

## Research Article

# Partner Matching Mechanism of Hainan Cold Chain Logistics Based on Multiobjective Optimization

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Received 21 July 2022; Revised 8 September 2022; Accepted 10 September 2022; Published 27 September 2022

Academic Editor: Zaoli Yang

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With the sustained and rapid development of the economy, the food consumption structure has changed correspondingly and the market of cold and fresh products has developed rapidly, which puts forward the matching of cold chain logistics. Under the background of the construction of the belt and road and the pilot-free trade zone, the organic integration of the fresh agricultural products market and industry in Hainan is facing opportunities and challenges. In particular, in-depth research on the design and planning of the entire logistics system has not been carried out and the research on the distribution vehicle routing problem is still in the initial stage. This paper combs the relevant policies of cold chain logistics development in Hainan province. Given the imperfect system, the lack of policy guarantee measures, and the lack of regionality of the policy objective system, this paper puts forward some suggestions for improvement. The effective inventory control model of Hainan fresh agricultural products under cold chain logistics is explored by using the inventory management theory and the related theory of system dynamics. The simulation is carried out by using Vensim software, which provides a reference for improving the status of cold chain logistics of fresh agricultural products in Hainan. By saving funds, the profits of cold and fresh products are increased and the market competitiveness is improved.

## 1. Introduction

In recent years, the fresh food market in the e-commerce field has developed rapidly. About 60% of fresh food e-commerce enterprises outsource logistics to professional third-party cold chain logistics service providers, so as to reduce the investment in heavy assets and logistics costs and focus on improving their core competitiveness [1]. The province with the lowest latitude is the tropical region. The annual average temperature is between 22 and 26 degrees, making it the province with the highest average temperature in China [2]. Compared with other provinces, Hainan province has more important and special significance because of its special economic location and the background of international tourism island construction. As an important means to achieve regional development goals, the cold chain logistics policy system in Hainan province has its own

characteristics, which are manifested in policy objectives, basic concepts, policy types, and policy measures [3–5].

At the current stage, my country's urbanization rate has reached 52.6% and is still rising steadily. In 2015, the market size of e-commerce, mainly fresh products, reached 52 billion yuan. In 2016, the market size increased to 91.1 billion yuan. "the one who obtains the cold chain wins the world" has become the consensus of the fresh food industry. Meat, milk, fruit, and aquatic products are perishable [6]. They are easy to rot and deteriorate when transported at normal temperatures, resulting in huge losses. Therefore, special refrigeration and insulation facilities need to be used for transportation. In addition, consumers pay attention to product quality and distribution timeliness of merchants. Therefore, we must pay attention to cold chain logistics transportation and distribution [7, 8]. From the above-mentioned data, it can be seen that the market demand for

refrigeration products in China is gradually increasing, and the main reason is H-point. First, with the rapid development of society and the economy, people have to speed up the pace of life in the increasingly fierce competition, which leads people to store some frozen and refrigerated foods to save time in daily life. Second, with people's consumption of refrigerated and frozen foods, more and more refrigerated and frozen foods are put on the table and people's awareness and recognition of such foods are also increasing [9]. However, due to the continuous improvement of freezing and cold storage technology, it can ensure that refrigerated and frozen foods can be kept at low and appropriate storage, so as to ensure the quality of food. People are more and more willing to eat all kinds of refrigerated and frozen foods [10].

Under this background, this paper establishes cost minimization considering fixed cost, transportation cost, cargo damage cost, and a time multiobjective optimization model of maximizing customer satisfaction with the constraint of the customer's prescribed delivery time. This paper comprehensively uses the theory of inventory management and related theories of system dynamics to explore the effective inventory control model of fresh agricultural products in Hainan under cold chain logistics and uses Vensim software to simulate, to provide a reference for improving the current situation of cold chain logistics of fresh agricultural products in Hainan.

## 2. Related Work

By constructing the unit relationship model of temperature, bacterial reproduction, and transportation system, Yu concluded that the biggest purpose of cold chain logistics is to maintain food quality and refrigeration is only a means to keep freshness [11]. Taking a certain region as the research object, Xu et al. conducted an in-depth study on the development trend and quality and safety status of local economic and environmental characteristics of Hainan and put forward targeted suggestions on this basis [12]. Wan et al. compared the domestic cold chain logistics system with foreign ones, and from the perspective of comparison, they summed up the enlightenment given to my country by the development experience of foreign cold chain logistics systems [13]. He et al. compared the relevant measurement standards for aquatic product qualities at home and abroad, found out the contradictions, and evaluated and improved the current aquatic product quality and safety standards in my country based on the principles of international standards and our actual situation [14]. Inprom et al. have studied the main modes channels and put forward integration in the middle, and overall shortening of circulation links [15]. On the basis of analyzing the problems and obstacles faced fresh, Chen proposed two modes, namely, horizontal enterprise alliance and vertical enterprise alliance, which can choose a better logistics scheme according to the specific strength of alliance enterprises [16]. Moradi et al. deeply analyzed the current conditions of products and discussed the innovation and development direction of the business model [17]. Hendriarto evaluated the evaluation method. The overall index system constructed includes five

