Simulation of Shenyang Pork Supply Chain System Based on System Dynamics Model

Qianqian Shao, Xiaojing Zhang, Yunfeng Zhang, and Siqi Zhang

Abstract In most of the leading research on pork supply chain (PSC) analysis, only a certain part of PSC is studied qualitatively or quantitatively. While they analyze the transmission of price in PSC, connection between price and operation of PSC has not been established. In this paper, system dynamics (SD) and supply chain theory are used to analyze the system behavior of PSC. The model takes into account the natural elimination of slaughtered pigs during feeding and the perishable nature of pork as fresh food. Based on the analysis of the logical relationship and data transfer between the links of PSC, the SD model of Shenyang pork supply chain system is formulated, and the corresponding flow diagram and the equations expressing the relationship between variables are developed. The simulation experiments are designed with step demand as the boundary condition of the system. The fluctuation trend of pork price in Shenyang is analyzed, and the robustness of Shenyang PSC is further discussed.

Keywords Pork price · Pork supply chain · System dynamic

1 Introduction

As an important part of daily consumption, pork industry is closely related to people's life and economic development. With the development of economy, the pork industry is gradually changing from retail farming and scattered related enterprises to large-scale breeding management, processing, transportation, and sales. The concept of pork supply chain (PSC) is gradually introduced for overall management with the development of economy. Aiming at the lack of combining qualitative and quantitative methods, the dynamic change and trend prediction of PSC are modeled and analyzed. System dynamics (SD), as a qualitative analysis of correlation feedback and a quantitative analysis of system flow diagrams, is suitable for analyzing complex systems of PSC. At present, with the rapid development of logistics in China, the research on SD applied to supply chain-related aspects in the existing literature

Q. Shao (✉) · X. Zhang · Y. Zhang · S. Zhang
School of Transportation Engineering, Shenyang Jianzhu University, Shenyang 100168, China
e-mail: mr_Crowley@163.com

Y. Li et al. (eds.), *Advances in Simulation and Process Modelling*,
Advances in Intelligent Systems and Computing 1305,
https://doi.org/10.1007/978-981-33-4575-1_17

focuses on cold chain logistics and inventory recently. A few literatures related to PSC analyze the composition structure and nodes of supply chain. Therefore, based on the existing supply chain literature, the PSC is modeled.

As a simulation method to analyze complex systems, SD has been widely used in logistics and supply chain modeling and simulation with the increase of supply chain level. Qiu and Chen [1] put forward the dynamic models of dual-channel supply chain inventory independent system, single-stage inventory cooperative system, and multi-stage inventory cooperative system by using the theory and method of system dynamics. These are used to study the characteristics of fresh agricultural products dual-channel supply chain system. He and Liu [2] proposed an SD simulation model for information transfer of aquatic product supply chain. Chen et al. [3] proposed taking banana supply chain as an example, analyzed, and sorted out the composition and characteristics of fresh agricultural products supply chain and drew the inventory flow diagram of four-level supply chain. Hu and Liu [4] proposed to determine the boundary of the supply chain system of fruits, vegetables, and agricultural products in western Hunan based on risk factors, analyze the system structure, determine the causal relationship between each subsystem, and finally build an SD model for simulation. In order to analyze the influence of various factors on fresh agricultural products logistics inventory, Wei and Liu [5] proposed to use SD method to establish the flow chart of fresh agricultural products logistics inventory system and used VENSIM software for simulation.

As a simulation method to analyze complex systems, SD has been widely used in logistics and supply chain modeling and simulation with the increase of supply chain level. The rest of this paper is organized as follows: Sect. 2 described A causal diagram of the PSC. The dynamic model of PCS is established, and the main equations are described in Sect. 3. Section 3 describes SD model of Shenyang PSC system. Section 4 analyzes the simulation and robustness of Shenyang PSC model. The price delay sensitivity analysis is also introduced. The last section provides conclusions and future work.

