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Modeling New Cold Chain Logistics Processes in the Post-Epidemic Period Based on Petri Net

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Abstract: Over the past few years, there has been a steady increase in demand for frozen and refrigerated products among Chinese residents. The growth of the cold chain logistics industry has played an important role in advancing China's economy. However, due to the impact of COVID-19, there is now concern over the safety of such products, which has led to a potential setback in economic recovery. This article attempts to describe the difference between the new cold chain logistics and the traditional cold chain logistics in the post-epidemic period from the structural changes in the cold chain logistics and to explore the structure of the process. To fill the gap in modeling study on new cold chain logistics, this article uses Petri net to model the new cold chain logistics in the post-epidemic period and then analyzes the model using TINA software. This study aims to provide an optimization solution for the new cold chain logistics process and to serve as a basis for future related research. However, there is a gap between the results obtained through simulation and the real situation. If researchers want to further improve the model and solve the problem, they still have to cooperate with related companies to understand the actual situation.

Keywords: post-epidemic period, new cold chain logistics, Petri Net, simulation, TINA

1. Introduction

1.1. Background

Cold chain logistics maintains the quality of frozen and chilled products at every stage of manufacture, storage, transportation, sale, and consumption. Each link in this system requires a specific temperature environment to minimize product loss [1].

Due to the rising need for cold chain products like food, medicine, and other goods including agriculture and animal products, China's cold chain logistics business has expanded dramatically in recent years. With the market size of cold chain logistics reaching over 458.6 billion yuan in 2021, an increase of 19.65% year-on-year. According to the "China Cold Chain Logistics Development Report (2022)" by the China Federation of Logistics and Purchasing, in 2021, the total demand for food cold chain logistics increased to 302 million tons, an increase of 13.96% year-on-year. This report indicates that cold chain logistics has become a key industry for promoting rural revitalization, economic development, and improving the two-way circulation system in urban and rural areas [2].

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Because of ongoing outbreaks both domestically and globally, several fresh items transported in the cold chain are commonly coronavirus-contaminated. Consumers have been quite concerned about this, which has slowed the economy's recovery. Due to the mobility of logistical activities, the cold chain logistics sector must take precautions to reduce the risk of viral transmission. To do this, RFID, blockchain, and other technologies must be used to create an information traceability platform for frozen and refrigerated goods.

1.2. Literature Review

The current research on cold chain logistics focuses on the discussion and analysis of the functional structure and management structure. Sun Yiling and Wang Bemeng analyzed the cost management of the cold chain logistics process and formulated a set of scientific improvement measures based on the analysis in the article [3].

The majority of modeling and research on models linked to cold chain logistics concentrate on cold chain logistics before the COVID-19 outbreak. Feng Yuan and Hu Dawei use Petri net to establish a model of the traditional cold chain distribution process [4]; Wen Bao used the CPNTOOLS software to model and simulate the cold chain logistics distribution process [5]. The modeling study of the new cold chain logistics process in the post-epidemic period is relatively vacant.

1.3. Motivation

After more than 50 years of development, Petri net has proven to be a useful tool for system modeling and analysis. They have intuitive graphical representations and technical features for simple programming implementation. Petri net can be used to evaluate and suggest ways to improve systems and examine the structure and behavior of various networks.

Jan-Phillip Herrmann et al. used Petri net to model real-time human activity recognition in work systems [6], and Kuldeep Kumar et al. used Petri net for the safety system used in nuclear power plants [7]. This article describes the new cold chain logistics process in the post-epidemic period, constructs a Petri net model of the process based on the most recent research on China's new cold chain logistics, and then analyzes the system's performance using the model. This fills the modeling gap for the new cold chain logistics and ensures the operation is carried out safely. Process merging and cancellation are used to improve the system's performance while also creating an optimization strategy.

2. Problem Description

2.1. Differences

The subject structure of cold chain logistics can be roughly divided into six segments: commodity handling and pre-cooling, cold storage, cold chain transportation, cold chain sales, cold chain distribution, and consumption [1]. Whether it is the traditional cold chain or the cold chain in the post-epidemic period, there is not much difference in its main structure.