aspects: transportation capacity, storage capacity, service capacity, distribution capacity, and informatization level. AHP is used to determine the weight [18]. Molina et al. constructed the system dynamics model of the three-level agricultural product supply chain under the regular procurement mode, studied the bullwhip effect of the supply chain and the relationship between the cost and the inventory adjustment coefficient, and found that retailers and wholesalers are more sensitive to the change of the inventory adjustment coefficient, and reasonable inventory objectives and inventory adjustment strategies can effectively reduce the bullwhip effect of the supply chain [19]. Chen et al. established a dynamic model of a dairy cold chain system composed of producers, suppliers, and retailers, introduced third-party logistics to simulate the inventory level and terminal sales at different temperatures and operating efficiencies, and concluded that shortening the ordering lead time and arrival delay would help reduce increase the profit of retailers [20].

## 3. Methodology

*3.1. Related Concepts and Theoretical Methods Based on Cold Chain Logistics Distribution.* China's national standard "Logistics Terminology" in 2006 defines the cold chain as "a logistics network that is always in a low-temperature state from production to consumption in order to maintain the quality of goods according to their characteristics". In 2009 and 2010, the Department of Agriculture of Hainan Province promulgated "Working Situation in 2008 and Working Ideas in 2009" and "Highlights of Hainan Agriculture in 2009 and Key Points of Work in 2010". and important measures to consolidate the foundation of modern agriculture. This goal is also the agricultural development goal of cold chain logistics development in most areas of China. The People's Government of Hainan Province promulgated the Opinions on Promoting the Development of Modern Fisheries. First of all, it pointed out that it would promote the construction of a cold chain logistics system of aquatic products through cooperation to promote the construction of aquatic products trading markets in key fishing areas such as Haikou and Sanya. At the same time, it pointed out that the cold chain logistics system of aquatic products facing ASEAN countries should be built to promote the foreign trade of aquatic products, as shown in Table 1.

In the ordinary logistics and distribution process, the vehicles used are ordinary trucks, while in distribution, the vehicles used must be trucks with refrigeration equipment. In the transportation system, rational allocation of vehicles can not only reduce transportation costs and improve transportation efficiency but also save energy and ensure the quality of fresh food. The distribution center is the starting point of the entire distribution process and the hub of logistics distribution. Its main function is to organize the delivery of goods by centralized classification and distribution. It is a necessary means to ensure the value of fresh agricultural products. All links of fresh agricultural products from production (or processing) to consumption are carried out in the cold chain environment. Usually, in the whole

TABLE 1: Product temperature zoning.

Thermosphere	Temperature requirements	Product
Frozen layer	-18°C	Meat, fish, and quick-frozen products
Cold storage layer	0-5°C	Fruits, vegetables, eggs, and beverages
Normal temperature layer	6-15°C	Chemical raw materials, and liquor

circulation process, fresh agricultural products need to flow through places of production (or processing), distribution centers, retailers, and consumers, and all processes must be at their proper temperature. The process is shown in Figure 1.

Vehicle routing problem (VRP) refers to planning the distribution scheme for all demand points according to the time window, capacity, traffic control, and other constraints and the actual situation, the least cost, and the least vehicles. This problem has been widely studied by researchers in operations research, computer application, logistics, and other disciplines and has achieved a lot of results. It is a classical combinatorial optimization problem and an NP-hard problem. The constituent elements of VRP mainly include the distribution center, customers, goods, distribution vehicles, road network, objective function, and constraints, as shown in Figure 2.

Multilevel inventory integration refers to making inventory strategies for each node enterprise in both VMI and JMI models require the joint participation of some or all node companies in the supply chain. Although these two management models can avoid the inventory burden caused by the bullwhip effect to a certain extent, from the perspective of core competitiveness, these two inventory management modes still have the phenomenon of waste of corporate resources and weakening core capabilities. These feedback loops are composed of different abstract variables, including different types of variables, such as accumulation, information transfer, delay state, and change rate. The changes in these variables provide "power" for the system and make the system show a dynamic state. Delays will cause the fluctuation of accumulation, so to control the fluctuation of variables in a certain range, managers need to consider these delays when making decisions to maintain the relative stability of the system. From the qualitative description to the quantitative solution, and through the simulation operation of the simulation software, the curves of various variables changing with time in the future of the system are obtained. The whole process can help researchers analyze and reason the dynamic change mechanism and then explore ways to improve the system's behavior.

