the node
else % If not, next bus
mm=1; % Status change
ditz=Distall(route(1,end),1); % increase distance
rinf(2)=rinf(2)+ditz; % increase distance

```

```

route=[route,[1;route(3,end);route(3,end)]]; % line update
end
end
if mm==0
distz=Distall(route(1,end),1); % increase distance
rinf(2)=rinf(2)+distz; % increase distance
route=[route,[1;route(3,end);route(3,end)]]; % line update
end
routedetail{nn}=route;
routeinf(nn,:)=rinf; % update
end
end
function Sel=selection_tournament(Score,numout,style)
%% Tournament Select Score fitness value numout number of data output,style select the number
of comparisons
Sel=zeros(1,numout);
numin=numel(Score);
for i=1:numout
r=randperm(numin,style); % Select multiple
[~,j]=max(Score(r));
Sel(i)=r(j);
end % Select multiple pick the best
function pop=rand_generate(Len_n,Encode)
%% Generate random: random generates Encode for the number of individuals generated by
Len_n within the set value range
pop=zeros(Len_n,sum(Encode.dnum)); % The range of the preset population
for j=1:Encode.degree % For each gene segment % Encode for each segment
range=sum(Encode.dnum(1:j-1))+1:sum(Encode.dnum(1:j));
cache=rand(Len_n,Encode.dnum(j));
if Encode.style(j)==1%1 real encoding

```

```

pop(:,range)=cache.*...
(ones(Len_n,1)*(Encode.bounds{j}(2,:)-
    Encode.bounds{j}(1,:)))+ones(Len_n,1)*Encode.bounds{j}(1,:);
elseif Encode.style(j)== % 2 sequential encoding
[~,index]=sort(cache,2);
pop(:,range)=Encode.bounds{j}(index);
end
end
end

%% Generate random: random generates Encode for the number of individuals generated by
    Len_n within the set value range

pop=zeros(Len_n,sum(Encode.dnum)); % The range of the preset population
for j=1:Encode.degree % For each gene segment % Encode for each segment
range=sum(Encode.dnum(1:j-1))+1:sum(Encode.dnum(1:j));
cache=rand(Len_n,Encode.dnum(j));
if Encode.style(j)==1%1 real encoding
pop(:,range)=cache.*...
(ones(Len_n,1)*(Encode.bounds{j}(2,:)-
    Encode.bounds{j}(1,:)))+ones(Len_n,1)*Encode.bounds{j}(1,:);
elseif Encode.style(j)== % 2 sequential encoding
[~,index]=sort(cache,2);
pop(:,range)=Encode.bounds{j}(index);
end
end
end

function [X,cache]=neighbor_swap(X,len_n)

%% Swap combinational optimization neighborhood operator, X: individual to be changed, len_n:
    individual dimension

cache=randperm(len_n,2);
X([cache(1),cache(2)])=X([cache(2),cache(1)]);

function [X,cache]=neighbor_insert(X,len_n)

```

```

%% Insert combinatorial optimization neighborhood operator, X: individual to be changed, len_n:
    individual dimension

cache=randperm(len_n,2);

n=X(cache(1));

X(cache(1))=[];

X=[X(1:cache(2)-1),n,X(cache(2):end)];

function [X,cache]=neighbor_2opt(X,len_n)

%% 2-opt combinatorial optimization neighborhood operator, X: individual to be changed, len_n:
    individual dimension

cache=randperm(len_n,2);

[cache,~]=sort(cache);

X(cache(1):cache(2))=X(cache(2):-1:cache(1));

classdef Model_delivery_num

properties % Data for this model

data;

nVar;