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The logistics process of traditional cold chain logistics is shown in Fig. 1 [8].

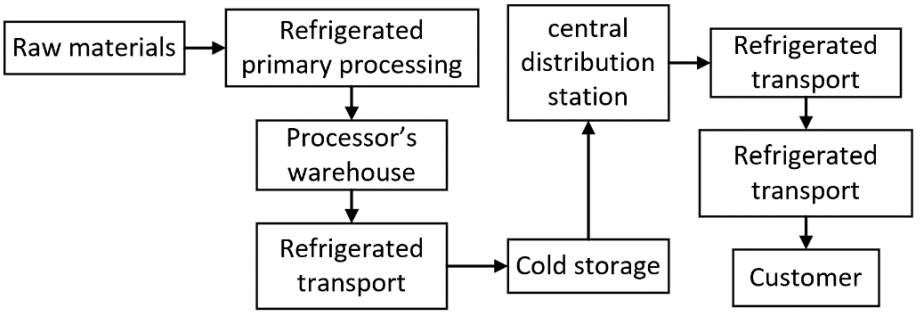

Figure 1: Traditional cold chain logistics process (Photo credit: Original).

The new cold chain logistics lowers the risk of epidemics while enhancing the information and transportation efficiency of the cold chain logistics. Using QR codes, GIS, and GPS, producers, customers, and regulators may quickly identify, locate, track, manage, and monitor everyone involved at each step of the process. To achieve traceability of information in the cold chain, RFID, GIS, GPS, and blockchain are used. The following four factors primarily highlight how the new cold chain logistics structure differs from the classic cold chain logistics structure. [9]:

1). To build a full producer information input system, the necessary data must be collected into a QR code, distributed to the lower nodes, and synced with the government regulatory information system using RFID technology.

2). Processors should employ GIS and GPS technology to enter processor and geographical information and synchronize it with the government's regulatory information system. Processors should also communicate additive and processing information to higher levels.

3). To enter warehouse data into wholesalers' and retailers' warehouse systems, GIS and GPS technology are required.

4). Retailers compile all the data from the higher-level nodes, add details about the pricing and texture of the products, and create a QR code to be applied to the merchandise.

2.2. The New Logistics of the Cold Chain in the Post-Epidemic Period

Fig. 2 depicts the new cold chain logistics flow chart for the post-epidemic period; Fig. 3 displays the chart for the cold chain product traceability system; and Fig.4 depicts the complete process flow of the new cold chain logistics in the post-epidemic period.

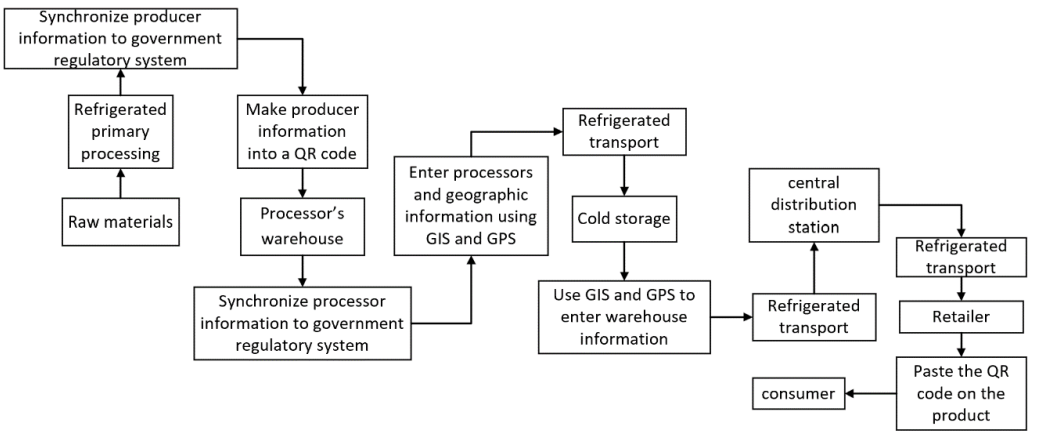

Figure 2: New cold chain logistics flow chart (Photo credit: Original).