There are two inventory control strategies for multilevel inventory optimization and control: one is distributed strategy. The supply chain inventory control is divided into three cost centers, i.e., manufacturer cost center, distributor cost center, and retailer cost center. Each of them formulates an optimization control strategy according to its inventory cost. The other is the centralized strategy, which places the control center on the core enterprise. The core enterprise controls the inventory of the supply chain system and coordinates the inventory activities of upstream and

downstream enterprises. The method of establishing a multilevel inventory optimization system around mass production assembly enterprises is to use a centralized strategy to take the core enterprise as the data center of inventory management in the supply chain. It is responsible for data integration and coordination.

*3.2. Distribution Cost Model of the Cold Chain Logistics Flow Based on Multiobjective Optimization.* As a special logistics operation mode, cold chain logistics has strict requirements on delivery time, and the choice of delivery route will largely determine the delivery time. Multiple optimization objectives should be considered during optimization and the simulation assumptions should be more realistic. The multiobjective dynamic optimization problem of time-dependent distribution fully combines the actual distribution environment and considers the real-time change of vehicle speed of cold chain distribution with traffic conditions. realizing the dynamic adjustment of the best distribution route of distribution vehicles in different time periods.

Fixed vehicles refer to the expenses incurred when vehicles are used, including depreciation of vehicles, labor cost, fixed loss of vehicles, etc., which are not directly related to distribution distance and use time. Assuming  $t$  cold chain logistics, there are  $n$  customer points that need to provide distribution services, the fixed cost of each vehicle is  $\Phi$  and is used to represent the fixed cost; then, the fixed cost of cold chain logistics vehicles during the distribution process cost is calculated as follows:

$$f_g = \varphi \sum_{i=1}^n \sum_{k=1}^m X_m^k. \quad (1)$$

It is assumed that the unit time refrigeration cost of cold chain logistics vehicles in the transportation process is  $Z_1$ . The refrigeration cost per unit time in the loading and unloading process is  $Z_2$ , that is, the refrigeration costs in both aspects are positively related to the delivery time  $t_{ij}$ . Therefore, the cost of refrigeration energy consumption during transportation can be expressed as follows:

$$f_{Z1} = \sum_{i=0}^n \sum_{j=0}^n \sum_{k=1}^m Z_1 \cdot X_{ij}^k \cdot t_{ij}. \quad (2)$$

The cost of refrigeration energy consumption during loading and unloading is as follows:

$$f_{Z2} = \sum_{j=0}^n \sum_{k=1}^m Z_2 \cdot t_j. \quad (3)$$

The total refrigeration cost is as follows:

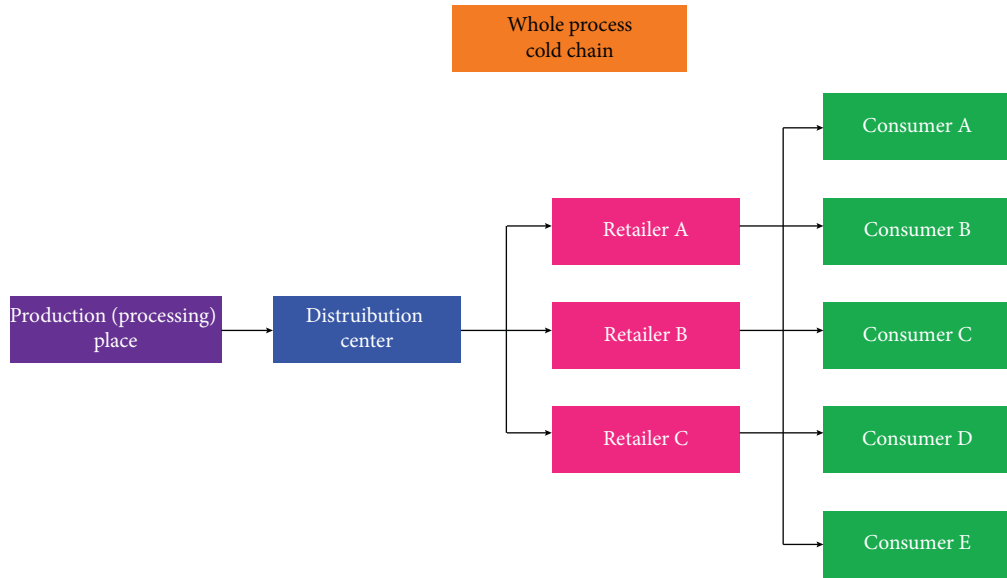


FIGURE 1: Flowchart of cold chain logistics.