Fnum=1; % Number of targets

Minmax=-1; %-1 means finding the minimum and 1 means finding the maximum

BestObj=inf; % optimal target value

BestObjn=-inf; % fitness

end

properties % Fixed parameter

BestSol; % best encoding bit

BestResult; % optimal result

BestRecord; % Record of the best solution of the generation

MeanRecord; % Record of the average target value

TimeUse; % Usage time

EncodeStyle; % encoding mode

end

methods

```

```

function obj = Model_delivery_num(varargin) % Enter an artificial parameter
% Finds the parameter corresponding to the name
isStr = find(cellfun(@ischar,varargin(1:end-1))&~cellfun(@isempty,varargin(2:end))); % finds the
    position of the character
for i = isStr(ismember(varargin(isStr), {'data'}))% Find the same number of the input character as
    the red character
% with double quotes becomes a character
obj.(varargin{i}) = varargin{i+1}; % assigns the next position of the input character to the variable
    corresponding to the character
end
obj=Preset(obj); % pretreatment
obj=SetEncode(obj); % Sets the encoding mode of this model
end
function obj=Preset(obj)% Preset data
datan=obj.data;
obj.nVar(1)=size(datan.CustInf,1); % Number of customers
obj.nVar(2)=size(datan.FlightU,1); % The number of airplanes
end
function obj=SetEncode(obj)% Encoding mode
Encode.degree=2; % integer -- number of coding layers
Encode.style=[2 2]; % One-dimensional array input - Data class 1 for each segment of genome is
    real value 2 sequence value range required
Encode.dnum= obj.nVar; % One-dimensional array input - each encoded bit
Encod.name ={' real order ',' real order '}; % one-dimensional array input -- the name of each
    segment encoded
Encode.bounds{1}=1:obj.nVar(1);
Encode.bounds{2}=1:obj.nVar(2);
% cell body input -- two-dimensional matrix of value range required; The order requires a specific
    set of one-dimensional matrices
obj.EncodeStyle=Encode; % The class that assigns the encoding to the model
end
function [F,Fn,Detail]=CalObj(obj,Xnow)

```

```

datan=obj.data;
%% Sequence of vehicles
CarSeq=Xnow(1+obj.nVar(1):end);
CustSeq=Xnow(1:obj.nVar(1));
[routeinf,routedetail]=UL_CVRP(CarSeq,CustSeq,datan); % calculation route
f=sum(datan.FlightU(routeinf(:,4),3))+sum(datan.FlightU(routeinf(:,4),4).*routeinf(:,2));
F=f;
Fn=F.*obj.Minmax;
Detail.f=f;
Detail.routeinf=routeinf;
Detail.routedetail=routedetail;
end
end
end
clc
clear all
close all
%% data
run datain.m
%% Indicates the algorithm parameter
PopSize =100; % population size
IterMax =200; % Maximum number of iterations
para={'PopSize',PopSize,'IterMax',IterMax};
model1=Model_delivery_num('data',data);
algot1=FS_GA(para{:}); % GA
model=algot1.Solve(model1);
printall(model,'GA')
ATuse=model.TimeUse;
ABe

```


North China	90	213	183	-58%	-51%	16	36	31	-55%	-48%
East China	255	274	361	-7%	-29%	33	29	43	12%	-24%
South China	102	257	135	-60%	-24%	12	21	14	-46%	-19%
West China	41	58	35	-30%	17%	16	21	15	-22%	9%
China total	487	803	714	-39%	-32%	77	108	103	-29%	-25%

I	Volume of transportation					income				
	Current period	Last year period	Last Period	year-on-year	month-on-month	Current period	Last year period	Last Period	year-on-year	month-on-month
America	96	384	137	-75%	-30%	131	734	449	-82%	-71%
Europe	3	1191	60	-100%	-94%	4	2663	117	-100%	-97%
Asia	89	221	146	-60%	-39%	142	319	221	-56%	-36%
Total	189	1796	344	-89%	-45%	277	3716	786	-93%	-65%

Air route	Current shift	month-on-month	Freight volume (tons)	month-on-month	Sales revenue (ten thousand yuan)	Average price (yuan)
CKG-ICN	8	0	0.6	-12.4%	1.0	16.2
CKG-HKG	16	7	0.4	-92.3%	0.5	11.2
CKG-SGN	4	0	0.2	34.4%	0.2	9.3
CKG-BUD	1	-1	0.0	-100.0%	0.0	
Total	29	6	1.2	-96.8%	1.7	13.3

Originating airport	Sales mode	Nature of flight	Flight number	Destination	Weigh	Income	Number of shifts	Continent	Month
CKG	Regular shift	Passenger aircraft to cargo aircraft	CA643	FRA	0	0	0	Europe	Jan.

CKG	Regular shift	Passenger aircraft to cargo aircraft	CA645	LHR	0	0	0	Europe	Jan.
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