2 PSC Causal Diagram

The causal cycle diagram is used to represent the feedback relationship between variables in the supply chain system and qualitatively represents the behavior of each node in the supply chain. This paper mainly studies the PSC system and only focuses on the inventory transfer and information transfer feedback between key nodes of the supply chain, without considering other meat substitutes, breeding industry consumption, feed cost, pig breeding capital quota, and other factors. In the simulation process, there is a time lag between the purchase decision of pig farm and the supply of pig from the upstream supplier. The cause-and-effect diagram of the PSC is shown in Fig. 1.

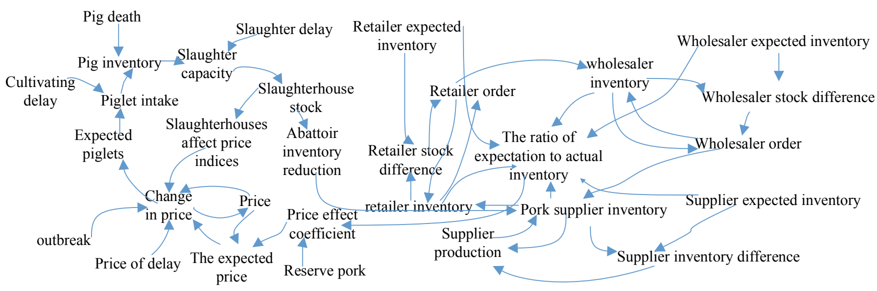

Fig. 1 PSC causal diagram

3 SD Model of Shenyang PSC System

3.1 Upstream Production Subsystem

The upstream production subsystem, as the upstream node, consists of two parts: piglet inventory and slaughterhouse. Slaughterhouses are connected to downstream pork suppliers, so the pigs slaughtered are affected by the productivity of the pork suppliers. First, the supplier determines the supplier's production demand based on the supplier's sales forecast. Then, production demand affects supplier productivity. Finally, according to the supplier's productivity feedback, the slaughterhouse will supply production. In the real world, slaughterhouse orders need to be verified and stocked, so they cannot be delivered immediately. Therefore, the supplier order cycle is set. The main equations of pork supplier inventory subsystem are shown in Table 1.

Table 1 Main equations of pork supplier inventory subsystem

Sequence number	Equation
1.	Pig inventory = INTEG(Piglet intake –Slaughter capacity-Pig death, Initial pig inventory)
2.	Slaughterhouse stock = INTEG(Slaughter capacity-Abattoir inventory reduction, Initial pig inventory)
3.	Piglet intake = IF THEN ELSE((Expected piglets- Pig inventory)/Cultivating delay ≤ 0,0,(Expected piglets- Pig inventory)/ Cultivating delay + Slaughter capacity)

Table 2 Main equations of the wholesaler inventory subsystem

No	Equation
1.	Pork supplier inventory = INTEG(+Supplier productivity-Supplier delivery rate-Pork supplier inventory quality rate change, Initial quantity of pork supplier inventory)
2.	Supplier productivity = DELAY3(Supplier production demand, Meet slaughterhouse order cycle time)
3.	Supplier delivery rate = MIN(Pork supplier inventory, DELAY3(Wholesaler order, transport delay))

3.2 Downstream Sales and Supply Subsystem

3.2.1 SD Model Analysis of Pork Supplier Inventory Subsystem

The slaughterhouse is the intermediary between the upstream supplier and the downstream wholesaler, whose demand information is also passed to the slaughterhouse by order. After slaughtering pigs in the slaughterhouse, the slaughterhouse supplies according to the wholesaler's order. At the same time, the slaughterhouse should also predict the demand of wholesalers and make replenishment in time. In reality, due to the periodicity of pig fattening, slaughterhouses do not slaughter pigs at any time, and they have the characteristics of periodic ordering. Therefore, the abattoir order cycle is added into the factor. After ordering, the supplier needs to transport the pigs, and there is a transportation time delay, so factor 1 of transportation delay is set. In addition, considering that the slaughterhouses have the preparation time after receiving the order from the wholesaler, the moving smoothing time of the slaughterhouse is set. The main equations of the wholesaler inventory subsystem are shown in Table 2.