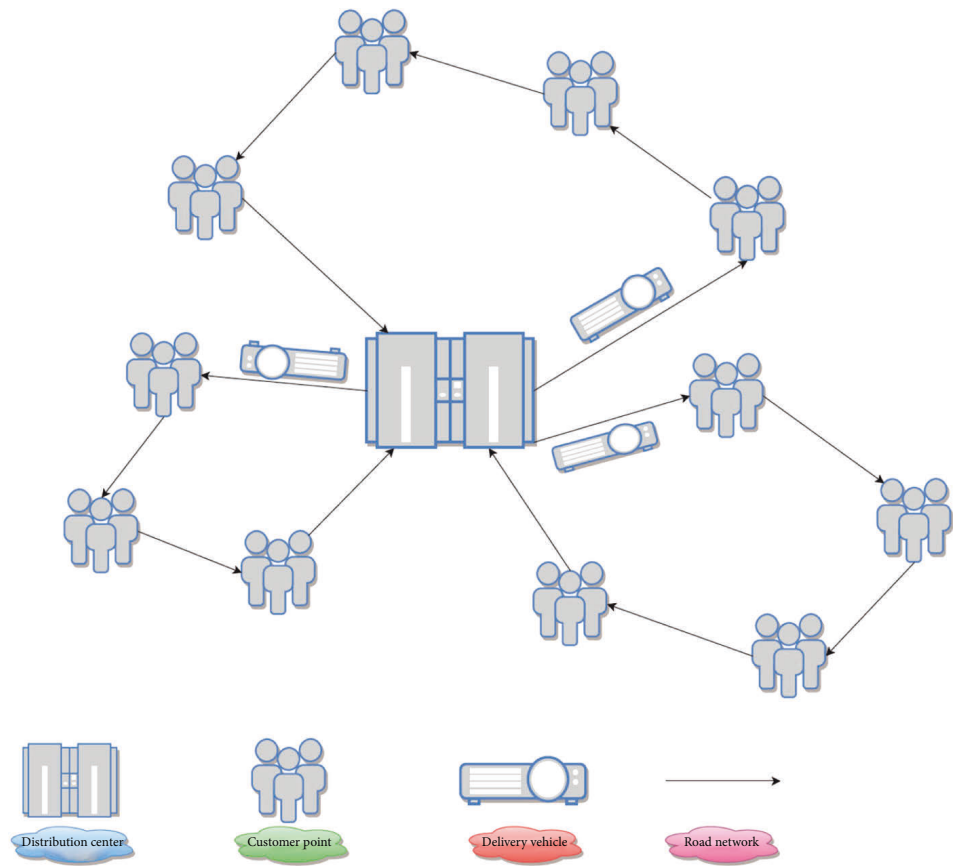


FIGURE 2: Schematic diagram of common VRP.

$$f_z = \sum_{i=0}^n \sum_{j=0}^n \sum_{k=0}^m Z_1 \cdot X_{ij}^k \cdot t_{ij} + \sum_{j=0}^n \sum_{k=1}^m Z_2 \cdot t_j. \quad (4)$$

It is easily affected by factors such as environment, pH value, delivery time, temperature, etc. During the delivery process, it is inevitable that there will be a certain loss in the quality of the goods and even directly cause the goods to lose their use value. To facilitate the description of the whole process, the cargo damage cost in this paper is described as two parts: the cargo damage caused by the time accumulation and the cargo damage caused by the sudden change of temperature during the loading and unloading process. Among them,  $B^*$  indicates the initial state of goods;  $T$  represents the cumulative delivery time; and  $A$  indicates the sensitivity coefficient of products to time, which is quite different among different categories of products. Therefore, the cost of goods damaged during transportation can be expressed as follows:

$$f_{s1} = J \sum_{i=1}^n q_i (1 - B\beta \cdot e^{-a(d_i^k - s_{ij}^k)}). \quad (5)$$

Among them,  $J$  is the unit value,  $q_i$  of customer point  $i$ ;  $s_o^k$  represents the time when vehicle  $K$  arrives at customer point  $i$ ;  $d_i^k \beta$  represents the loss rate in the process, and the loss cost in the loading and unloading processes is related to the loading and unloading time and the number of goods loaded by the cold chain logistics vehicles in the current state; then, the loading and unloading cost can be expressed as follows:

$$f_{s2} = \sum_{i=0}^n \sum_{k=1}^m \beta_2 \cdot t_j \cdot (Q_{ij}^k + q_i). \quad (6)$$

