Optimization of air cargo business process of C Airport

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Abstract

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With the development of global economy, international trade and exchange become more and more frequent. As trade and people flow, so does the movement of goods around the globe. Due to the increasing demand for transportation time, air transportation has become the first choice for international cargo transportation. With the rapid development of the global aviation industry, China's international air cargo transport market is also gradually expanding, and foreign air transport giants have intensified the competitive pressure in the Chinese market. If China's domestic and international air cargo transport enterprises want to survive in the increasingly fierce competition, they must cooperate, optimize the business process, improve the efficiency and enhance the competitiveness of enterprises.

This thesis conducted a field investigation on the operation of international cargo business in C Airport, understood the structure of each link of international cargo business in C airport and the relationship between the relevant links, and integrated the overall operation flow chart of international cargo business in C airport.

Subsequently, Petri net modeling was carried out on the flow chart of international cargo business in C airport, random Petri net model and isomorphic Markov chain were used to analyze the whole operation process, and the existing problems were put forward.

According to the existing problems, the business process is segmented to optimize, and finally integrated to get a new international cargo business inbound and outbound operation process. Then Markov chain was used to compare the optimized process before and after, and the effectiveness of optimization was analyzed.

Key words
Airport international cargo, Business process optimization, Petri net, Markov chain

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1 Introduction

As China enters the stage of high-quality development and the quality of life of its people continues to improve, higher requirements have been placed on production, distribution, circulation and consumption. At the same time, the outline of China's 14th Five-Year Plan clearly puts forward the goal of promoting the construction of modern circulation system as a whole. Aviation logistics is an important part of the modern circulation system, and airports, as the most important nodes in the process of aviation logistics, will usher in new development opportunities. At the present stage, aviation logistics has put forward higher requirements for the airport's capacity level, storage level and timeliness level. In order to meet the growing cargo demand, the airport should not only carry out the construction and improvement of related hardware and software facilities, but also adjust and reform the development mode, management mode, operation process and other aspects, so as to ensure the smoothness and integrity of the modern circulation system.

Air cargo is one of the five modes of cargo transportation, and it is also an important part and carrier of modern logistics industry. "In the context of economic globalization, air transport will replace seaport transport, inland river transport, railway transport and highway transport, and become the driving force of economic development" (Kasarda 1992). Kasarda, a professor at the University of North Carolina, proposed the fifth wave theory based on the study of American cities. With the prevalence of Just-in-time production" and "zero inventory" management ideas, developed aviation logistics network system plays an increasingly important role in modern manufacturing industry. The separation of production chain, value chain and service chain also makes air cargo become a bridge linking trade. Improving the accessibility of air cargo and the smoothness of ground services will drive the convergence of logistics, people, business flow and information flow, and significantly improve regional competitiveness.

Since 2020, the global aviation industry has been hit hard to varying degrees with the spread of the novel coronavirus. Development of airport air cargo Because countries need to limit the number of flights due to epidemic prevention, air cargo terminals are frequently overrun. Although the disruption of cargo function caused by the outbreak of the epidemic is temporary, it also exposes some long-term problems in the airport air cargo business process. The figure shows the cargo throughput data of Chinese airports from 2013 to 2022.

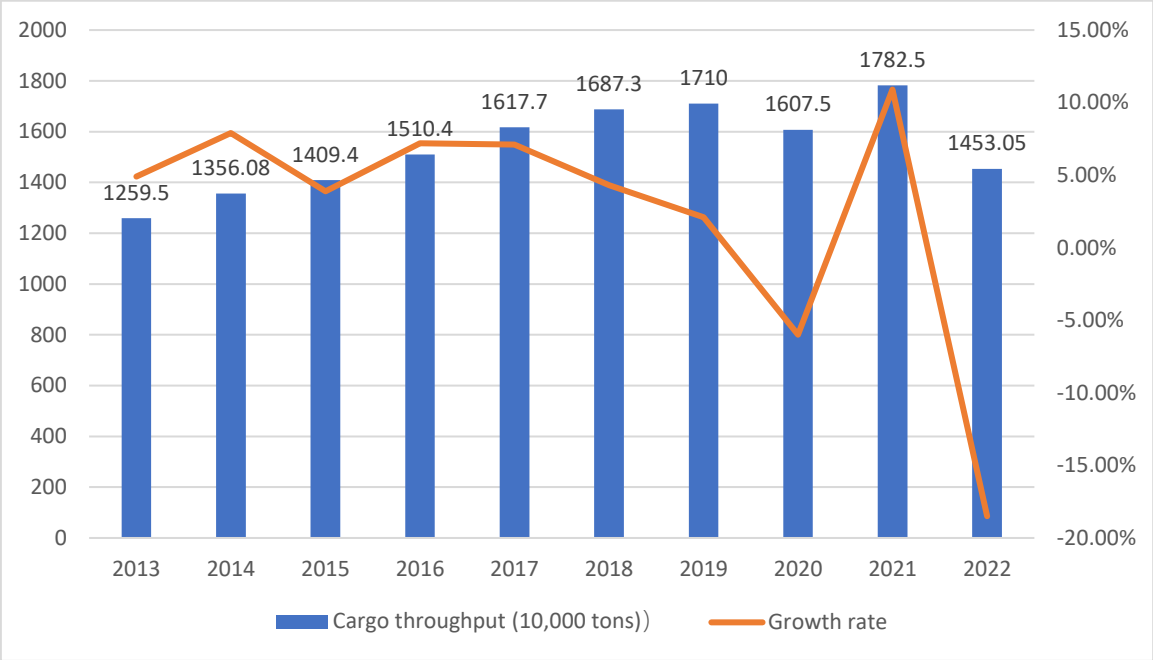

Figure 1 Airport cargo throughput and year-on-year growth rate from 2013 to 2022 (Civil Aviation Administration of China 2022)

2 Theoretical Framework

2.1 Relevant basic theories

2.1.1 Service Process

In order to achieve a certain value goal or a certain established state, a business process is operated separately by different departments and personnel to complete a series of activities together (Yin Gai 2011, 29). The time span and space span of business process activities can be large, but each activity has a strict time sequence, activity content, activity mode and activity responsibility division is also very clear.

Air cargo business process design to the owners of cargo, air cargo agents, land transport service agents, airlines, airport cargo stations, customs, inspection and quarantine and other subjects, each subject to participate in different links of cargo business, during the crossover of business, undertake different responsibilities. The air cargo business starts from the consignor entrusted by the freight forwarder to receive and deliver the goods, and ends with the delivery of the goods to the consignee. It involves the intersection of people, logistics, information flow, documents flow and capital flow, which is a complex system.

2.1.2 Process Optimization

The theory of process optimization is gradually derived from the development process of enterprises, and is also an important means of enterprise management improvement. Based on the internal and external problems of the enterprise itself, find out the crux of the problem and seek optimization plan, so as to highlight the advantages of the overall development of the enterprise. In the early stage of process optimization, it is necessary to sort out the existing process, find out the efficiency of the whole process or other key problems, and improve the process according to the problems. The whole process is process optimization. The characteristics of process optimization are based on the current process in operation, according to the company's newly adjusted strategy or goal, maintain the overall framework, make changes to the process, and gradually achieve quantitative change (Mcheal·Hammer & James·Champy, 2007).

Process optimization is not only about making the right optimization solution, but also about how to correctly apply the solution to the actual work. The purpose of process optimization is to improve the evaluation and satisfaction index of customers for products and services, so as to create more value for enterprises. In the traditional management mode, the whole focus is only on the division of rights, focusing on the internal management of the company rather than the feelings of customers, and the process is not recognized by everyone. The process is the existence of the

service organization, rather than customer-centric, which makes the operation of the process more complicated, less effective, so that customer satisfaction and other problems continue to emerge. When enterprises are faced with the new social and economic environment, many thorny problems will appear under the mode of traditional central management as the function. Instead, the problems cannot be effectively solved through only changes, but new problems will arise. In order to maintain the market competitiveness, the enterprise must restructure the business process, reflect on all the links of the process in essence, retain the backbone of the business process, redesign and optimize it, so as to achieve breakthrough changes in the key issues. The optimization of the process, whether it is the overall optimization of the process or the improvement of part of the process, is aimed at improving the quality and efficiency, saving resources and so on.

2.1.3 International air cargo business process

The international air cargo business process refers to the realization, control and management of the whole process of logistics, information flow and capital flow from the shipper to the recipient in order to satisfy the cargo consumers (Ping Jing 2007). Air cargo outbound business is a very important part of air cargo, which refers to the mutual flow of logistics, information flow and capital flow between the consignor's entrustment of transport and the shipper's receipt and issuance of documents.

The departure of international air cargo involves many subjects, including shippers, freight forwarders, airlines, airport ground service units and customs, etc. All subjects need mutual coordination and cooperation to ensure the smooth completion of aviation and aviation export business. It involves the complex flow of documents, goods, information and money. Usually, the export business process of air cargo is shown in Figure 2. However, since the airport is not used, the cargo business process will be different.

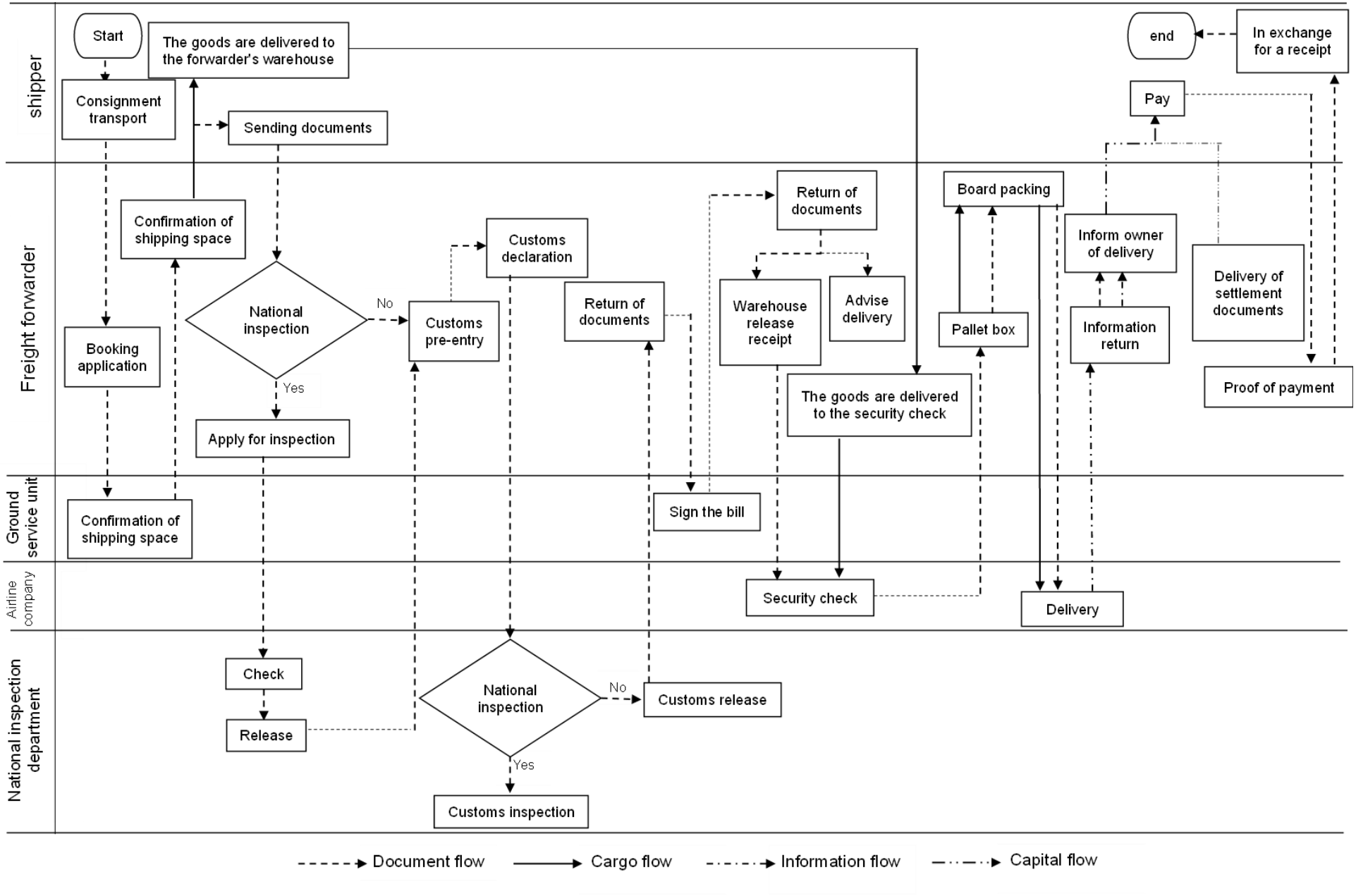
shipper
Freight forwarder
Ground service unit
Airline company
National inspection department
Start
The goods are delivered to the forwarder's warehouse
Consignment transport
Sending documents
Confirmation of shipping space
National inspection
No
Yes
Customs pre-entry
Customs declaration
Booking application
Apply for inspection
Return of documents
Return of documents
Warehouse release receipt
Advise delivery
Board packing
Pallet box
Inform owner of delivery
Information return
Delivery of settlement documents
Pay
end
In exchange for a receipt
Proof of payment
The goods are delivered to the security check
Confirmation of shipping space
Sign the bill
Security check
Delivery
Check
Release
National inspection
No
Yes
Customs release
Customs inspection
Document flow
Cargo flow
Information flow
Capital flow

Figure 2 Flow chart of international air cargo departure (Modified from Shaoyong Tang 2015, 31)

2.1.4 Petri Net

Petri net is a website information flow model which is used to describe distributed system, including condition and event information flow nodes. It can not only describe the system structure, but also simulate the operation of the system. Petri net is mainly composed of the following elements:

Table 1 Petri net element composition

Element	Meaning	Symbol	Function
Place	Conditional node	○	The place where resources are stored determines whether changes occur.
Transition	Time node	□	Change the system state in response to changes in the library.
Collection	Connect Place and Transition	→	Represents the relationship between local states and events.
Token	Tolkien	·	Represents the relationship between local states and events.

Petri nets usually contain four basic structures: serial, parallel, selection and cycle.

(1) Serial structure

It is carried out in the sequence of business processes. When a certain business occurs, all the preceding business processes must be completed. The whole model is a straight line.