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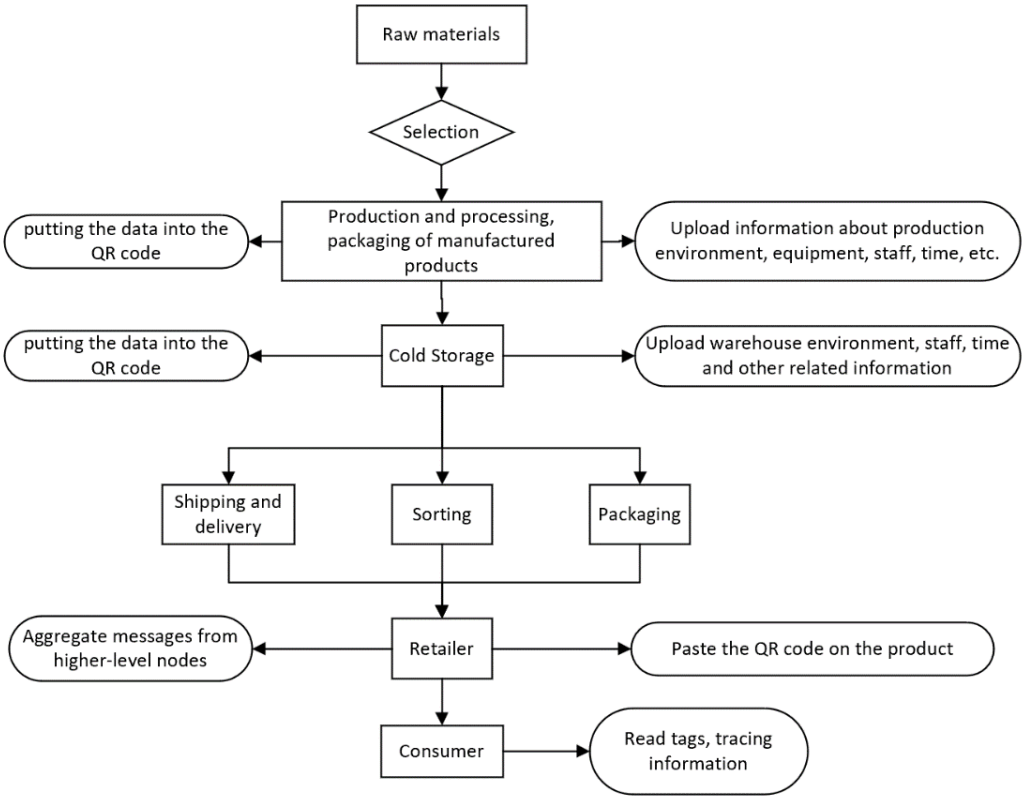

Figure 3: Flow chart of cold chain product traceability system (Photo credit: Original).