Among them,  $q_i$  represents the demand of customer point  $J$ ;  $Q_{ij}^k$  indicates the load capacity of the delivery vehicle  $K$  in the process from customer point  $I$  to customer point  $J$ . The cost of goods damage generated in the whole distribution process can be expressed as follows:

$$f_s = J \sum_{i=1}^n q_i \left( 1 - B^* \beta_1 e^{-a(d_i^k - s_{ij}^k)} \right) + \sum_{i=0}^n \sum_{k=1}^m \beta_2 \cdot t_j \cdot (Q_{ij}^k + q_i). \quad (7)$$

Based on the abovementioned reasons for the penalty cost, assuming that the customer's expected delivery time window is  $[et_i, lt]$ , and the acceptable delivery time window is  $[ET_i, LT_i]$ , the penalty cost and the arrival time of the cold chain distribution vehicle generated during the cold chain logistics distribution service process can be expressed as follows:

$$P_c(d_i^k) = \begin{cases} M & d_i^k \leq ET_i, \\ \theta_e \cdot J \cdot q_i (et_i - d_i^k) & ET_i \leq d_i^k \leq et_i, \\ 0 & et_i \leq d_i^k \leq lt_i, \\ \theta_1 \cdot J \cdot q_i (d_i^k - lt_i) & lt_i \leq d_i^k \leq LT, \\ M & d_i^k \geq LT_i, \end{cases} \quad (8)$$

where  $M$  is a maximum value;  $\theta_e$  represents the penalty coefficient that arrives earlier than the expected delivery service time window of the customer;  $\odot 1$  refers to the penalty coefficient of delivery service arriving later than the customer's expected time;  $J$  refers to the unit price of delivered goods; and  $Q I$  represent the demand of customer point  $I$ . To sum up, the penalty cost in cold chain logistics distribution can be expressed as follows:

$$f_c = \sum_{i=1}^n P_c(d_i^k). \quad (9)$$

#### 4. Result in Analysis and Discussion

The "cold chain" mainly refers to the logistics distribution network is always in a low-temperature state in the production and consumption processes. Moreover, professional equipment is always equipped during the transportation process. Cold chain transportation can keep the food fresh and ensure the quality of frozen food. Cold chain mainly includes transportation objects, transportation carriers, low-temperature storage technology, and storage and transportation systems. With a deeper understanding of a healthy and green diet, the demand for fresh food in our daily diet is soaring, which has become inseparable from cold chain logistics. However, the shortcomings and problems, which have become a hot spot of social concern, are also exposed to the public: First, cold and fresh goods stay in the transportation process for a long time, which leads to serious decay and food safety. Second, if the cost and distribution are high, then the time reliability distribution is not high, and the distribution efficiency needs to be improved, thus increasing the distribution cost in disguise. In this paper, a refrigerated truck is selected as the delivery vehicle, where the acceleration of gravity  $g = 9.81 \text{ kg/m}^2$  and the air density  $p = 1.225 \text{ kg/m}^3$ . The slope refrigerated truck and the outside environment is  $\Delta T = 20^\circ\text{C}$ . The number of times  $\lambda = 0.6$ ; the transport price of goods  $tc = 1$ ,  $\Delta = 0.01$ ,  $\varepsilon_1 = 0.6$ ; late arrival time penalty coefficient  $\varepsilon_2 = 0.8$ ; maximum vehicle load 200; and refrigerated truck fixed cost = 200. The specific refrigerated truck parameters are shown in Table 2:

According to the abovementioned model, iteration times and  $R^n = 20$ , volatilization coefficient  $p = 0.8$ , pseudorandom proportional action selection rule parameter  $q = 0.9$ , the maximum and minimum values of pheromone  $\tau$  max and  $\tau$  mins are 10 and 0.001, respectively, and the weight factors of  $W_1$ ,  $w_2$  and  $w_3$  optimization objectives are all 1/3, as shown in Figure 3.

Extreme condition testing refers to verifying the stability and validity of the model by testing how well the model's behavior in extreme and unexpected situations matches the real system under extreme conditions. The following two situations are used to test the simulation in Hainan, namely, the nonreplenishment test and the behavior reproduction test. The no replenishment test in this article means that from the 150th day, TPL will no longer send replenishment orders to manufacturers, but only deliver goods to retailers. Reflected in the variable setting, the equation of TOL order

TABLE 2: Parameters of refrigerated trucks.