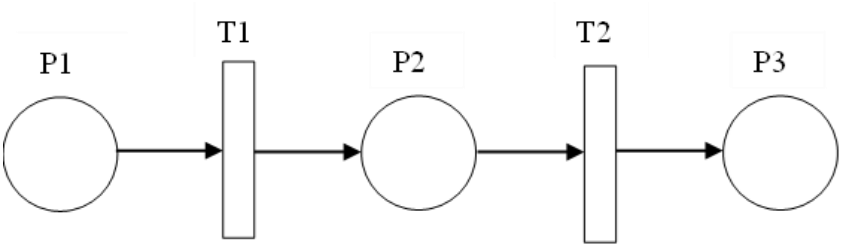

Figure 3 Serial structure

(2) Parallel structure

Two or more businesses are carried out at the same time. P2→P4 and P3→P5 are parallel structures. The two services can be executed at the same time without interference.

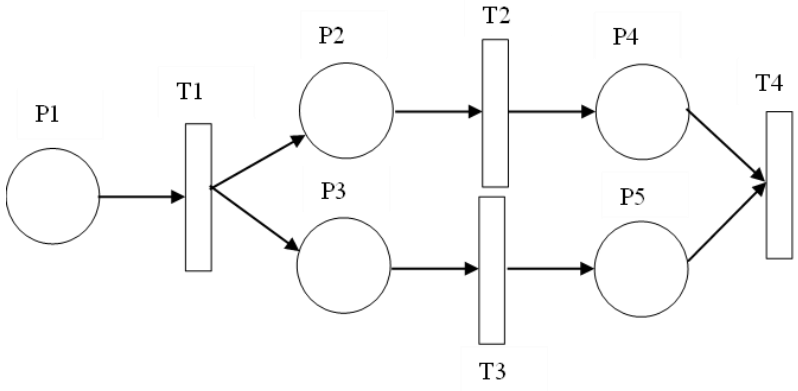

Figure 4 Parallel structure

(3) Selection structure

If resources are limited, multiple services cannot be executed at the same time. Therefore, only one service can be executed. T1→T5 and T2→T6 Only one item can be selected for execution.

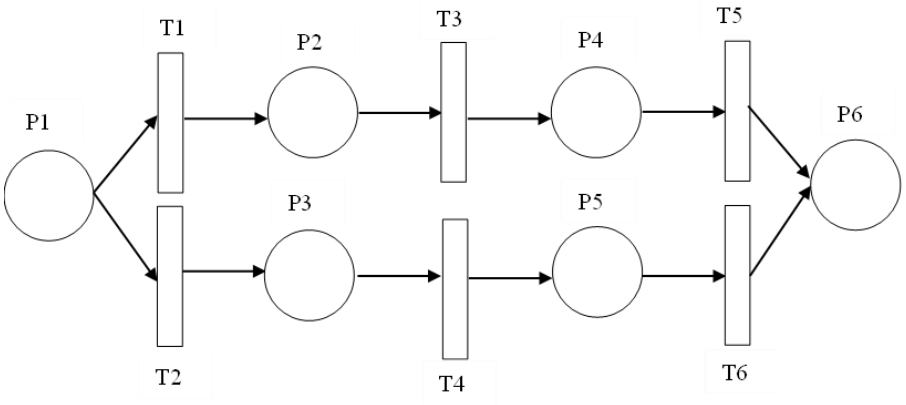

Figure 5 Selective structure

(4) Cyclic structure

Some parts of the process need to be repeated. P2→T3→P4→T4 is a cyclic structure, and the number of repeats is t.

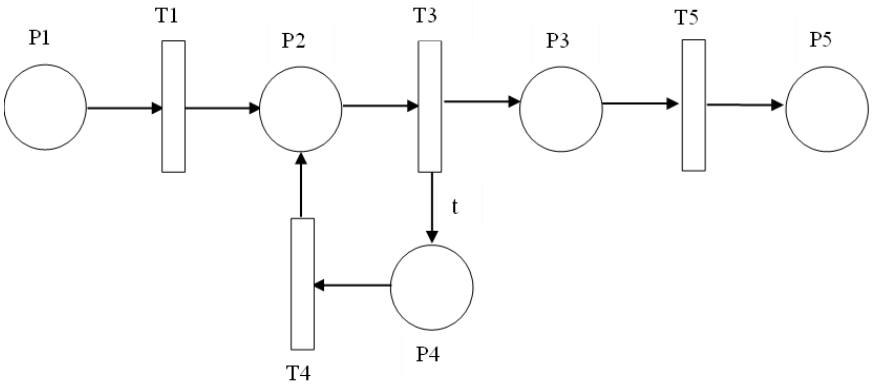

Figure 6 Cyclic structure

2.1.5 Random Petri nets and isomorphic Markov chains

Random Petri nets are an extension of Petri nets to provide modeling and performance analysis for systems with stochastic processes.

In continuous time random Petri nets, the implementation process of transition T requires a certain time interval, and continuous random variable X_T can be used to represent the delay time between the implementable condition and the implementation of transition T. X_T obeys the distribution function:

$$F_T(X) = P\{X_T \leq X\}$$

At present, scholars at home and abroad mostly use Molloy to define the distribution function of transition t:

$$\forall t \in T: F_t = 1 - e^{-\lambda_t x}$$

The distribution function of transition t is an exponential distribution function, which is easy to prove:

Continuous time random Petri nets are isomorphic to a continuous time MC (Markov chain). Each identification of random Petri net reflects every state of MC. The place and transition of random Petri net are limited.

The isomorphism of MC and random Petri net is as follows: by converting transition delay on the reachable identification graph of random Petri net into average implementation rate, MC is converted from the reachable identification graph. The transfer rate matrix of Markov process can be obtained from MC, and the probability of each state of MC in stable state can be calculated, and the performance index of random Petri net model can be calculated.

2.1.6 Performance analysis of random Petri nets

The performance analysis of stochastic Petri nets mainly uses the transfer rate matrix to solve and analyze the isomorphic MC:

The stable state probability of n states on MC is a row vector $\mathrm{X} = (\mathrm{x}_1, \mathrm{x}_2, \mathrm{x}_3, \cdots, \mathrm{x}_\mathrm{n})$, then according to Markov process:

$$\begin{cases} XQ = 0 \\ \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x}_\mathrm{i} = 1, \ \ 1 \le \mathrm{i} \le \mathrm{n} \end{cases}$$

Where Q is the transition matrix. Solve the linear equations to obtain the stable state probability $\mathrm{P}(\mathrm{M}_\mathrm{i}) = \mathrm{x}_\mathrm{i}$ $(1 \le \mathrm{i} \le \mathrm{n})$ of each reachable identifier. Then take a closer look at the performance metrics:

(1) Busy rate of warehouse

$$\mathrm{P}[\mathrm{M}(\mathrm{s}) = \mathrm{i}] = \sum\nolimits_{\mathrm{j}} \mathrm{P}[\mathrm{M}_\mathrm{j}]$$

Represents the probability of the number of tokens included in each place in a steady state.

(2) The average number of marks in the place

$$\overline{u_t} = \sum\nolimits_{\mathrm{j}} \mathrm{j} \times \mathrm{P}[\mathrm{M}(\mathrm{p}_\mathrm{i}) = \mathrm{j}]$$

Represents the average number of tokens contained in the attainable mark of the place.

$$\overline{N} = \sum\nolimits_{p_i \in P} \overline{u_\iota}$$

The average number of tokens representing a place set $\mathrm{p}_\mathrm{i} \in \mathrm{P}$ is the sum of the average number of tokens for each place.

(3) Transition utilization rate

$$\mathrm{U}(\mathrm{t}) = \sum P[M]$$

Denotes the sum of the stable probabilities of all states that make the transition t implementable.

(4) Marked velocity of change

$$R(t, p) = U(t) \times \lambda$$

Represents the average number of tags of corresponding place p after flow t in unit time.

(5) System average delay

$$\bar{N} = R(t,p) \times T$$

Said according to the principle of balance of Little related theorem and queuing theory, the flow of queue length $\bar{N}$is equal to the system R(t,p) and the product of the average delay time T, the system average delay time T is

$$T = \bar{N}/R(t,p)$$

2.2 Research status at home and abroad

2.2.1 Air cargo business process optimization

With the rapid development of the air transport industry, air cargo business process optimization has been gradually concerned by experts and scholars at home and abroad in recent decades. The existing researches mainly analyze the critical path, business bottleneck or resource bottleneck of the existing process, find the reasons for the business bottleneck, and then improve the operation efficiency and resource utilization rate through process optimization and reengineering or resource integration.

In fact, as early as 1968, there were scholars who focused on the problem of ground operation in air cargo transportation. The author points out in the study that cargo loading, unloading and distribution are two basic functions of the air transport system. In air transport, about 80% of the time is spent on the ground due to the problems of airport ground entrance, increasing congestion, lack of operating space and control, etc. These problems must be solved for the sustainable development of air cargo. (David H. Reeherl 1968, 11.)

In 2000, researcher used enterprise process reengineering technology to optimize the air cargo handling system of international airports to achieve the following goals: 1. Improve air cargo transport services by harmonizing similar operations, clearly defining norms and responsibilities, designing and changing working practices; 2. From the current manual operating system to more efficient automated operating system; 3. Update the concepts and models of cargo handling processes used in air transport services; 4. Reduce paperwork as much as possible; 5. Design and develop effective methods to improve the speed of data and information exchange; 6. Reduce ground operation time. (Khan MR 2000, 63.)

In 2006, Zhuodan Zhou made a detailed comparison of the advantages, disadvantages and applicability of different process modeling methods, and pointed out that workflow technology is suitable for cross-organization process modeling. Therefore, stochastic Petri net was used to model, simulate and optimize the export business process in estimated aviation business. (Zhuodan Zhou 2006.)

In the same year, Yunchun Cao analyzed the big problems existing in China's air cargo business process, demonstrated the feasibility of BPR theory in the air cargo industry, and proposed implementation strategies and technical tools suitable for air cargo process reengineering. (Yunchun Cao 2006,26.)

In 2012, Shuxia Qu adopted VOC and fishbone diagram analysis method to put forward a customer-centered process optimization scheme only for small and medium-sized international freight forwarder enterprises, aiming at reducing cost, improving service quality and speed, and demonstrated the process optimization scheme theoretically. (Shuxia Qu 2012.)

In 2013, researchers used Flexsim simulation technology to simulate the cargo operation process of Shanghai Pudong Airport West Cargo Terminal, and found that inefficient manpower supply was the biggest bottleneck, and proposed measures to improve the process. (Danyang S 2013, 12.)

2.2.2 Petri net

Professors from Eindhoven University of Science and Technology in the Netherlands earlier conducted a series of studies on the establishment of workflow model in Petri net. In 1994, the application of advanced Petri net in software design, logistics system design, administrative organization design, traffic control and so on is introduced. It is pointed out that Petri net is a kind of unified design language, and Petri net has great application prospect. In 1998, it was pointed out that Petri net had both graphic properties and formal semantics, was based on state rather than events, and had rich analytical techniques. Based on the above three reasons, Petri Net was used in workflow management. (Van der Aalst W M P 1994,25; Van der Aalst W M P 1998,66.)

In 2006, a time colored Petri network was used to establish a simulation model of air cargo station operation, which was used to analyze route allocation policy and automatic access system. The results show that it has a significant effect on air cargo station process optimization. (Chulung Lee, Huei Chuen Huang&Bin Liu 2006, 102.)

In 2012, Yang Bai and Jifu Zhu (2012,199) studied the air cargo outbound system by using stochastic Petri net and Markov chain, analyzed the average delay time and average operation

efficiency of the system, put forward the bottleneck link of business operation, and obtained the optimization method through research.

In 2013, Lei Liu (2013) combined stochastic Petri net and probability theory in his doctoral thesis, proposed quantitative indicators and analysis methods of workflow, modified simulation scheduling strategy, and established a logistics management system JXWF by combining Java technology and XML technology.

2.3 Overlay matrix

Table 2 Overlay matrix

Business operation	Before optimization		After optimization	
	Petri net	MC	Petri net	MC
Outbound	3.3.1	3.4.1	4.2.1	4.3.1
Inbound	3.3.2	3.4.2	4.2.2	4.3.2

3 Empirical part

Air cargo is an important part of modern aviation logistics industry, and it is gradually extending its development to aviation logistics industry. Due to its timeliness and safety, air cargo has become an indispensable mode of transportation for valuable goods, fresh and perishable goods, precision instruments and so on. Air cargo is characterized by high value and high added value. Therefore, optimizing air cargo process, reducing operating costs and improving service quality are necessary measures for air cargo related enterprises to maintain competitiveness. Airport cargo business is divided into international business and domestic business, domestic business is relatively simple, international cargo business involves international trade, related to many subject departments, according to different regions there are some differences, the operation is more complex.

3.1 Research method

Modeling of business processes is the basis of business process optimization. It can help understand business processes and support process optimization and improvement. There are many existing process modeling methods and tools. According to the research of Hommes, there are about 350 process modeling methods and tools that support business process optimization. The commonly used ones include flowchart, data flow diagram, role activity diagram, IDEF0, IDEF3, Petri net, unified modeling Language, workflow, event-driven process chain, etc. These modeling methods are put forward for the study of different problems, so they have advantages and disadvantages in modeling direction, dynamics, comprehensibility, computer ability and so on.

(1) Flow chart

Flowchart is a structured modeling method, which uses some specified symbols and lines to represent the specific business process. Its analysis is based on the decomposition of business process into multiple activities and events, which can be used to analyze a specific business, and can be used to analyze the management process of the whole enterprise. It is simple and clear, but not precise enough to describe business details, and suitable to reflect the process of business processing type.

(2) Data flow diagram

Data flow graph is the basis of system function model and belongs to a structured analysis method. From the perspective of data transfer and processing, DFD represents the logical function of the system and the flow and transformation process of data in the system in a graphical way. It is a graphical technology that describes the changes of information and data from input to output. It

focuses on describing the relationships between the data within the business and treats the business as a whole function, not suitable for modeling specific events.

(3) Role activity diagram

Role activity diagrams were originally proposed by Holt et al to express problems in work coordination. RAD emphasizes the roles and connections between each role in the system and between the roles and the outside world. It describes the characteristics of goals, roles and decisions in the enterprise process through graphical elements. But RAD does not decompose models, does not represent structured workflows well, and is not suitable for large process models.