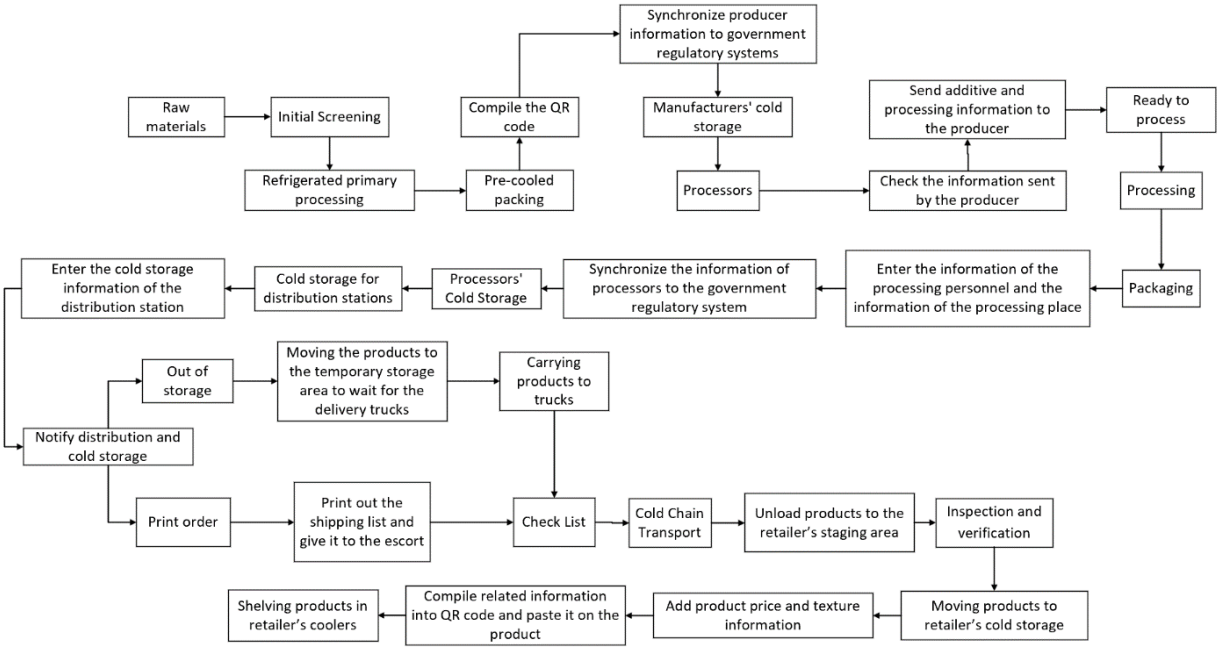

Figure 4: Complete the new cold chain logistics flow chart for the post-epidemic era (Photo credit: Original).

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3. Methods

Petri net is a mathematical and graphical tool for system description and analysis. Any system can comprise two types of components: those that represent the state and those that represent the state change. The former can be represented by the place in Petri nets, whereas the latter can be represented by the transition. The transition's function is to alter the state, and the place's function is to determine whether the change is permitted. A directed arc is used to illustrate how the two are dependent on one another. The place is typically represented graphically by a circle, the transition is typically represented by a rectangle or vertical line, and the ordered even is typically represented by a directed arc from x to y [10].

4. Modeling and Simulation Study of New Cold Chain Logistics in the Post-Epidemic Period

4.1. Modeling

The new cold chain logistics flow chart in the post-epidemic period is described in the model, which is based on Fig. 5 above, and the meanings of its places and transitions are shown in Table 1.