3.2.2 SD Model Analysis of Wholesaler Inventory Subsystem

In reality, retailers have a large sales volume, but their inventory is small, so the demand should be from wholesalers with certain storage conditions to order. As the intermediate node between downstream retailers and upstream pork suppliers, wholesalers need to consider the transportation delay and inventory adjustment time in the process, so as to set the transportation delay factor. In addition, after receiving the order from the retailer, the wholesaler prepares and transports the goods to the retailer. Therefore, the ordering period of the wholesaler is set to express the material and information delay in the transportation process. The main equations of the wholesaler inventory subsystem are shown in Table 3.

Table 3 Main equations of the wholesaler inventory subsystem

No	Equation
1.	Wholesaler inventory = INTEG(Supplier delivery rate- Wholesaler delivery rate-Wholesalers change the quality of inventory, Wholesaler stock initial quantity)
2.	Supplier delivery rate = MIN(Pork supplier inventory,DELAY3(Wholesaler order, transport delay))
3.	Wholesaler delivery rate = MIN(Wholesaler inventory,DELAY3(Retailer order, Meet wholesaler order cycle time) + Reserve pork)

Table 4 Main equations of the retailer inventory subsystem

No	Equation
1.	retailer inventory = INTEG(+Wholesaler supply rate- Market demand rate- Retailer inventory quality change, Retailer initial inventory)
2.	Wholesaler delivery rate = MIN(wholesaler inventory,DELAY3(Retailer order, Meet wholesaler order cycle time) + Reserve pork)

3.2.3 SD Model Analysis of Retailer Inventory Subsystem

The retailer is a downstream node connecting the terminal consumer demand of the wholesaler, and the demand information of the retailer is transmitted to the wholesaler by order. The wholesaler supplies goods according to the retailer's order forecasts the retailer's sales and makes replenishment in time. In reality, after ordering, the wholesaler needs to prepare and transport the products after receiving the retailer's order. There is a delay in transportation time, so the factor of satisfying the ordering cycle of the wholesaler is set. The main equations of the retailer inventory subsystem are shown in Table 4.

3.3 Price Response Subsystem

The price will affect the purchase intention of piglets, thus affecting the expected piglet quantity. The price is mainly affected by the change in price and the expected price. In the absence of external influence conditions, the expected price is affected by the price effect coefficient, and the price change is affected by the price delay. The main equations of the price response subsystem are shown in Table 5.

3.4 Global Flow Diagram of Shenyang PSC System

After analyzing the above upstream production subsystem, inventory subsystem and price response subsystem of three nodal enterprises, a complete SD model of

Table 5 Main equations of the price response subsystem

No	Equation
1.	Price = INTEG(Change in price, initial price)
2.	Price effect coefficient = ABS(IF THEN ELSE(ABS(The ratio of expected to actual inventory) < 3, The ratio of expected to actual inventory/3,RANDOM NORMAL(0.7, 0.9, 0.8, 4.4)))

Shenyang PSC system were obtained. The global system flow diagram is shown in Fig. 2.

4 Simulation Study and Result Analysis

4.1 Simulation Study

After testing the model, the simulation experiment was carried out on the PSC system model. Set the simulation time step to 1 week and the simulation time to 100 weeks. In this paper, we observe the change of inventory level under the condition of step demand fluctuation. Through the analysis of the demand of Shenyang pork market, this situation is a special holiday before and after the Spring Festival, the pork market demand will suddenly increase. The simulation model assumes the consumer function in the pork market for the above situation and the related system dynamics research on the supply chain inventory. The function is used for two simulations.

STEP function: STEP function describes the sudden increase of the initial value to the final value, which can be used to represent the sudden increase of pork demand due to special holidays in reality, and is an important situation for research.

4.2 Results and Analysis

(1) Simulation results output under STEP demand: in the condition of STEP demand, $1000 + STEP(1800, 30)$ was input into the market demand formula, that is, consumer demand increased by 1800 in the 30th week. The simulation output results are shown in Fig. 3.