(4) Definition of integrated computer aided manufacturing

IDEF is the definition of integrated computer-aided manufacturing, including IEDF0 developed by Armstrong Laboratory of the United States Air Force and IDEF1 for information analysis, IDEF2 for dynamic analysis, IDEF3 for process analysis, etc., which has great influence and wide application. Among them, IDEF0 and IDEF3 are more useful for process modeling. IDEF can decompose activities hierarchically, but IDEF lacks the expression of time and roles, while IDEF3 requires a large amount of data to describe a process, which is time-consuming in complex system modeling.

(5) Petri Net

Petri net was put forward in 1962. It is a method for analyzing discrete event dynamic systems and is suitable for describing asynchronous and concurrent computer system models. With intuitive graphical description means and strict mathematical basis, it has been applied in computer hardware modeling and analysis, distributed database, production management, communication network, flexible manufacturing system, workflow technology and other fields. The subsequent extension forms of Petri nets, such as random Petri nets, mixed Petri nets, colored Petri nets, layered Petri nets, etc., enable Petri nets to describe both the overall work flow and the specific business flow. Meanwhile, hierarchical application enables Petri nets to describe complex systems. Greatly enhanced the ability to describe the system.

(6) Unified Modeling Language

Unified Modeling Language (UML) is based on OMT, BOOCH, and OOSE methods, and absorbs some aspects of object-oriented languages. It is accepted by object management organizations as the standard modeling language. UML has powerful descriptive capabilities that can describe both static and dynamic objects, and is suitable for modeling where time flow requirements are explicit.

(7) Workflow

Workflow originated in the field of production organization and office automation. In 1993, the Workflow Management Alliance was established to standardize workflow management. Subsequently, the WFWC defined the basic terms of workflow, the interfaces between various parts of the workflow management system and the basic entities contained in the model.

(8) Event-driven process chain

Event - driven process chain is a graphical and intuitive business process description language. It includes three elements: function, event and logical connection. EPC has a cross-functional hierarchy, rich description of information, easy to understand, and is widely used in business process reengineering and workflow definition, but it has weak computerization ability.

Comparing different process modeling and analysis methods, you can find that each type of method has its own advantages and disadvantages.

Table 3 Comparison table of business process modeling methods

Technology	Peculiarity	Merit	Shortcoming
Flow chart	Graphs depict the flow of business process activities	Flexible, simple and easy to communicate	Imprecise and not described in general
Data flow diagram	There is the concept of sublayers, which are often used for structured analysis	Easy to understand, verify and draw	Only the display of data flow, no representation of control flow
Role Activity Diagram	Individual role streams, not described as a whole	Easy to read, support communication with users, including business objects	Cannot be decomposed, with different symbols
IDEF0	Structured graphical description with sublayer concept	Overall and detailed description of inputs, outputs, controls, and mechanisms, hierarchical understanding of activities	It is only a sequence of activities, without the expression of time or role
IDEF3	Describe the sequence and causality of business process activities, focusing on system behavior description	Has strict symbols and rules that describe the dynamics of the system	Modeling is complex, requires a large amount of data, requires multiple diagrams to describe a process, and modeling is time-consuming
Petri net	Has a strict mathematical definition to describe the structure and dynamic behavior of the system, has a hierarchy, can be decomposed	Good grammatical and semantic definition, with a formal mathematical basis, suitable for describing synchronous, parallel systems	High-level, complex business process description and analysis process is not concise enough
UML	The software can be detailed, visualized,	From multiple angles, various parts that at-	Models can be very large, too detailed,

	constructed, and documented	tempt to describe the structure of the software, behavior, etc	and time-consuming to model complex systems
Workflows	Business processes are computer-assisted and automated, describing information, tasks, and process rules	Easy to analyze, understand and modify	Lack of uniform modeling techniques and notation, lack of flexibility
Event-driven chains	Conditional Event Network variants that extend with logical symbols	It supports implicit and circular termination, and has strong control and expression capabilities	The lack of formal semantics is completely equivalent to intuitive semantics

By comparing the characteristics of each method, it can be seen that Petri net has rigorous logical relationship, wide application, excellent compatibility, and can carry out effective quantitative analysis, and good visualization effect. At the same time, from the domestic research status, Petri net application research in business process is also relatively mature, the characteristics of airport international cargo business operation process suitable for Petri net modeling.

3.2 C Airport international cargo business process

3.2.1 C Airport international cargo departure business process

Through field research on the national cargo business of C airport, the overall operation flow chart of international cargo outbound business of C Airport is concluded. Specifically, it includes: consignment → booking after receiving orders → confirmation of shipping space → booking notice → receiving tally → making and issuing documents → customs declaration and inspection → return of documents → confirmation of documents → security check after signing documents → packing and packing → installation and shipping etc.

The process of international cargo departure involves multiple subjects, such as consignor, freight agent, airline, international cargo station, national inspection and customs, etc. At the same time, it closely combines, crosses and transfers logistics, human flow, document flow and information flow.

International cargo departure operation process				
Client	Freight forwarder	Airline	National inspection department and customs	International cargo terminal

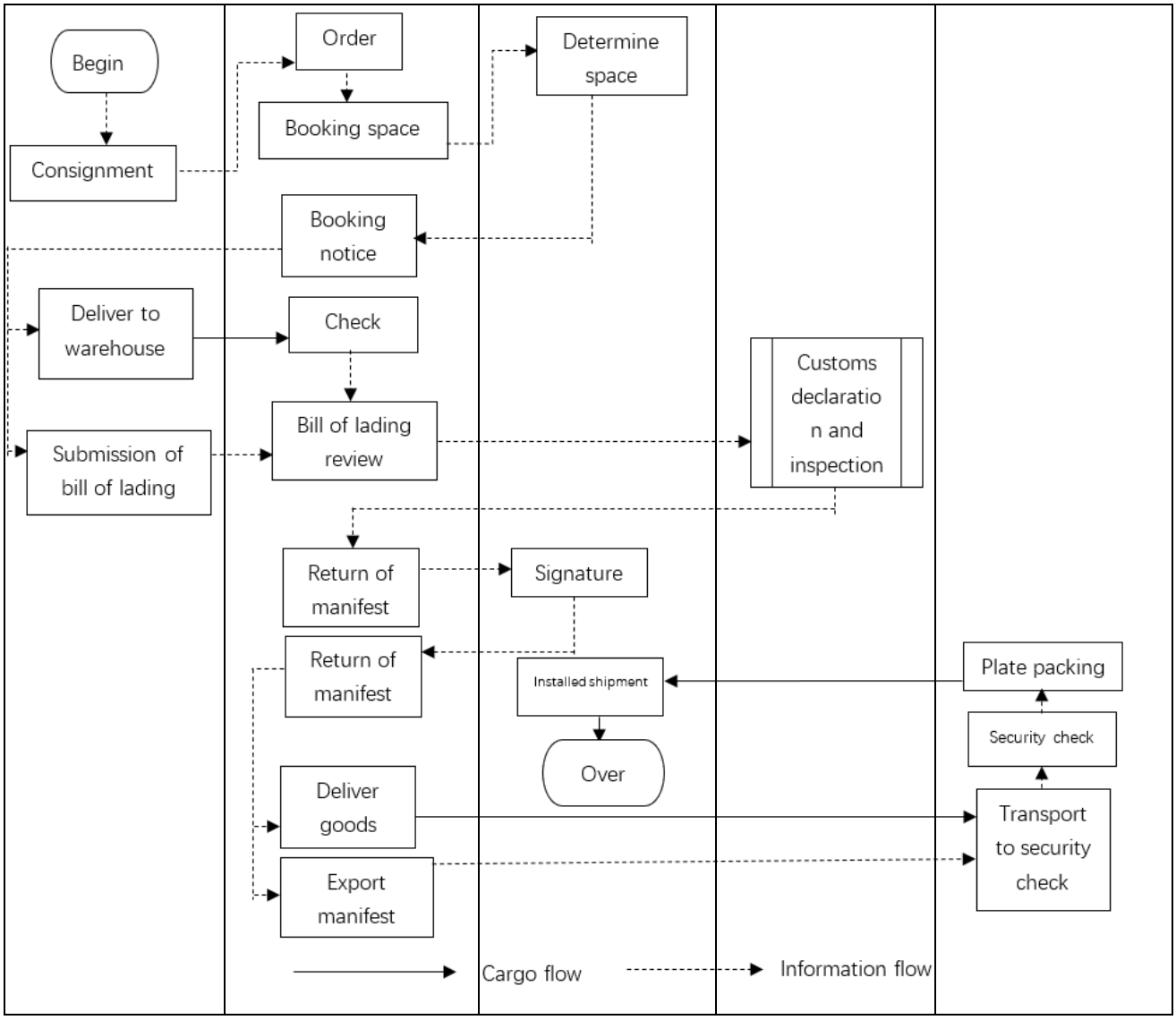

Figure 7 Operation flow chart of international cargo departure from the C airport

3.2.2 International cargo inbound business process of C airport

In the same way, the overall operation flow chart of international cargo arrival at C airport is determined, including: arrival forecast → receipt of orders and goods → tally storage → customs declaration and inspection → pick-up and transfer, etc.

International cargo departure operation process				
Airline	International cargo terminal	Freight forwarder	National inspection department and customs	Client

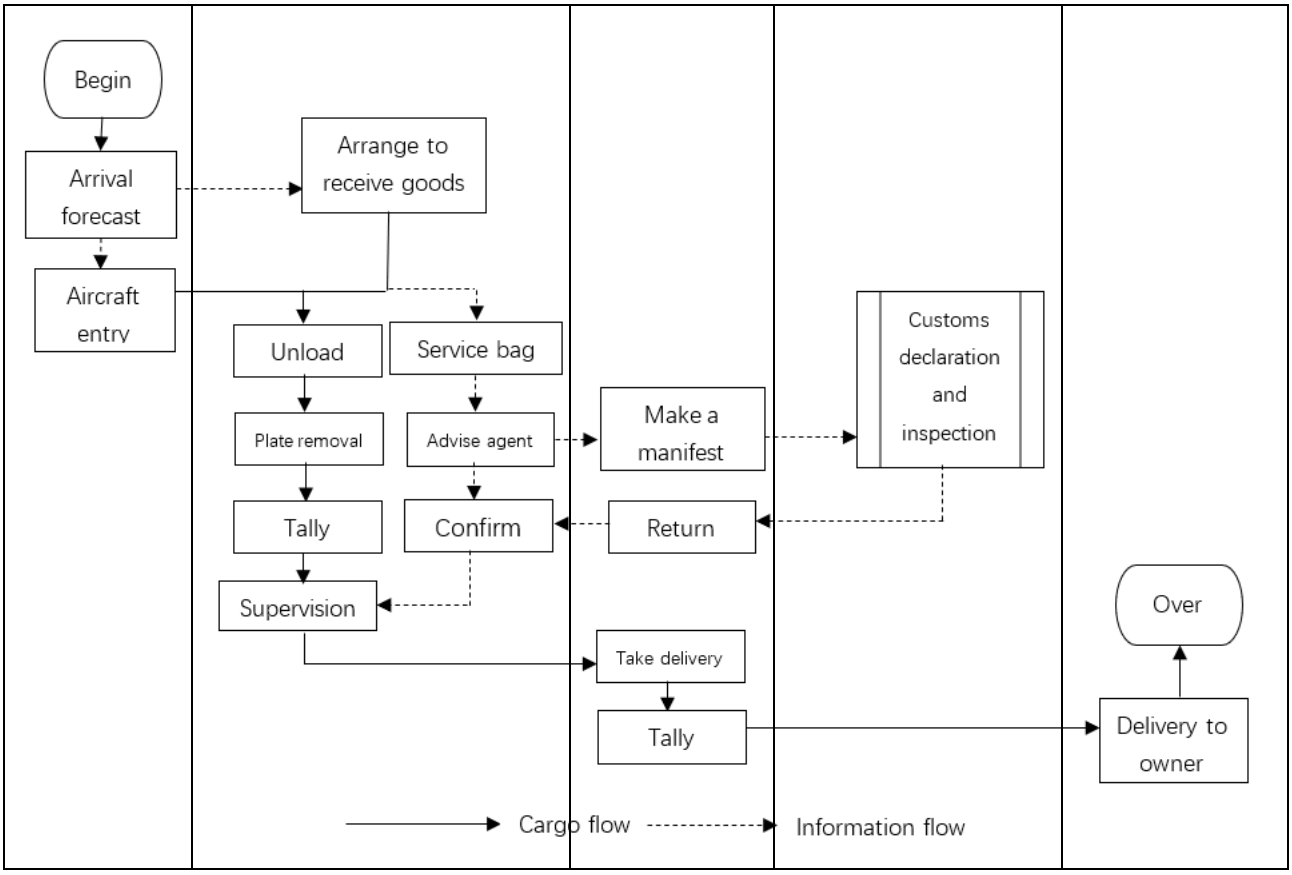

Figure 8 Flow chart of international cargo inbound operation at the C airport

3.3 Construction and analysis of Petri net model of international cargo business process at C airport

In this section, based on the operation process of international cargo business at C airport, Petri net theory is used to abstract describe the operation process of international cargo inbound and outbound, and verify and analyze the model.

The model assumes:

(1) For the convenience of analysis, only the customs declaration by the freight forwarder is considered, and the situation of the owner's self-declaration is not considered;

(2) All links are carried out smoothly, and no accidents occur: that is, the audit fails without documents, the goods are detained and other circumstances occur;

(3) Consider only international general goods, not special goods;

(4) Under certain circumstances, all personnel can be effectively contacted and artificial delay time is ignored. The operation time of all links is the process operation time;

(5) Without considering the impact of capital flow, payment is defined as instantaneous behavior;

(6) International cargo transit is not taken into account.

3.3.1 Establishment of Petri net model of international cargo outbound business process at C airport

The corresponding Petri net model is established according to the overall departure flow chart of C airport in Figure 7.