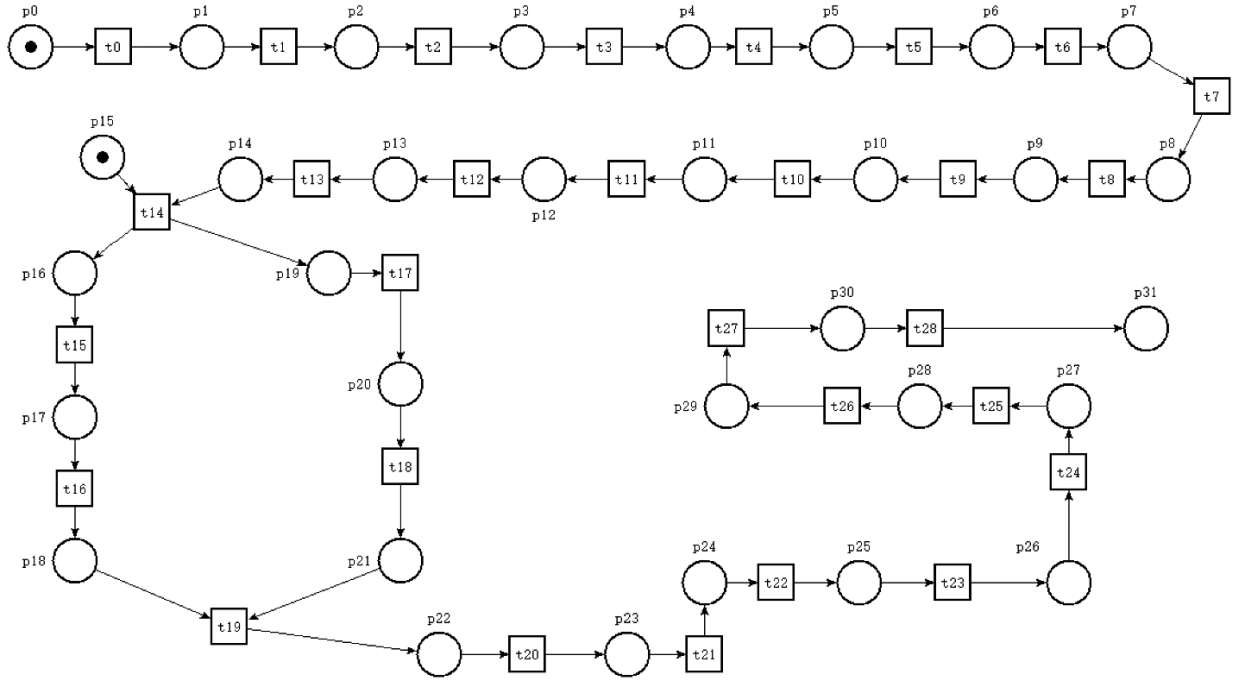

Figure 5: Petri net model of cold chain logistics in the post-epidemic period.

Table 1: Meaning of each place and transition in the model.

Place	Meaning	Transition	Meaning
P0	Raw materials	T0	Preliminary screening
P1	Initial screening completed	T1	Refrigerated primary processing
P2	Primary processing completed	T2	Pre-cooled packaging
P3	Complete packaging	T3	Compile QR Code
P4	Compilation completed	T4	Upload producer information
P5	Complete synchronization	T5	Refrigerated transport

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Table 1: (continued)

P6	Processors	T6	Processors read information
P7	Verify compiled information	T7	Send processing information to producer
P8	Complete sending	T8	Processing
P9	Processing completed	T9	Packaging
P10	Complete packaging	T10	Entry of geographic information
P11	Complete the entry	T11	Upload processer information
P12	Complete synchronization	T12	Refrigerated transport
P13	Distribution Station Cold Storage	T13	Entering geographical information
P14	Complete the entry	T14	Notify the cold storage
P15	Orders	T15	Printing shipment notes
P16	Delivery Department	T16	Giving the escort shipping order
P17	Print completion	T17	Performing outbound operations
P18	Escort receives the shipment order	T18	Waiting for transport vehicles
P19	Distribution Station Cold Storage	T19	Checklist
P20	Complete outbound	T20	Loading the goods onto the truck
P21	Vehicles arrive at staging area	T21	Refrigerated transport
P22	Complete the reconciliation	T22	Handling the products to staging area
P23	Complete the handling	T23	Inspection and verification
P24	Supermarket staging area	T24	Handling products to refrigerator
P25	Complete unloading	T25	Summary data from higher-level nodes
P26	Supermarket check and sign orders	T26	Add price and texture information
P27	Supermarket Cold Storage	T27	Compile the QR code
P28	Complete information summary	T28	Paste onto the product
P29	Complete adding		
P30	Compilation completed		
P31	Supermarket refrigerator		

4.2. Simulation Analysis

TINA is a set of tools for editing and analyzing Petri nets, Time Petri nets, and an extension of Time Petri nets called Time Transition Systems with data handling [11]. Using these toolboxes in TINA to analyze the performance of the model.

To verify the feasibility of the created model, structural analysis and reachability testing in TINA software are used, as shown in Fig 6 and Fig 7.