Parameter	Meaning	Value
R	Fuel consumption per unit of time	22.37
H	Fuel consumption and carbon emission conversion factor	1.7/2.7
$\Delta$	Fuel-to-air mixing ratio	1
$\Phi$	Engine friction factor	0.3
T	Refrigerated truck engine speed	2500
M	Energy consumption constant	1.0525
A	Vehicle windward area $m^2$	2.98

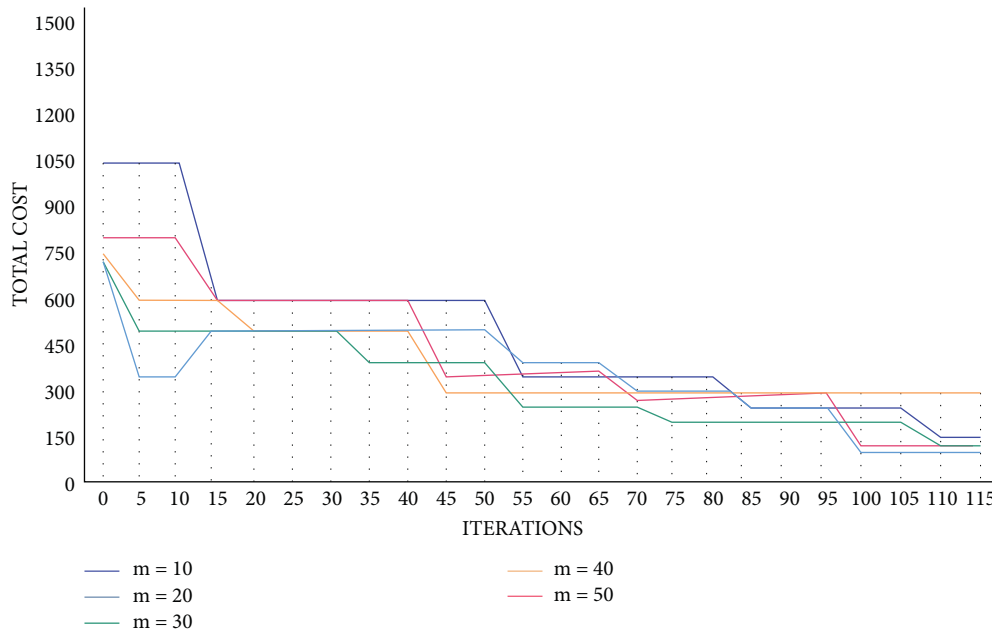


FIGURE 3: Experimental iteration of parameters.

quantity is changed from the original “TPL expected inventory-TPL total inventory” to “If then else (time>150,0.tpl expected inventory - TPL total inventory),” and the results are shown in Figure 4.

As can be seen from the figure, the related variables were stable at first, but after the 150th day, as the TPL order quantity became zero, the TPL inventory gradually decreased, the supplier inventory gradually increased, the retailer inventory kept the original fluctuation, and the system inventory level gradually decreased, which was less than zero, and the overall stock was out of stock. The retailer’s demand will not change, so the TPL delivery rate also maintains the original fluctuation. Because this model builds an information-sharing supply chain, the retailer’s demand will make the manufacturer keep production, and due to the total system inventory. As the level fluctuates greatly, the fluctuation range of supplier productivity will gradually increase. The supplier’s inventory will gradually generate a backlog due to the nonreplenishment of TPL.

In this paper, the behavior reproduction test is mainly to observe the changes in inventory at each node of the supply chain by changing the market demand. In this paper, the market demand increases suddenly in 150 days, which is reflected in the variable equation that the retailer demand rate =  $100 \times$  retailer product freshness + step (200150). The

behavior reproduction test results constructed in this paper are shown in Figure 5.

As can be seen from Figure 5, after 150 days, the demand rate of retailers suddenly increased from nearly 100 per day to nearly 300 per day, an increase of about 3 times, which is an extreme condition, and the original balance of the system was broken. Therefore, it can be seen that retailers’ inventory, TPL inventory, and suppliers’ inventory all declined to a certain extent in market demand, and after the system adjustment, they quickly rose to an appropriate level and then maintained stable fluctuations. The delivery rate and replenishment rate of TPL and the productivity of suppliers are also greatly improved, and the fluctuation range and time of the three are not much different because the TMI model constructed in this paper general supply chain inventory management model. The information transmission efficiency is more efficient, and its production and demand information can be shared in real time, and the bullwhip effect of the system has been better suppressed compared to the traditional supply chain. To sum up, the TMI model of Hainan fresh agricultural products in this paper can achieve realistic expectations and reproduce the dynamic behavior of the real system. When customer satisfaction is 80% and the result is shown in the image, the relationship between the number of iterations and the solution result is shown in Figure 6:

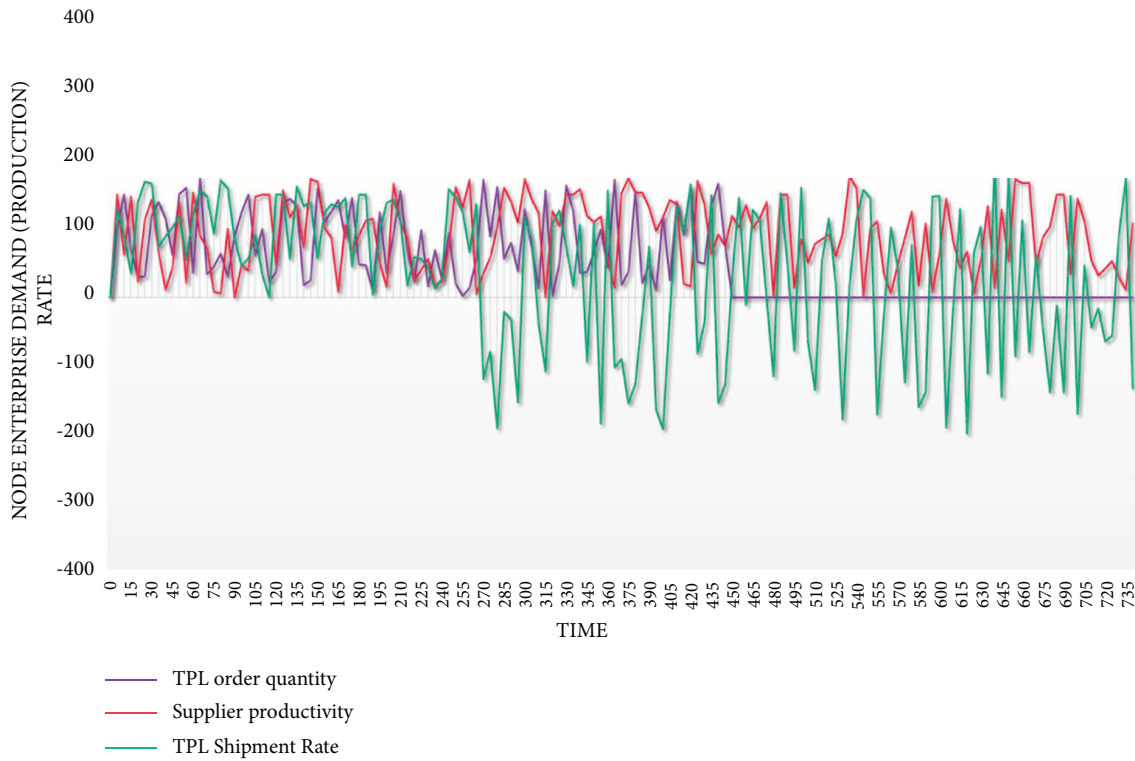


FIGURE 4: No replenishment test.

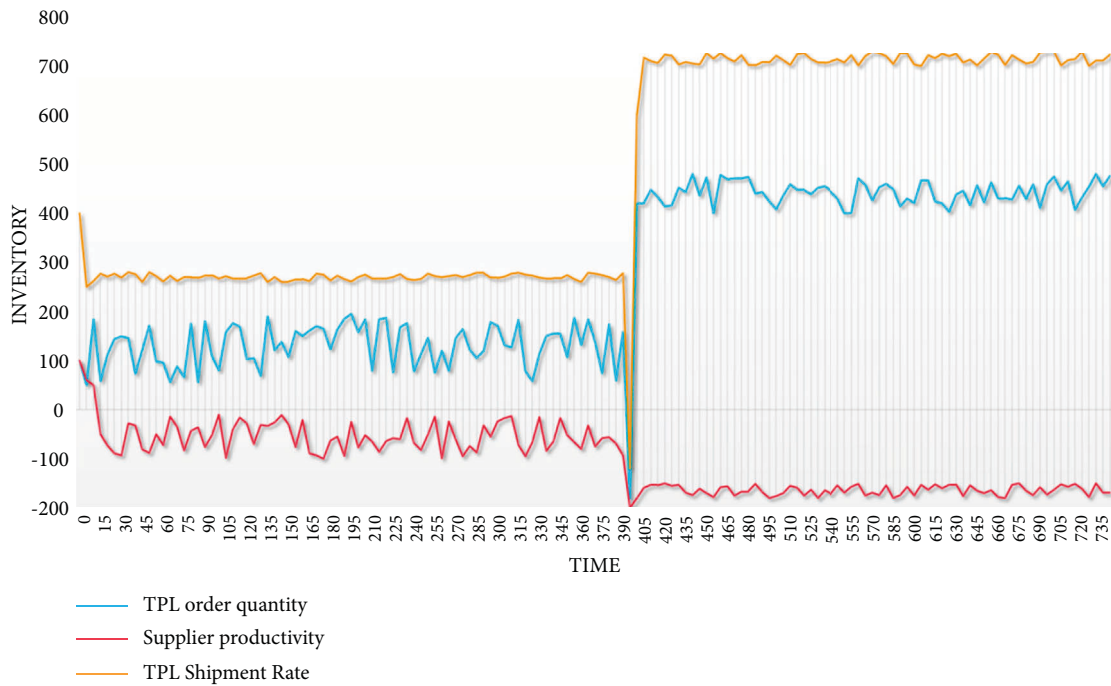


FIGURE 5: Behavior re-line test.