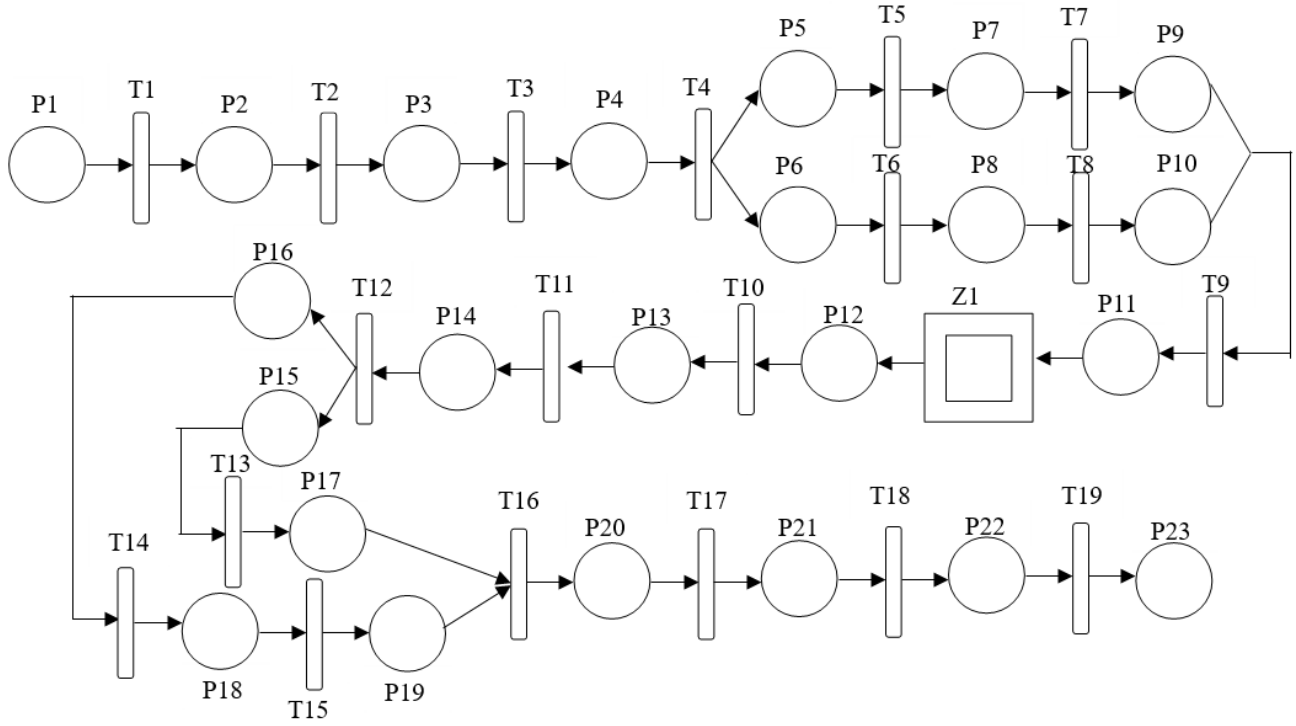

Figure 9 Petri net model of outbound operation of international cargo business at C airport

The meanings of each node are as follows:

Table 4 Semantic description of Petri net library for outbound operations of international freight business

Place	Semantic description
P1	The principal is ready to make a freight commission
P2	The freight forwarder is entrusted to prepare the booking application to the airline
P3	The airline booking is confirmed and ready to notify the freight forwarder
P4	The freight forwarder accepts the space notice and is ready to notify the principal
P5	The principal receives the booking notice and is ready to submit the relevant materials to the freight forwarder
P6	The client receives the booking notice and prepares the shipment to the forwarder's warehouse
P7	The freight warehouse receives the relevant materials submitted by the client and prepares for review

P8	The freight forwarding warehouse accepts the goods and prepares to confirm the cargo information
P9	The freight forwarder collects the materials and prepares the bill
P10	The freight forwarder has completed the verification and prepared the order
P11	The freight forwarder completes the preparation of documents and prepares to declare and inspect to the national inspection
P12	At the end of the inspection, customs prepares to return the documents to the freight forwarder
P13	The freight forwarder receives the document and prepares it for signature with the airline
P14	The signing is completed and the airline is ready to return the documents
P15	The freight forwarder receives the documents and prepares the warehouse receipt
P16	The freight forwarder is ready to send a shipment notice to the warehouse
P17	The security checkpoint receives the outbound receipt and prepares for the security check
P18	The forwarder's warehouse receives the shipping notice and prepares to ship the goods to the security checkpoint
P19	The goods are transported to the security checkpoint and prepared for the security checkpoint
P20	After the security check, prepare the pallet for packing
P21	After the pallet is packed, it is ready to be punched and boxed
P22	After the plate is packed, it is ready to be loaded and shipped
P23	The shipment is completed and the departure of international goods is completed

Table 5 Transition Semantic description of Petri Net for outbound operations of international freight business

Transition	Semantic description
T1	The principal submits a freight commission
T2	The freight forwarder makes a booking request
T3	The airline confirms the booking request
T4	The freight forwarder notifies the principal of the space confirmation
T5	The principal submits the materials to the freight forwarder
T6	The consignor delivers the goods to the freight forwarder's warehouse
T7	The freight forwarder reviews the information submitted by the client
T8	The freight forwarder checks the cargo information
T9	The freight forwarder makes the documents
Z1	Customs inspection and quarantine and inspection sub-processes
T10	Customs returns the documents to the freight forwarder
T11	The freight forwarder signs the order with the airline
T12	The airline returns the document to the freight forwarder
T13	The freight forwarder makes a warehouse receipt and sends it
T14	The freight forwarder notifies the freight forwarder to ship the goods at the warehouse
T15	The freight forwarder sends the goods to the security checkpoint
T16	Security checks are carried out on cargo inside the International Cargo Terminal
T17	Freight forwarder pallet box
T18	Palletize and lift the goods
T19	Installed and shipped

3.3.2 Establishment of Petri net model of international cargo inbound business process at C airport

According to the flow chart of international cargo entry operation in Figure 8, Petri net model of international cargo entry operation is established.

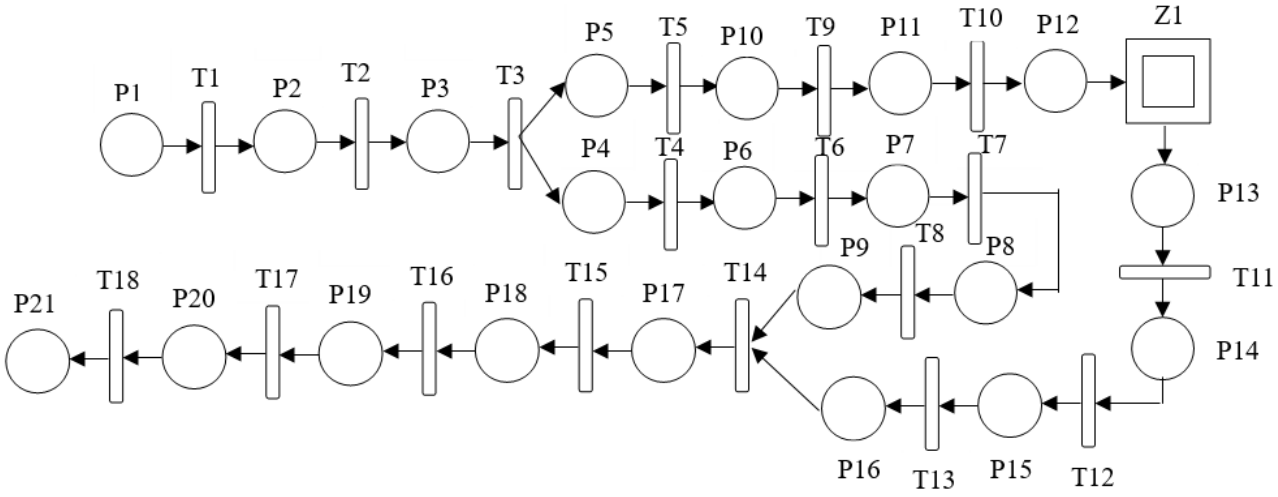

Figure 10 Petri net model of inbound operation of international cargo business

The meanings of each node are as follows:

Table 6 The semantic description of Petri net library for inbound operation of international freight business

Place	Semantic description
P1	Airlines are ready to send cargo arrival forecasts
P2	Hactl accepts information and is ready to arrange pickup
P3	The plane is ready to enter the port
P4	Prepare to unload the goods and move them to the warehouse
P5	Hactl staff ready to accept business bags
P6	The interior of the international cargo terminal is ready to be dismantled and disassembled
P7	The dismantling of the plates is completed and the sorting is ready for tallying
P8	The tally is completed and the goods are ready for regulatory temporary storage
P9	Shipped to a regulatory staging area. Wait for the freight forwarder to pick up the goods
P10	The business bag is received and ready to notify the freight forwarder of the arrival
P11	The freight forwarder collects the materials and prepares the bill
P12	The freight forwarder completes the documents, prepares customs declaration and inspection
P13	At the end of the inspection, customs prepares to return the documents to the freight forwarder
P14	The freight forwarder receives the document and prepares it for signature at Hactl
P15	The signing is completed and Hactl is ready to return the documents
P16	The freight forwarder receives the documents and prepares them for pick-up for verification
P17	After the pick-up check is completed, the goods are ready to be shipped to the freight forwarding warehouse
P18	After shipping to the freight forwarding warehouse, prepare the tally order
P19	After the tally order is completed, the goods are ready to be delivered to the principal
P20	Wait for the principal to pick up the goods
P21	The client's pick-up is completed, and the inbound operation process is complet-

ed

Table 7 Petri Net Transition Semantic description of port entry operation of international freight business

Transition	Semantic description
T1	Airlines send cargo arrival forecasts
T2	Hactl arranges pick-up
T3	Aircraft entering the port
T4	Relevant personnel carry out unloading and transportation to the warehouse
T5	Hactl employees accept business bags
T6	Disassemble and disassemble the goods
T7	Sort and tally the goods
T8	Ship the goods to the regulatory staging area
T9	Notify the cargo agent of the arrival
T10	The freight forwarder makes the documents
Z1	National inspection, customs inspection and quarantine and inspection sub-processes
T11	Customs returns the documents to the freight forwarder
T12	The freight forwarder signs the bill with Hactl
T13	Hactl returns the document to the freight forwarder
T14	Freight forwarder pick-up check
T15	The freight forwarder ships the goods to the warehouse
T16	Tally the goods
T17	Notify the principal to pick up the goods
T18	The principal goes to the freight forwarder's warehouse to pick up the goods

3.3.3 Petri Net Performance Analysis of international Cargo Inbound and Outbound Business Processes at C airports

According to the Petri net model of the inbound and outbound operation flow of international cargo business of C Airport, the relevant characteristics were analyzed to verify the correctness and rationality of the inbound and outbound operation flow model of international cargo business, and provide a basis for the subsequent optimization. In this paper, correlation performance of Petri nets will be analyzed by using correlation matrix and invariant analysis method, and reachability, boundedness and activity of Petri nets will be judged by solving invariants.

Taking the departure operation of C airport as an example, the input matrix C^- of petri net model of the departure operation flow can be obtained according to the figure:

$$C^- = \begin{bmatrix} 1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1 \end{bmatrix}$$

The output matrix C^+ is:

$$C^+ = \begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1 \end{bmatrix}$$

The corresponding correlation matrix $C^* = C^+ + C^-$ of Petri net model of outbound operation flow of international freight business is:

$$C^* \begin{bmatrix}
-1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}$$

Through the input matrix, output matrix and correlation matrix, the S_X invariant of the library is obtained from the formula $C^{*^T} X = 0$.

And you can also get a fundamental set of solutions for X.

$$X_1 = (0,0,0,0,-1,1,-1,1,-1,1,0,0,0,0,0,0,0,0,0,0,0,0)^T$$

$$X_2 = (0,0,0,0,0,0,0,0,0,0,0,0,0,0,-1,1,-1,1,1,0,0,0,0)^T$$

$$X_3 = (1,1,1,1,1,0,1,0,1,0,1,1,1,1,1,1,0,1,0,0,1,1,1,1)^T$$

The output invariant function is: $S_X = k_1 X_1 + k_2 X_2 + k_3 X_3$

Since the basic solutions are among X_1, X_2 and X_3, all the vectors in the solutions of X_3 are non-negative numbers, combined with the characteristics of Petri net activity, accessibility and boundness, etc., the validity and feasibility of Petri net model for the outbound process of international cargo business are proved. However, since the solutions of X_1 and X_2 both contain negative numbers, only X_3 can explain the library S_X invariant of Petri net in the process of international cargo departure, so it is necessary to eliminate all negative solutions through the assignment of k_1 and k_2, and find out the logical minimal library invariant S_X.

$$\text{The } k_1 = 0、\ k_2 = 0,\ \text{get } S\_X1 = (1,1,1,1,1,0,1,0,1,0,1,1,1,1,1,1,0,1,0,0,1,1,1,1)^T$$

$$\text{The } k_1 = 1、\ k_2 = 0,\ \text{get } S\_X2 = (1,1,1,1,0,1,0,1,0,1,1,1,1,1,1,0,1,0,0,1,1,1,1)^T$$

$$\text{The } k_1 = 0、\ k_2 = 1,\ \text{get } S\_X3 = (1,1,1,1,1,0,1,0,1,0,1,1,1,1,1,0,1,0,1,1,1,1,1,1)^T$$

$$\text{The } k_1 = 1、\ k_2 = 1,\ \text{get } S\_X4 = (1,1,1,1,0,1,0,1,0,1,1,1,1,1,1,0,1,0,1,1,1,1,1,1)^T$$

The process corresponding to the invariant S_X of the warehouse covers every link of the outbound operation of the international freight business process, indicating that every warehouse and transition in the Petri Net can be reached after certain changes, which proves that the design of the Petri net model of the outbound operation process of the international freight business is reasonable.

Similarly, the input matrix, output matrix and correlation matrix of Petri net model of the port entry process of international freight business can be obtained, and the library S_Y invariant can be obtained by $J^{*T}Y = 0$ respectively. And you can also get a set of fundamental solution systems for Y.

Through calculation, the basic solution of Y in Petri net model of port entry operation flow of international freight business is:

$$Y_1 = (0,0,0,-1,1,-1,-1,-1,-1,1,1,1,1,1,1,1,0,0,0,0,0)^T$$

$$Y_2 = (1,1,1,1,0,1,1,1,1,0,0,0,0,0,0,0,1,1,1,1,1)^T$$

S_Y invariant of the library with a change in assignment:

$$S\_Y1 = (1,1,1,1,0,1,1,1,1,0,0,0,0,0,0,0,1,1,1,1,1)^T$$

$$S\_Y2 = (1,1,1,0,1,0,0,0,0,1,1,1,1,1,1,1,1,1,1,1,1)^T$$

The process corresponding to the invariant S_Y in the library covers every link of the outbound operation process of international freight business, which proves that the Petri net model design of the inbound operation process of international freight business is reasonable.