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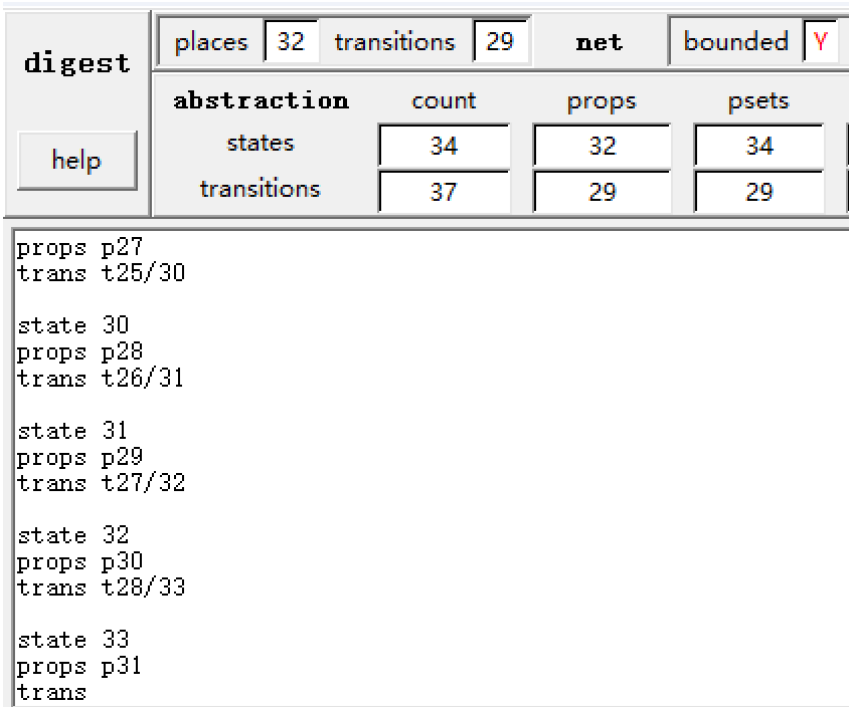

Figure 6: Diagram of the model reachability analysis procedure (Photo credit: Original).

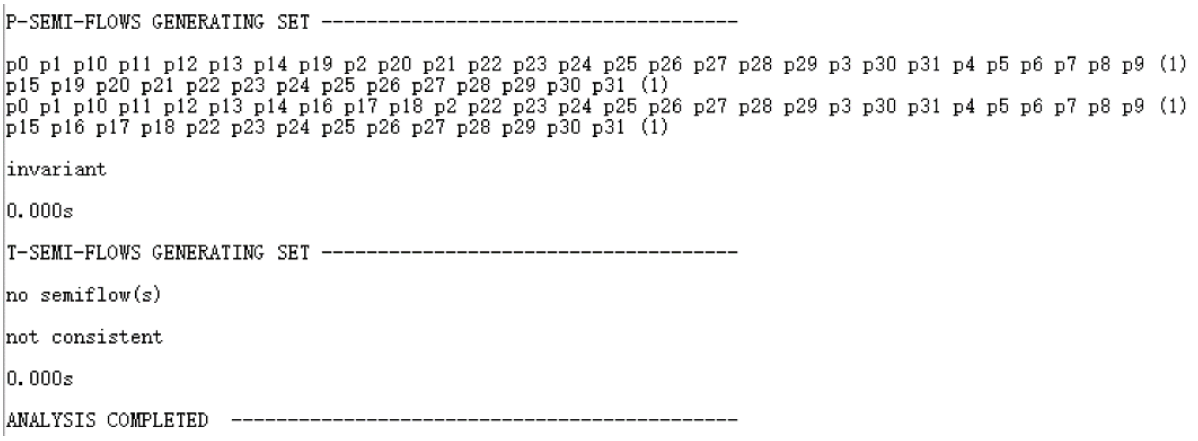

Figure 7: Structural analysis program diagram (Photo credit: Original).

The number of tokens at any place in the process is less than or equal to 1, which is consistent with the boundedness and security of Petri net; the model has no deadlock. Thus, it can be seen that the Petri net model described above is reachable, secure, and bounded.

5. Optimization based on Essential Processes

The simulation reveals that the entire procedure requires 1450 minutes and is inefficient. First, the path links related to goods handling and transportation in the aforementioned parallel business processes are P0→P1→P3, P5→P6→P7→P8→P9→P10, and P19→P20→P21→P22→P23→P24→P25→P26→P27→P28→P29. Therefore, increasing the efficiency of these three processes will help increase the overall efficiency of the business process. Second, the staging area's interim storage and supermarket distribution are both time-consuming steps in

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the process. The effectiveness of the entire process can be effectively increased if these two links are improved.