With the acceleration of third-party cold chain logistics and cross-border cooperation in various fields, the cold chain industry has triggered a new competitive pattern. As the small and decentralized cold chain infrastructure cannot better meet the huge market demand, it means it is a general

trend to invest in the construction of large-scale cold storage logistics parks. Cold chain enterprises can maintain their advantages, develop their capabilities, and promote the high-quality development of the industry through continuous integration and integration. The level of fresh-keeping

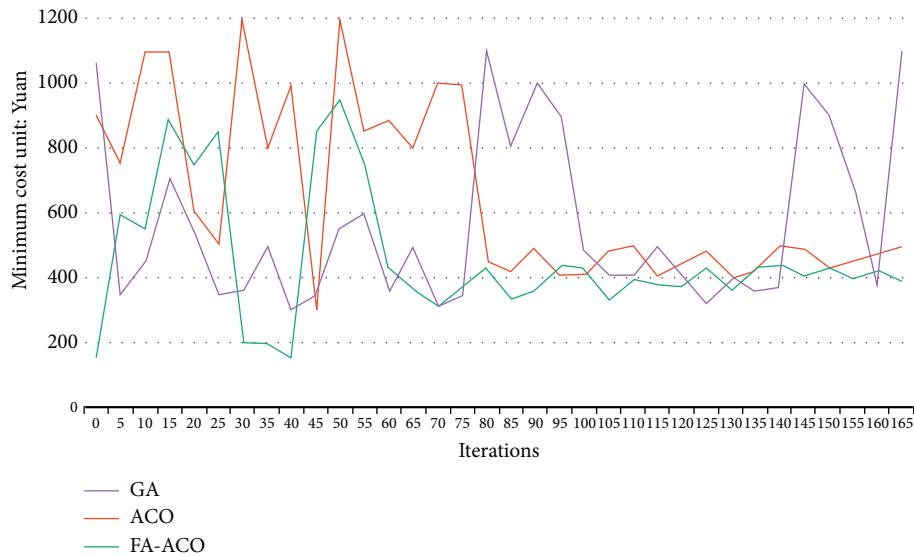


FIGURE 6: Relationship between solution results of three algorithms and iteration times when customer satisfaction is 80%.

logistics directly affects the product quality and loss of each node enterprise in the supply chain. Advanced cold chain logistics preservation means can greatly reduce unnecessary losses.

## 5. Conclusions

To sum up, the policy system of cold chain logistics development in Hainan province needs to be further improved, and the starting point of policy improvement is the further development of a policy objective system, which requires local governments to pay attention to the perfection and characteristics of policy objective system and the supporting policies to ensure the realization of policy objectives. Through the comparative analysis of simulation experiments, it is concluded that the improved ant colony algorithm has more advantages than the ordinary ant colony algorithm, which can effectively avoid falling into local optimization and obtain more Pareto optimal solutions. The improved ant colony algorithm can reduce distribution costs, reduce carbon emissions, and improve customer satisfaction. At present, there is a lack of research on constructing a service provider selection model in an e-commerce environment from the angle of negotiation. Taking logistics enterprises into account and considering the characteristics that the service capability of cold chain logistics enterprises in e-commerce logistics not only affects the loss cost of fresh e-commerce enterprises but also affects the market sales of fresh products, a bi-level programming model of cold chain logistics enterprise selection is constructed. To sum up, the policy system for the development of cold chain logistics in Hainan province needs to be further improved, and the starting point of policy improvement is the further development of the policy target system, which requires local governments to pay attention to the perfection and characteristics of the policy target system, supporting policies to ensure the achievement of policy objectives.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Acknowledgments

This work was supported by Hainan Provincial Natural Science Foundation of China: Acknowledgements Study on the Development Path of Hainan Port Industry Based on the Construction of Free Trade Port (No: 720RC666); Hainan Federation of Social Sciences of China: Research on Supply Chain Optimization of Hainan Fresh Agricultural Products in Digital Economy Era (No: HNSK(YB)22-22).

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