3.4 Performance analysis of Petri Net Markov Chain for inbound and outbound operations of international freight business

3.4.1 Construction of Markov chain of outbound operation process of international freight business

The construction of Markov chain requires the construction of random time Petri nets, that is, adding time parameters obeying certain probability distribution into Petri nets. In order to ensure the authenticity and validity of the results, the average operation time of each link of the international cargo business of C Airport was obtained through field research on the operation process of the international cargo business of C Airport and field visits to the relevant staff. The relevant information was sorted out to determine the operation time of each link of the international cargo inbound and outbound ports. Ensure that the time setting is in line with the reality of international freight business, and assign the time changes in the outbound operation process of international freight business as shown in the table.

Table 8 Implementation delay time of outbound operation process change of international cargo business (Data from C Airport Aviation Logistics Park)

Transition	Implementation delay time（min）	Transition	Implementation delay time（min）
T1	15	T10	30
T2	10	T11	15
T3	25	T12	20
T4	8	T13	15
T5	135	T14	10
T6	135	T15	60
T7	50	T16	30
T8	15	T17	15
T9	50	T18	30
Z1	145	T19	30

Therefore, the operation time and corresponding implementation rate table of each process in the outbound operation process of international freight business can be obtained.

Table 9 The outbound operation process of international cargo business corresponds to the implementation rate (Data from C Airport Aviation Logistics Park)

Transition	min	Rate	1/min	Transition	min	Rate	1/min
T1	15	λ_1	0.0667	T10	30	λ_{11}	0.0333

T2	10	λ_2	0.1000	T11	15	λ_{12}	0.0667
T3	25	λ_3	0.0400	T12	20	λ_{13}	0.0500
T4	8	λ_4	0.1250	T13	15	λ_{14}	0.0677
T5	135	λ_5	0.0074	T14	10	λ_{15}	0.1000
T6	135	λ_6	0.0074	T15	60	λ_{16}	0.0167
T7	50	λ_7	0.0200	T16	30	λ_{17}	0.0333
T8	15	λ_8	0.0667	T17	15	λ_{18}	0.0677
T9	50	λ_9	0.0200	T18	30	λ_{19}	0.0333
Z1	145	λ_{10}	0.0069	T19	30	λ_{20}	0.0333

It is assumed that every change in the outbound operation process of international cargo business follows exponential distribution:

$$\mathrm{F_i}(x) = 1 - e^{-\lambda_i x}$$

Where $\lambda_i = 1,2,3,\ldots\ldots,20$. Thus, the Petri net model is transformed into a random Petri net model.

According to the random Petri net of the international cargo outbound operation process, the reachable mark map is obtained. The state of resource flow to the next repository is a mark caused by the change. The preliminary identification starts from P1, and with the departure of the change, the resources obtained by the next library form a new identification. The identification state corresponding to Petri net in the operation process of international cargo departure and the identification library are shown in the table.

Table 10 Identification state and inclusion repository of Petri net model of international cargo outbound operation flow

Mark	M0	M1	M2	M3	M4	M5	M6
Place	P1	P2	P3	P4	P5、P6	P5、P8	P5、P10
Mark	M7	M8	M9	M10	M11	M12	M13
Place	P6、P7	P7、P8	P7、P10	P6、P9	P8、P9	P9、P10	P11
Mark	M14	M15	M16	M17	M18	M19	M20
Place	P12	P13	P14	P15、P16	P15、P18	P16、P17	P15、P19
Mark	M21	M22	M23	M24	M25	M26	
Place	P17、P18	P17、P19	P20	P21	P22	P23	

Markov chain diagram isomorphic can be obtained according to the reachability identification state and the library included.

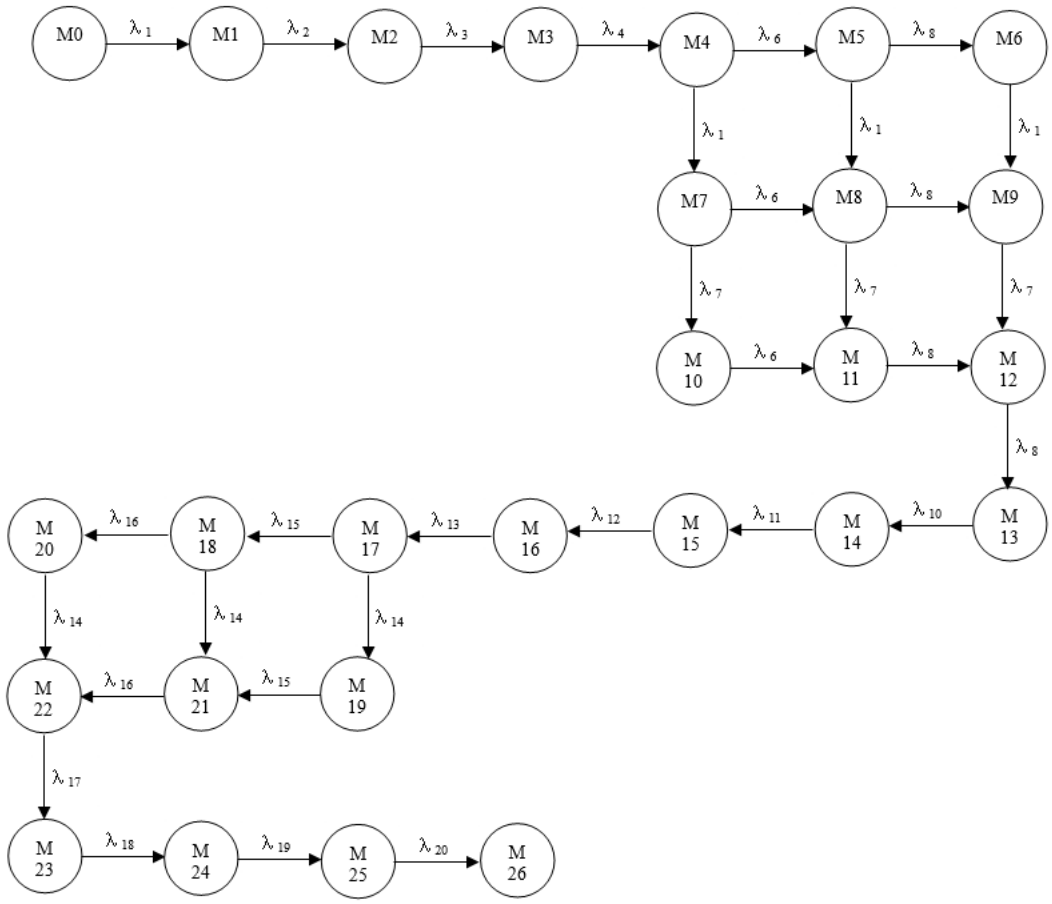

Figure 11 Markov Chain of SPN model of international cargo outbound operation flow

The transfer rate matrix Q of the Markov process can be obtained according to the Markov chain of the international cargo outbound operation process, and the stable probability of each identification state of the Markov chain can be calculated from the transfer rate matrix. Let the stable state probability in Markov chain process be the row vector $X = (x_1, x_2, x_3, \cdots, x_{27})$。

$$\begin{cases} XQ = 0 \\ \sum_{i=1}^{n} x_i = 1, \quad 1 \le i \le 27 \end{cases}$$

The value of the relevant implementation rate is substituted into the equation, and the overdetermined linear equations are calculated using MATLAB. The stability probability of each state can be written as:

Table 11 The stability probability of the outbound model of international freight service

Mark	M0	M1	M2	M3	M4	M5	M6
Rate	0.0180	0.0120	0.0299	0.0096	0.0809	0.0081	0.0729
Mark	M7	M8	M9	M10	M11	M12	M13
Rate	0.0219	0.0026	0.0355	0.0591	0.0073	0.0599	0.1198
Mark	M14	M15	M16	M17	M18	M19	M20
Rate	0.0360	0.0180	0.0240	0.0072	0.0086	0.0048	0.0022
Mark	M21	M22	M23	M24	M25	M26	
Rate	0.0717	0.0360	0.0180	0.0360	0.0360	0.0024	

After the stability probability of each marker in the Markov chain is obtained, the busy rate of each library and the transition utilization rate of the system can be calculated.

(1) Busy rate of warehouse

Library busy rate refers to the probability of the number of token contained in each library, which can be expressed as:

$$\forall p \in P, \forall i \in N, P[M(p) = i]$$

The busy rate of the library represents the running efficiency of the whole process activity, which mainly reflects the proportion of the time required in each business process in the total time. From this, we can calculate the Petri net library busy rate of international cargo business outbound operation process of C airport.

Table 12 Outbound operation flow of international freight business Petri net busy rate of warehouse

Place	Busy rate	Place	Busy rate	Place	Busy rate
P1	0.0180	P9	0.1263	P17	0.0120
P2	0.0120	P10	0.1683	P18	0.0803
P3	0.0299	P11	0.1198	P19	0.0382
P4	0.0096	P12	0.0360	P20	0.0180
P5	0.1619	P13	0.0180	P21	0.0360
P6	0.1619	P14	0.0240	P22	0.0360
P7	0.0600	P15	0.0180	P23	0.0024
P8	0.0180	P16	0.0120		

P5, P6, P7, P9, P10, P11 and P18 have a high busy rate of warehouses. The warehouses with a high busy rate are prone to blockage, which will affect the outbound operation process of international cargo business.

(2) Change utilization rate

The utilization rate of the system transition represents the sum of the stability probabilities of all state expressions that can change T, and the Petri net transition rate of the outbound operation flow of international freight business can be calculated by the formula.

Table 13 Petri net transition utilization rate of outbound operation flow of international freight business

Transition	Utilization rate	Transition	Utilization rate	Transition	Utilization rate
T1	0.0180	T8	0.0180	T14	0.0120
T2	0.0120	T9	0.2946	T15	0.0803
T3	0.0299	Z1	0.1620	T16	0.0502
T4	0.0096	T10	0.0360	T17	0.0180
T5	0.1619	T11	0.0180	T18	0.0360
T6	0.1619	T12	0.0240	T19	0.0360
T7	0.0600	T13	0.0180	T20	0.0024

According to the transition rate utilization table, T5, T6, T7, Z1 and T15 have higher transition utilization rate. The higher transition utilization rate indicates that the transition needs more time to complete and has a certain impact on the overall operation process.

3.4.2 The construction of Markov chain for international cargo business entry process

Similarly, Markov chain analysis is carried out on Petri net of the inbound operation flow of international freight business in Figure 9, where the time assignment of each transition and the corresponding implementation efficiency are shown in the table, and it is assumed that the implementation delay time of each transition in the table also follows exponential distribution.

Table 14 Implementation rate of inbound operation process for international cargo business (Data from C Airport Aviation Logistics Park)

Transition	min	Rate	1/min	Transition	min	Rate	1/min
T1	5	λ_1	0.2000	Z1	175	λ_{11}	0.0057
T2	8	λ_2	0.1250	T11	30	λ_{12}	0.0333
T3	20	λ_3	0.0500	T12	20	λ_{13}	0.0500

T4	65	λ_4	0.0154	T13	20	λ_{14}	0.0500
T5	25	λ_5	0.0400	T14	15	λ_{15}	0.0667
T6	40	λ_6	0.0250	T15	30	λ_{16}	0.0333
T7	25	λ_7	0.0400	T16	30	λ_{17}	0.0333
T8	20	λ_8	0.0500	T17	5	λ_{18}	0.2000
T9	10	λ_9	0.1000	T18	60	λ_{19}	0.0167
T10	50	λ_{10}	0.0200				

The corresponding identification state and library of Petri net model of international cargo entry operation flow are shown in the table.

Table 15 Identification state and inclusion library of Petri net model of international cargo entry operation flow

Mark	M0	M1	M2	M3	M4	M5	M6
Place	P1	P2	P3	P4、P5	P5、P6	P5、P7	P5、P8
Mark	M7	M8	M9	M10	M11	M12	M13
Place	P5、P9	P4、P10	P6、P10	P7、P10	P8、P10	P9、P10	P4、P11
Mark	M14	M15	M16	M17	M18	M19	M20
Place	P6、P11	P7、P11	P8、P11	P9、P11	P4、P12	P6、P12	P7、P12
Mark	M21	M22	M23	M24	M25	M26	M27
Place	P8、P12	P9、P12	P4、P13	P6、P13	P7、P13	P8、P13	P9、P13
Mark	M28	M29	M30	M31	M32	M33	M34
Place	P4、P14	P6、P14	P7、P14	P8、14	P9、P14	P4、P15	P6、P15
Mark	M35	M36	M37	M38	M39	M40	M41
Place	P7、P15	P8、P15	P9、P15	P4、P16	P6、P16	P7、P16	P8、P16
Mark	M42	M43	M44	M45	M46	M47	
Place	P9、P16	P17	P18	P19	P20	P21	