The new procedure can be achieved through improvement: P21 and T18 can be canceled when the delivery time is changed so that the incoming goods no longer need to wait; P25 can be canceled after improving contact with retailers to address the phenomena of queuing unloading; If the processor implements the parallel operation of product packaging and entering pertinent information, the original processes of P10, T10, and P11 in the original process are canceled, and P34 is added to indicate the parallel relationship. If the manufacturer implements the parallel operation of pre-cooling packaging and compiling QR codes, P3, T3, and P4 are canceled, and the new P33 indicates the parallel relationship. Fig.8 displays the optimized Petri net model.

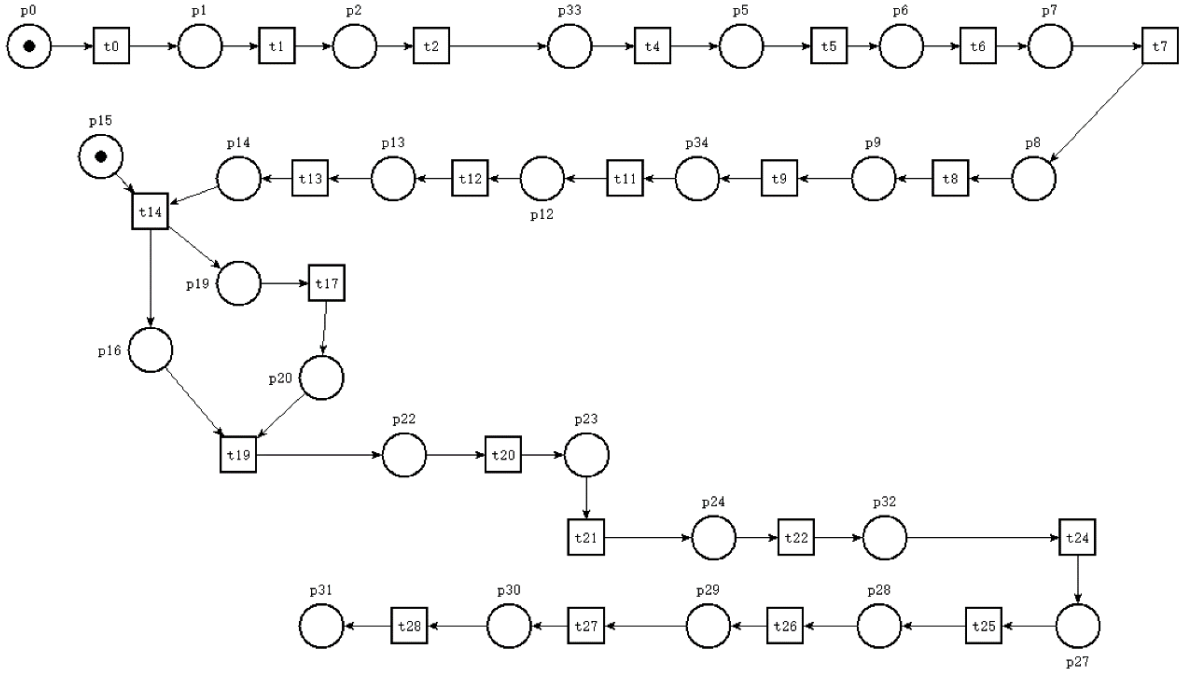

Figure 8: Optimized Petri net model (Photo credit: Original).

Through the implementation of two means of efficiency improvement and process reconstruction, the time consumption of the whole process was reduced from the original 1450 minutes to 761 minutes, which is a 47.52% improvement in efficiency.

6. Conclusion

Four changes to the new cold chain logistics processes are listed in the articles. The activity, accessibility, and structure of the model are examined with the use of TINA simulation software, and the functioning of a Petri net is simulated. The Petri net's logical representation is used to build the cold flow logistics procedure during the post-epidemic period. The results show that the current model is useful and capable of modeling cold chain logistics activities in the post-epidemic period, and future research can be built on it. By researching the crucial cold chain logistics tasks, the model may be enhanced to optimize operational efficiency.

The current findings of this article still have flaws. Petri net modeling can only simulate how a process interacts in an ideal situation; actual system operation often involves more arbitrary conditions. The time obtained from the simulation, as a result, does not accurately reflect the problems in

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the real process. If researchers wish to further enhance the model and address the issue, they must collaborate with relevant companies to fully understand the situation.

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