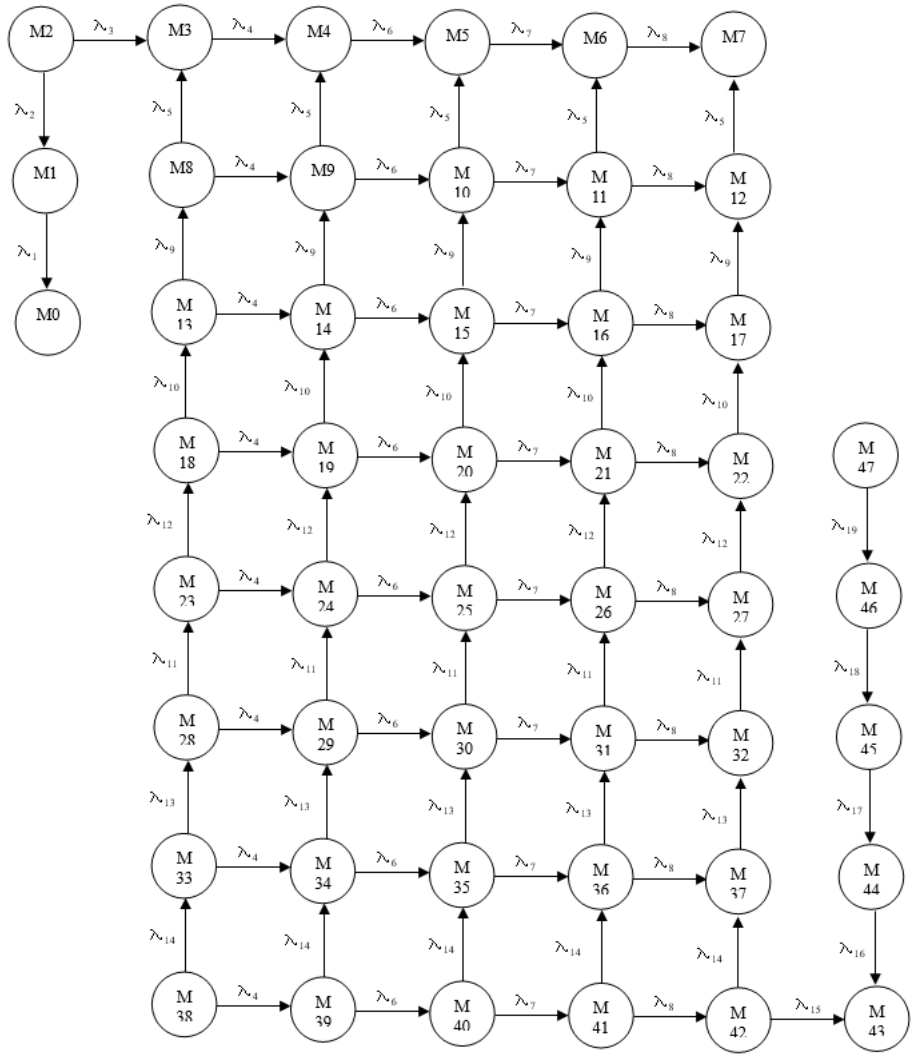

Figure 12 Markov Chain based on Petri Model of international cargo entry flow

Similarly, the transfer rate matrix of the Markov process can be obtained according to the Markov chain of the port entry operation flow. After listing the equation, the value of the relevant implementation rate can be put into the equation, and the stability probability of each state can be calculated as:

Table 16 The stability probability of each state of the inbound model of international freight service

Mark	M0	M1	M2	M3	M4	M5	M6
Rate	0.0124	0.0198	0.0496	0.0448	0.0107	0.0034	0.0015
Mark	M7	M8	M9	M10	M11	M12	M13
Rate	0.0020	0.0156	0.0054	0.0019	0.0009	0.0013	0.0440
Mark	M14	M15	M16	M17	M18	M19	M20
Rate	0.0270	0.0145	0.0097	0.0309	0.0077	0.0114	0.0079

Mark	M21	M22	M23	M24	M25	M26	M27
Rate	0.0006	0.0196	0.0129	0.0190	0.0162	0.0120	0.2206
Mark	M28	M29	M30	M31	M32	M33	M34
Rate	0.0013	0.0019	0.0016	0.0013	0.0266	0.0011	0.0018
Mark	M35	M36	M37	M38	M39	M40	M41
Rate	0.0001	0.0008	0.0274	0.0037	0.0060	0.0040	0.0040
Mark	M42	M43	M44	M45	M46	M47	
Rate	0.0236	0.0473	0.0474	0.0791	0.0949	0.0032	

The busy rate of Petri net database and the utilization rate of changes are shown in the table.

Table 17 Inbound flow of international freight business Petri net warehouse busy rate

Place	Busy rate	Place	Busy rate	Place	Busy rate
P1	0.0124	P8	0.0308	P15	0.0312
P2	0.0198	P9	0.3520	P16	0.0413
P3	0.0496	P10	0.0251	P17	0.0473
P4	0.1311	P11	0.1261	P18	0.0474
P5	0.0624	P12	0.0472	P19	0.0791
P6	0.0832	P13	0.2807	P20	0.0949
P7	0.0496	P14	0.0327	P21	0.0032

Table 18 Petri net transition utilization rate of inbound operation flow of international freight business

Transition	Utilization rate	Transition	Utilization rate	Transition	Utilization rate
T1	0.0124	T8	0.0308	T14	0.3933
T2	0.0198	T9	0.0251	T15	0.0473
T3	0.0496	Z1	0.2807	T16	0.0474
T4	0.1311	T10	0.1261	T17	0.0791
T5	0.0624	T11	0.0472	T18	0.0949
T6	0.0832	T12	0.0327	T19	0.0032
T7	0.0496	T13	0.0312		

As shown in the table above, the busy rate of P4, P9, P11 and P13 warehouses is relatively high, which is prone to blockage and affects the whole inbound operation process of international freight business. Among the transition utilization tables, T4, Z1, T10 and T14 are relatively high, indicating that the transition takes more time to complete.

3.5 International cargo business process problems at the C airport

(1) Serial processes are mostly numerous, and there is a lack of parallel business processes

Serial mode refers to two interconnected processes occur successively, the occurrence of the latter activity depends on the previous activity is output, serial connection will consume more time, greatly reducing the efficiency of the operation process, efficient freight business operation process is multiple links at the same time parallel operation, the main reason for the serial process is the delay in information transmission. This is due to the lack of information sharing and interaction between various subjects in the process of international cargo business inbound and outbound operation process of airport C.

(2) Lack of integrated information service platform

Information service is the main direction of the development of international freight business, and the inbound and outbound operation process of international cargo business of C Airport is designed to multiple entities such as airlines, international cargo terminals, customs freight forwarders and principals, and there is a lack of information sharing and interaction between each entity. Information exchange can only be carried out by relying on two interrelated processes, so that the information flow and document flow do not interact smoothly, and the documents often need to be entered and confirmed repeatedly, which wastes manpower and financial resources and affects the efficiency of the operation process.

4 Process optimization

Based on the existing international cargo business operation process of Airport C, with the goal of improving the overall operation process efficiency of airport C's international cargo business, solve potential problems in the operation process of airport C's international cargo business, and improve C by improving the local operation process The airport's international cargo business guarantee capability enables the efficient and smooth development of international cargo business. There are certain principles that need to be followed in the optimization process, as follows:

(1) ECRS principle

The ECRS principle is the most commonly used method in process optimization, which takes the optimization goal as the starting point to make a reasonable optimization of the entire process, that is: reasonably arrange the sequence of process links, delete redundant links, and make the process more compact and efficient.

ECRS is mainly composed of four basic principles:

①Cancellation principle: try to remove non-value-added or invalid activities in existing processes, and avoid or reduce the number of occurrences of processes that are difficult to eliminate.

②Consolidation principle: Merge processes with other processes and organizations according to the actual situation.

③Rearrangement principle: Analyze the exit order of each process and adjust accordingly to reduce the repetition rate and improve operational efficiency.

④Simplification principle: Simplify the organization, operation, and actions of the design process.

(2) Systemic principles

In the optimization process of the operation process, it is necessary to systematically consider the problem to deal with it, grasp the overall situation, and optimize the processing from all aspects to avoid the waste of resources caused by one-sided and partial optimization of the operation process.

(3) The principle of informatization

The improvement of informatization level can help the international cargo business of C Airport integrate internal and external resources, form a good organizational management structure, and an efficient business processing system. Therefore, the operation process of international freight

business should improve the level of informatization, promote the construction of information platform, enable multiple entities to share logistics and management information, and improve the management ability and competitiveness of international freight business.

4.1 Optimization strategy

4.1.1 Operation process optimization strategy based on association matrix reorganization

Through the analysis of the Petri network model of the international cargo business operation process of Airport C, it can be concluded that there is no conflict relationship between the inbound and outbound operations, so there is no conflict relationship table in the subnet of the Petri network association matrix, and the operation process can flow smoothly. For the optimization of the synchronization relationship, it is necessary to shorten the time difference between each branch before the transition synchronization, so that the branches can reach a relatively balanced state, so that the overall time consumption is minimized.

（1）Optimization of the receiving process

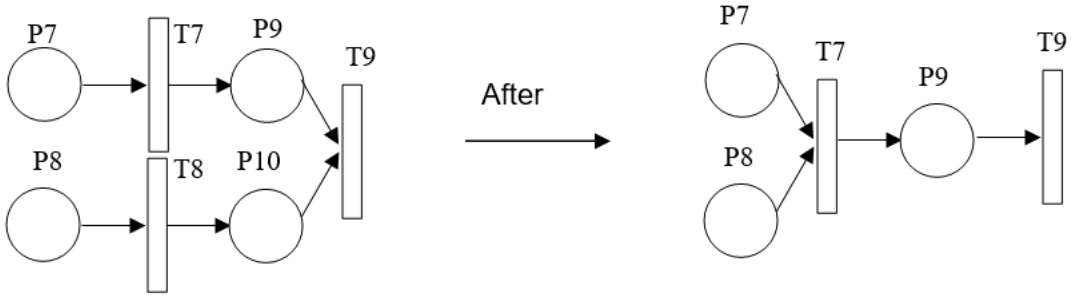

Figure 13 Order receiving link local optimization diagram

In Petri net of outbound operation flow of international cargo business at C airport, a synchronization relationship appears in T9. Transition T9 involves two tributaries, namely P5→P9 and P6→P10. The former tributaries represent two processes: the consignor submits documents related to goods and the freight agent inspects documents. The latter process refers to two processes: the consignor sends goods to the forwarder's warehouse and the forwarder accepts and confirms the goods. T7 and T8 both contain the confirmation of goods information, which can be combined according to the merging principle in ECRS. The confirmation of goods related information and the collection and sorting of materials can be carried out simultaneously, so as to realize one check and one confirmation and simplify the process. Avoid repeated operations.

(2) Order signing and warehouse release

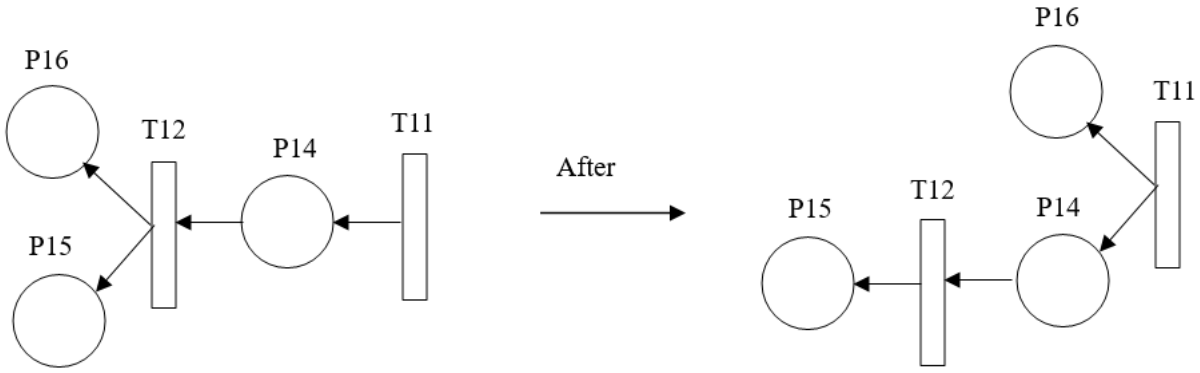

Figure 14 Local optimization diagram of order signing out warehouse link

Similarly, in the outbound operation process, T16 also appears a synchronization relationship. The change T16 involves two tributaries, namely P15→P17 and P16→P19. The former tributary represents the process of the freight agency system making warehouse receipt and sending it, while the latter one represents the process of the freight agency notifying the warehouse of delivery and the arrival of goods at the security check. Considering that there are many changes in the backward flow and it involves the actual transportation of goods, which takes a long time, it is considered to use the rearrangement principle in ECRS to advance the delivery process. The triggering condition T12 of P16 can be adjusted to T10, and the warehouse will be notified to deliver the goods when the customs returns the documents to the freight forwarder after customs declaration, so as to reduce the unnecessary waiting time in the transportation process.

(3) Optimization of tally warehousing, document signing and delivery

In Petri of inbound operation at C airport, synchronization relationship appears in T14, involving two branches, namely P4→P9 and P5→P16. The former branch is the link of tally storage, while the latter branch includes the link of order receiving, document making, inspection and customs declaration, document signing and delivery. The latter branch involves many serial processes, and the synchronous relationship between the two tributaries involves several processes, so it is difficult to reduce the time consumption gap between the two tributaries through the adjustment of a single link. Therefore, it is necessary to adjust the serial process of the latter branch and carry out the overall business process reorganization.

4.1.2 Job process optimization strategy based on business process Reengineering

There are a large number of serial relationships in the inbound and outbound operation process of international cargo business at the airport, in which the output of the previous link is the input of the later link. The operation process must be carried out one by one in accordance with the trigger

rules, resulting in widespread low efficiency links in the operation process. This paper proposes to optimize the flow tributaries of port operation based on business process reengineering strategy.

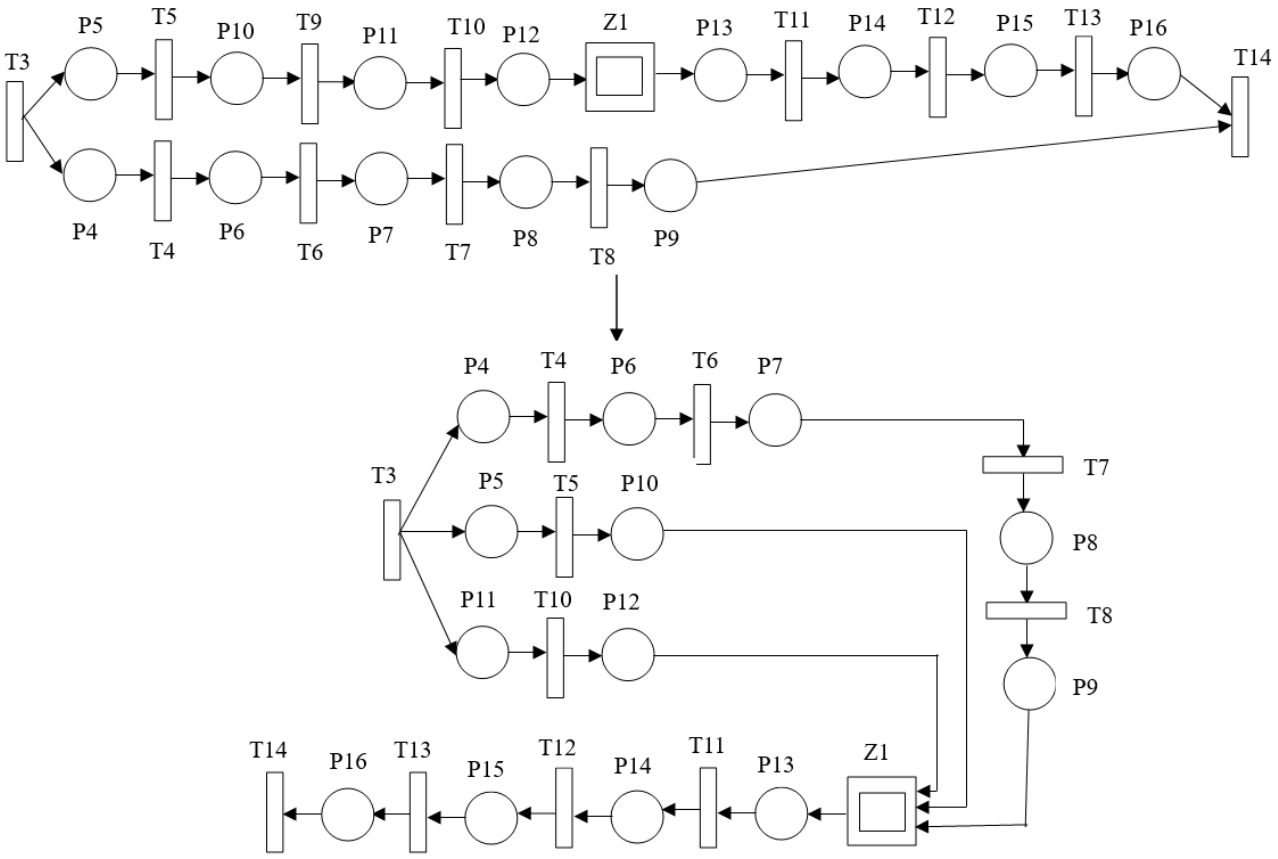

Figure 15 Optimization diagram of inlet flow tributaries

Through the analysis of the two tributaries that have synchronization relationship in the process of port entry operation in the recombination and optimization of the correlation matrix, the business process reorganization of P5→P16 will be carried out. The two serial links P5→P10 (cargo station receiving orders) and P11→P12 (cargo agent making documents) are implemented in parallel. After the aircraft enters the port, the cargo agent starts to prepare documents for customs declaration. There is no need to wait for the international cargo station to inform the cargo agent of the arrival of goods. In addition, the process of Z1→P16 (inspection and quarantine and delivery) will be postponed, and the overall tributaries will be simplified.

4.1.3 Job process optimization strategy based on value added value chain

Many operational processes of international freight transport business involve the interaction of information flow and document flow. Through the comprehensive information platform, information flow and document flow will be reasonably optimized, information barriers will be broken, non-

value-added links will be reduced, paperless customs clearance will be realized, and the efficiency of operational processes will be significantly improved.

(1) Optimization of entrusted booking links

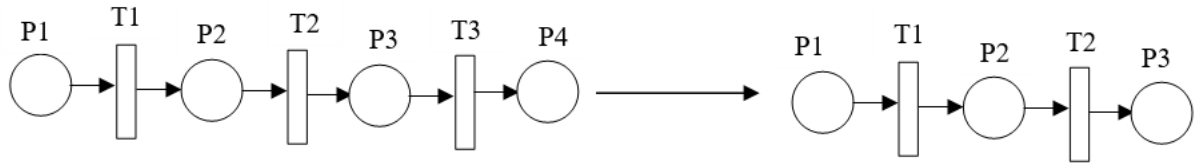

Figure 16 Consignment booking process optimization

In P1→P4 (booking by consignment) in Petri of the outbound operation flow of C airport, the information between the consignor, freight forwarder and airline company in the process of entrusting and booking is not free, and only feedback step by step and transfer step by step after confirmation, resulting in a waste of manpower, time and resources. In fact, through the construction of information platform, electronic booking service can be used to simplify booking process, reduce repeated data entry, achieve one-time entry and multi-party sharing, so as to make the information interaction between various subjects more flexible and transparent. The principal and freight forwarder can book space immediately and know the processing status of booking application. The airline can handle booking application in time, manage booking demand and accurately control shipping space.

(2) Optimization of the signing process

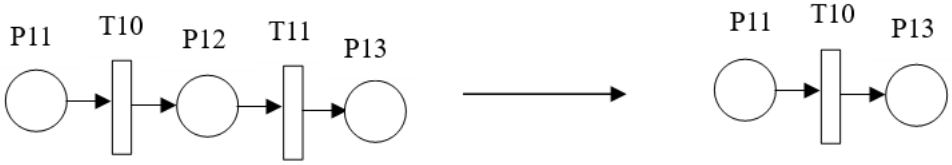

Figure 17 Outbound operation process signing link optimization

In Petri net of the outbound operation process of C airport, the link P11→P13 (outbound document signing) indicates that after the customs declaration documents are returned to the freight forwarder by the customs, the freight forwarder needs to hand over the relevant documents to the airline for signature before proceeding to the next step, resulting in time delay. In fact, the cargo agent, the customs and the airline company can realize the instant information interaction through the electronic information work. After the customs returns the documents, the documents information will be immediately uploaded to the airline company for signing the documents, and the

airline company will directly sign the documents online and return to the cargo agent, reducing the unnecessary flow of documents.

In the same way, the P13→T11→P14→T12→P15 (entry and document signing) process of international cargo business is optimized, so as to realize the information interaction among freight agents, customs and international cargo stations, and reduce the unnecessary flow of documents.

4.2 Optimization result

4.2.1 Outbound optimization results

The redesigned Petri network model of the overall outbound operation process of international cargo at Airport C.

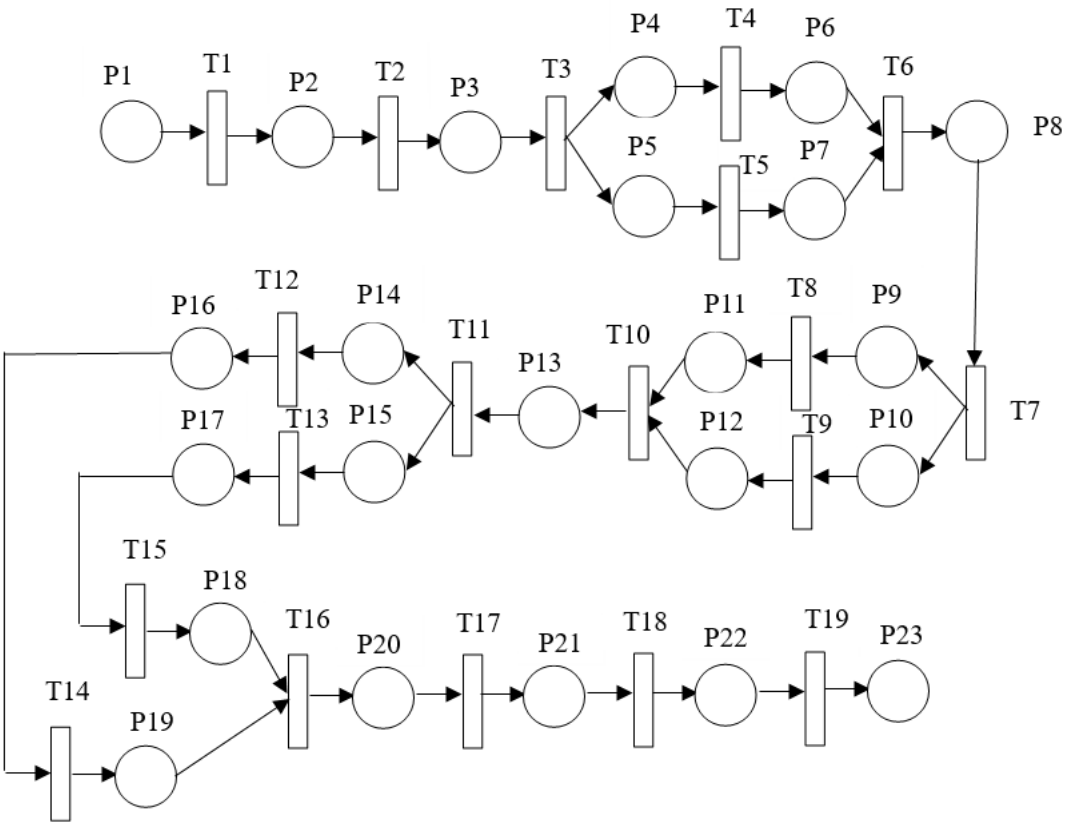

Figure 18 Optimization of C Airport outbound operation flow chart

Table 19 After optimization, the semantic description of C airport outbound operation flow Petri net model base

Place	Semantic description
P1	The client is ready to submit a freight commission through the information platform
P2	The freight forwarder takes orders on the platform and prepares to apply to the airline for booking

P3	The airline company is ready to confirm the booking request
P4	After the booking is confirmed, the principal receives information from the electronic platform and prepares for shipment
P5	The principal is ready to upload information about the goods to the freight forwarder
P6	The freight forwarding warehouse accepts the goods, prepares to confirm the cargo information, and makes electronic documents
P7	The freight forwarder accepts the uploaded materials and prepares the production of electronic documents
P8	The freight forwarder warehouse completes the documents and prepares the declaration for inspection
P9	The state inspection department accepts the declaration and prepares for inspection
P10	The customs department has completed the inspection and is ready for inspection
P11	The inspection by the state inspection department is completed and it is ready to be released
P12	The customs department has completed the inspection and is ready to release
P13	After the release is completed, the customs is ready to return the electronic document
P14	The freight forwarder accepts the electronic document and is ready to send the shipment notice to the warehouse
P15	The airline accepts the electronic document and prepares it for issuance
P16	The freight forwarder's warehouse receives the delivery notice and prepares to send the goods to the security checkpoint
P17	The freight forwarder receives the signature and prepares to make the warehouse receipt
P18	The security checkpoint receives the outbound receipt and prepares for the security check
P19	The goods are transported to the security checkpoint and prepared for the security checkpoint
P20	After the security check, prepare the pallet for packing
P21	After the pallet is packed, it is ready to be punched and boxed
P22	After the plate is packed, it is ready to be loaded and shipped
P23	The shipment is completed and the departure of international goods is completed

Table 20 After optimization, Petri net model transition semantic description of C airport outbound operation flow

Transition	Semantic description
T1	The principal submits a freight commission
T2	The freight forwarder makes a booking request
T3	The airline confirms the booking request
T4	The consignor delivers the goods to the freight forwarder's warehouse
T5	The principal uploads the cargo information
T6	Freight forwarders produce electronic documents
T7	Freight forwarder declaration inspection
T8	The national inspection department conducts inspections
T9	Customs conducts inspections
T10	Customs clearance
T11	Customs uploads and returns electronic documents
T12	The freight forwarder notifies the freight forwarder to ship the goods at the warehouse
T13	The airline signs the order
T14	The freight forwarder warehouse sends the goods to the security checkpoint
T15	Freight forwarder makes and uploads electronic outbound receipts
T16	Security checks are carried out on cargo inside the International Cargo Terminal

T17	Freight forwarder pallet box
T18	Palletize and lift the goods
T19	Installed and shipped

4.2.2 Port Entry Optimization Results

The redesigned Petri network model of the overall inbound operation process of international cargo at Airport C.

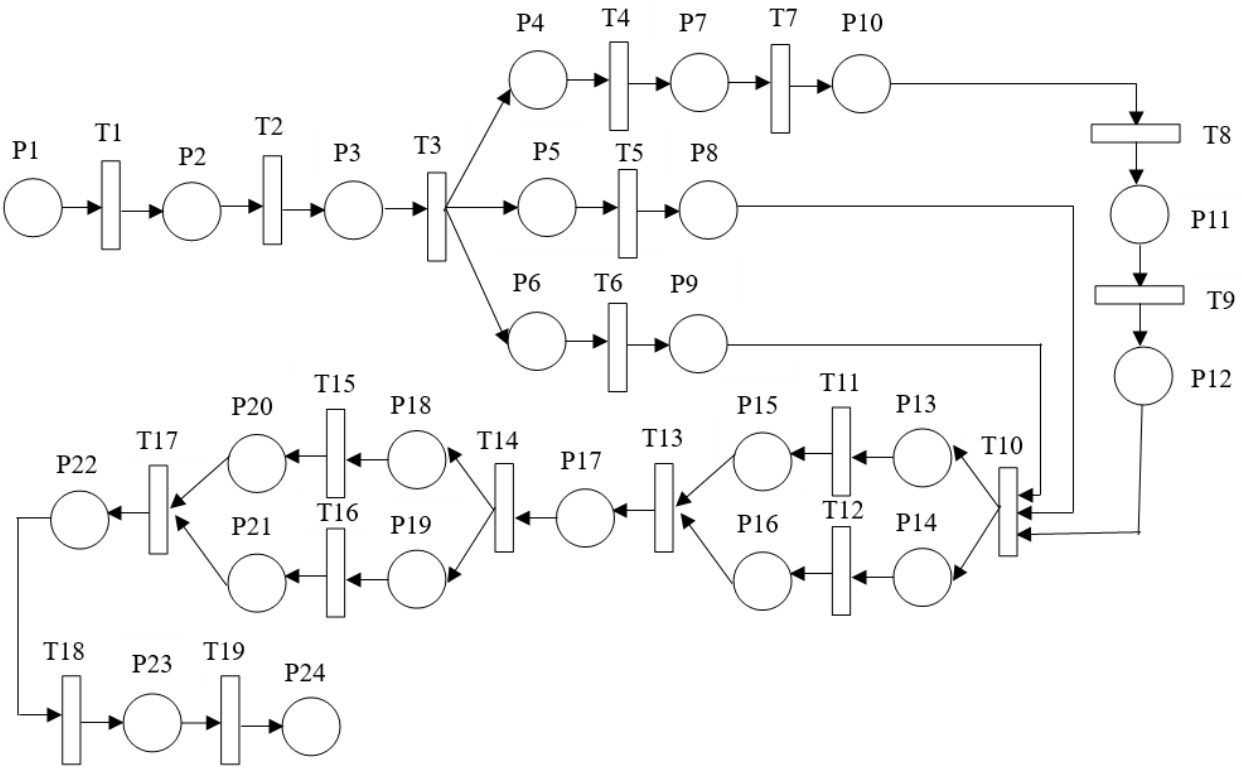

Figure 19 Petri net of the optimized inbound operation flow of C Airport

Table 21 After optimization, the semantic description of the Petri net library of C airport inbound operation flow

Place	Semantic description
P1	Airlines are ready to upload cargo arrival forecasts on the information platform
P2	ICCS accepts the platform information and is ready to arrange pick-up
P3	The plane is ready to enter the port
P4	Ready to unload and move goods to Hactl warehouse
P5	Hactl staff ready to accept business bags
P6	The freight forwarder prepares the production of electronic customs declaration documents
P7	Prepare to disassemble the plate
P8	Waiting for customs declaration and inspection
P9	The electronic document is completed and prepared for declaration and inspection
P10	The dismantling of the plates is completed and the sorting is ready for tallying
P11	The tally is completed and the goods are ready for regulatory temporary storage
P12	Shipped to a regulated staging area for inspection and pickup

P13	The national inspection department receives the declaration and prepares it for inspection
P14	The customs department receives the declaration and prepares it for inspection
P15	The inspection by the state inspection department is over, and it is ready to be released
P16	The customs department has completed the inspection and is ready to release
P17	After the release is completed, the customs is ready to upload the return documents
P18	Hactl prepares to sign the return document
P19	The freight forwarder receives the documents and prepares them for pick-up for verification
P20	Hactl is signed and waiting for the freight forwarder to pick up the goods
P21	After the pick-up check is completed, the goods are ready to be shipped to the freight forwarding warehouse
P22	After shipping to the freight forwarding warehouse, prepare the tally order
P23	After tallying, prepare to deliver the goods to the principal
P24	The client's pick-up is completed, and the inbound operation process is completed

Table 22 Petri Net transition semantic description of the optimized C airport inbound operation flow

Transition	Semantic description
T1	Airlines send inbound forecasts on electronic platforms
T2	Hactl arranges pick-up
T3	Aircraft entering the port
T4	Relevant personnel carry out unloading and transportation to the warehouse
T5	Hactl employees accept business bags
T6	Freight forwarders produce electronic documents for customs declaration
T7	Disassemble and disassemble the goods
T8	Sort and tally the goods
T9	Ship the goods to the regulatory staging area
T10	Freight forwarder declaration inspection
T11	The national inspection department conducts inspections
T12	Customs conducts inspections
T13	Customs clearance
T14	Customs uploads the returned electronic document
T15	Hactl signs the return document
T16	Freight forwarder pick-up check
T17	The freight forwarder ships the goods to the warehouse
T18	Tally the goods
T19	The principal goes to the freight forwarder's warehouse to pick up the goods

4.3 Construction and performance analysis of Markov chain of Petri Net for optimized operation flow

4.3.1 Construction and performance analysis of Markov chain of optimized outbound operation flow

MC analysis is carried out on Petri net of the optimized C airport outbound operation flow, wherein the time of each transition is shown in the table, and the implementation delay time of each transition in the table is assumed to obey exponential distribution.

Table 23 After optimizing the implementation delay time and corresponding implementation efficiency of outbound operation process

Transition	min	Rate	1/min	Transition	min	Rate	1/min
T1	15	λ_1	0.0667	T11	30	λ_{11}	0.0333
T2	10	λ_2	0.1000	T12	10	λ_{12}	0.1000
T3	25	λ_3	0.0400	T13	20	λ_{13}	0.0500
T4	135	λ_4	0.0074	T14	60	λ_{14}	0.0167
T5	135	λ_5	0.0074	T15	15	λ_{15}	0.0667
T6	50	λ_6	0.0200	T16	30	λ_{16}	0.0333
T7	10	λ_7	0.1000	T17	15	λ_{17}	0.0667
T8	45	λ_8	0.0222	T18	30	λ_{18}	0.0333
T9	45	λ_9	0.0222	T19	30	λ_{19}	0.0333
T10	10	λ_{10}	0.1000				

The identification state and palce corresponding to Petri net of optimized international cargo outbound operation flow are shown in the table.

Table 24 Optimized Petri net model of international cargo outbound operation flow identifies the status and contains the place

Mark	M0	M1	M2	M3	M4	M5	M6
Place	P1	P2	P3	P4、P5	P4、P7	P5、P6	P6、P7
Mark	M7	M8	M9	M10	M11	M12	M13
Place	P8	P9、P10	P9、P12	P10、P11	P11、P12	P13	P14、P15
Mark	M14	M15	M16	M17	M18	M19	M20
Place	P14、P17	P14、P18	P16、P15	P16、P17	P16、P18	P19、P15	P19、P17
Mark	M21	M22	M23	M24	M25		
Place	P19、P18	P20	P21	P22	P23		

The stability probability of each state is obtained as shown in the table, which is the same with the analysis and calculation process of Petri net MC model of international cargo outbound operation flow before optimization.

Table 25 The stability probability of each state of the optimized international cargo outbound operation process model

Mark	M0	M1	M2	M3	M4	M5	M6
Rate	0.0116	0.0165	0.0413	0.1116	0.1116	0.1116	0.0826

Mark	M7	M8	M9	M10	M11	M12	M13
Rate	0.0165	0.0826	0.0372	0.0372	0.0165	0.0628	0.0110
Mark	M14	M15	M16	M17	M18	M19	M20
Rate	0.0033	0.0022	0.0165	0.0139	0.0686	0.0055	0.0076
Mark	M21	M22	M23	M24	M25		
Rate	0.0496	0.0248	0.0496	0.0496	0.0033		

The optimized outbound operation flow of international freight business is shown in the following table: Petri net place busy rate and transition utilization rate.

Table 26 Optimized outbound operation flow of international freight business Petri net busy rate of place

Place	Busy rate	Place	Busy rate	Place	Busy rate
P1	0.0116	P9	0.1198	P17	0.0248
P2	0.0165	P10	0.1198	P18	0.1204
P3	0.0413	P11	0.0537	P19	0.0627
P4	0.2232	P12	0.0537	P20	0.0248
P5	0.2232	P13	0.0628	P21	0.0496
P6	0.1942	P14	0.0165	P22	0.0496
P7	0.1942	P15	0.0330	P23	0.0033
P8	0.0165	P16	0.0990		

Table 27 Petri transition utilization ratio of outbound operation process of international freight business is optimized

Transition	Utilization rate	Transition	Utilization rate	Transition	Utilization rate
T1	0.0116	T8	0.1198	T15	0.0248
T2	0.0165	T9	0.1198	T16	0.1831
T3	0.0413	T10	0.1074	T17	0.0248
T4	0.2232	T11	0.0628	T18	0.0496
T5	0.2232	T12	0.0165	T19	0.0496
T6	0.3884	T13	0.0330	T20	0.0033
T7	0.0165	T14	0.0990		

4.3.2 Construction and performance analysis of Markov chain for optimized inlet operation flow

MC analysis is carried out on Petri net of the optimized port entry operation flow, in which the time assignment of each transition is shown in the table.

Table 28 Optimize the implementation delay time and the corresponding implementation rate of the operation process after port entry

Transition	min	Rate	1/min	Transition	min	Rate	1/min
T1	5	λ_1	0.2000	T11	45	λ_{11}	0.0222
T2	8	λ_2	0.1250	T12	45	λ_{12}	0.0222
T3	20	λ_3	0.0500	T13	10	λ_{13}	0.1000
T4	65	λ_4	0.0154	T14	30	λ_{14}	0.0333
T5	25	λ_5	0.0400	T15	20	λ_{15}	0.0500
T6	50	λ_6	0.0200	T16	15	λ_{16}	0.0677
T7	40	λ_7	0.0250	T17	30	λ_{17}	0.0333
T8	25	λ_8	0.0400	T18	30	λ_{18}	0.0333
T9	20	λ_9	0.0500	T19	60	λ_{19}	0.0167
T10	10	λ_{10}	0.1000				

The identification and place corresponding to Petri net of optimized operation flow of international cargo entering port are shown in the table.

Table 29 Identification state and inclusion place of Petri net model of international cargo entry flow after optimization

Mark	M0	M1	M2	M3	M4	M5	M6
Place	P1	P2	P3	P4、P5、P6	P4、P5、P9	P4、P8、P6	P4、P8、P9
Mark	M7	M8	M9	M10	M11	M12	M13
Place	P7、P5、P6	P7、P5、P9	P7、P8、P6	P7、P8、P9	P10、P5、P6	P10、P5、P9	P10、P8、P6
Mark	M14	M15	M16	M17	M18	M19	M20
Place	P10、P8、P9	P11、P5、P6	P11、P5、P9	P11、P8、P6	P11、P8、P9	P12、P5、P6	P12、P5、P9
Mark	M21	M22	M23	M24	M25	M26	M27
Place	P12、P8、	P12、P8、	P13、P14	P13、P14	P14、P15	P15、P16	P17

	P6	P9					
Mark	M28	M29	M30	M31	M32	M33	M34
Place	P18、P19	P18、P21	P19、P20	P20、P21	P22	P23	P24

The stable probability of the obtained state is shown in the table.

Table 30 The stability probability of each state of the inbound model of international freight service

Mark	M0	M1	M2	M3	M4	M5	M6
Rate	0.0112	0.0179	0.0448	0.0297	0.0107	0.0336	0.0714
Mark	M7	M8	M9	M10	M11	M12	M13
Rate	0.0054	0.0042	0.0163	0.0637	0.0013	0.0016	0.0077
Mark	M14	M15	M16	M17	M18	M19	M20
Rate	0.0453	0.0005	0.0008	0.0047	0.0388	0.0004	0.0013
Mark	M21	M22	M23	M24	M25	M26	M27
Rate	0.0125	0.0224	0.0504	0.0504	0.0504	0.0224	0.0672
Mark	M28	M29	M30	M31	M32	M33	M34
Rate	0.0192	0.0256	0.0144	0.0672	0.0672	0.1341	0.0045

The busiest rate of Petri net library is shown in the table.

Place	Busy rate	Place	Busy rate	Place	Busy rate
P1	0.0112	P9	0.2602	P17	0.0672
P2	0.0179	P10	0.0559	P18	0.0448
P3	0.0448	P11	0.0448	P19	0.0336
P4	0.1454	P12	0.0366	P20	0.0816
P5	0.0559	P13	0.1008	P21	0.0928
P6	0.1121	P14	0.1008	P22	0.0672
P7	0.0896	P15	0.0728	P23	0.1341
P8	0.0559	P16	0.0728	P24	0.0045

5 Result effect analysis

5.1 Comparative analysis of process performance indexes of international freight business

The average number of marks, average rate of marks and average delay time of the system were used as indicators to analyze the optimization effect of the international cargo business process of C Airport. Among them, the average number of system identifiers indicates the utilization rate of system links. The larger the value, the higher the utilization rate table. The average labeled flow rate represents the processing level of the link, and the higher the value, the stronger the processing level. The average delay time indicates the process efficiency. The shorter the delay time, the higher the process efficiency. The following will analyze and calculate the performance indicators of the international cargo operation process of C airport.

According to the analysis of MC for outbound operation at C airport, the average number of signs of the system can be obtained.

$$\overline{N} = \sum_{i=0}^{34} P[M(p_i) = 1]$$

Plug in the data to find $\overline{N} = 1.3786$

Utilization rate of transition T1:

$$u(T1) = P(M0) = 0.018$$

The average marked flow rate into the system is:

$$\lambda_c = U(T1) \times \lambda_1 = 1.2006 \times 10^{-3}$$

The average system delay time is:

$$T_c = \overline{N}/\lambda_c = 1148.3\ min$$

By the same token, the average delay time of C airport entry operation process is obtained.

$$T_j = \overline{N}/\lambda_j = 730.32\ min$$

Table 31 Comparison of performance indexes before and after port operation optimization

Performance index	Before optimization	After optimization	Rate of change

Average number of signs	1.3786	1.8142	31.60%
Average labeled velocity	0,0012006	0,0023212	93.30%
Average delay time	1148.3	781.6	-31.93%

Table 32 Comparison of performance indexes before and after port entry optimization

Performance index	Before optimization	After optimization	Rate of change
Average number of signs	1.6471	1.8033	9.48%
Average labeled velocity	0,0022553	0,0033157	47.02%
Average delay time	730.32	543.86	-25.53%

It can be seen that the optimized operation process system of international cargo business at C airport has a higher utilization rate, stronger processing level and higher process efficiency. It can be seen that the optimization is effective. To a certain extent, short operation process time improves the efficiency of international freight transportation, which can better meet and adapt to the needs of international freight business.

5.2 Optimization comparison

The optimized outbound operation process of international cargo business of C Airport mainly improves and optimizes the links of entrusted transportation, booking space, customs declaration, inspection and clearance, document signing and warehouse clearance, etc., among which: (1) Optimization of entrusted transportation links: electronic entrusting is improved for paper consignments to shorten the time of consignor's submission and freight forwarder's review; (2) Optimization of booking links: the one-way booking process of freight forwarder → airline → freight forwarder → principal is improved into a unified electronic booking platform for booking activities. Airlines, freight forwarder and principal can realize real-time sharing of booking information and reduce unnecessary information transfer links. (3) Optimization of inspection and customs declaration: on the basis of parallel inspection and customs declaration processes, electronic customs clearance is implemented to realize one declaration, one inspection and one release, which greatly improves the efficiency of customs clearance; (4) Optimization of document signing and warehouse booking: the optimization process is similar to that of booking space. Through a unified electronic customs clearance platform, the one-way serial process between customs, freight forwarder, airline and freight forwarder is improved to realize the sending of electronic customs clearance documents

upon confirmation and real-time signing of documents, which reduces the link of information transmission. In addition, the implementation of electronic flower of documents for freight forwarders receiving orders and making documents has greatly shortened the time required for paper documents process.

The optimized operation process of international cargo business at C Airport mainly optimizes the business process after cargo approach, including: (1) Document process optimization: The process of making and sending documents is advanced, and the freight forwarder starts to make documents after receiving the cargo arrival information through the electronic information platform. There is no need to wait for the international cargo station to receive the business bag and then notify the freight forwarder. The original serial process is changed to parallel. ② Optimization of pick-up link: After the goods are cleared, the supervision temporary storage of international cargo station can directly sign the documents on the electronic customs clearance platform in real time, and the freight forwarder can also directly pick up the goods, reducing unnecessary intermediate links.

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