(2) Simulation results output under STEP demand: in the condition of STEP demand, $1000 + STEP(2000, 30)$ was input into the market demand formula, that is, consumer demand increased by 2000 in the 30th week. The simulation output results are shown in Fig. 4.

In Figs. 3 and 4, it shows that early step demand for flat demand fluctuations, so prices fluctuate at first is in a stable state, when a step change, after a sudden increase demand remains at a relatively high demand, the original inventory to meet

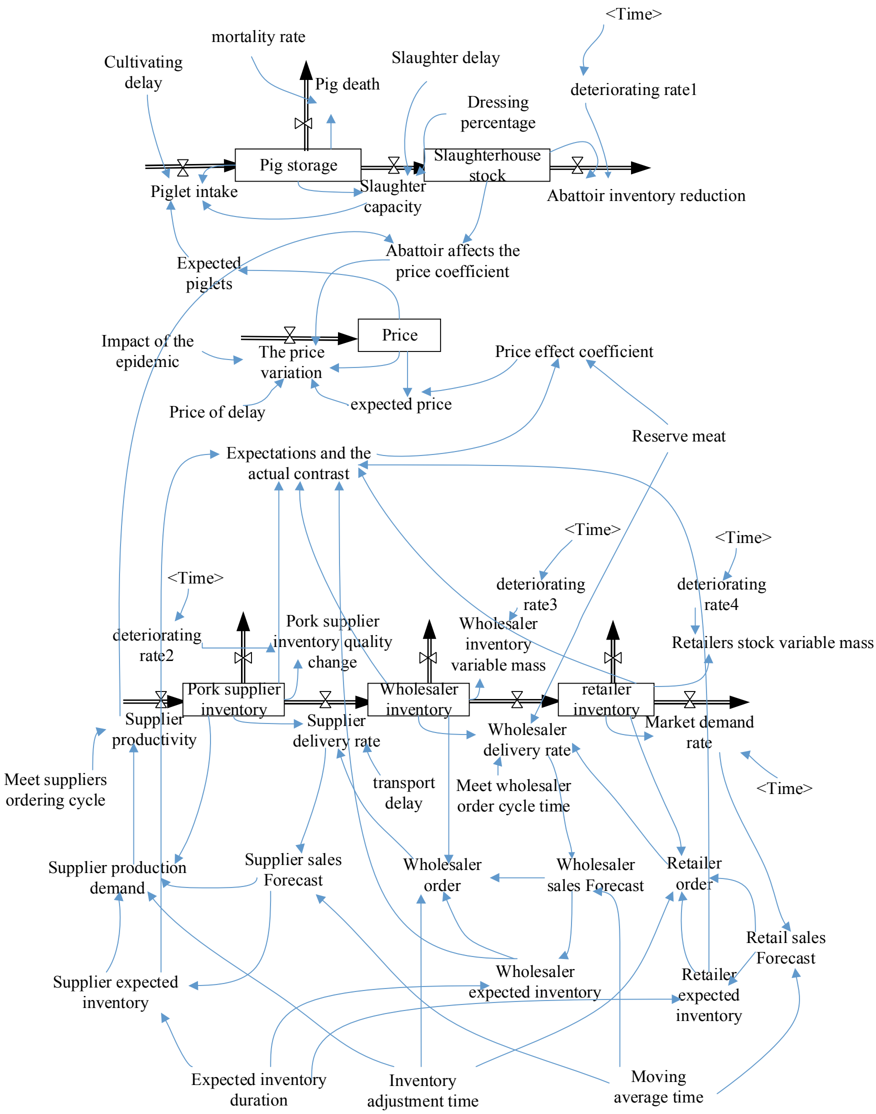

Fig. 2 Global flow diagram of Shenyang PSC system

the sudden increase in demand, added a large number of products, one could be down at the next higher level at the same time increase the order. However, due to the delay of transportation and stock preparation, the original stock was in short supply after the maximum supply was allowed, which led to a sudden increase in the price later. By increasing the arrival of supplementary products to adjust the market, slow down the price rising trend. Compare Fig. 3 with Fig. 4, it can be concluded that there is a

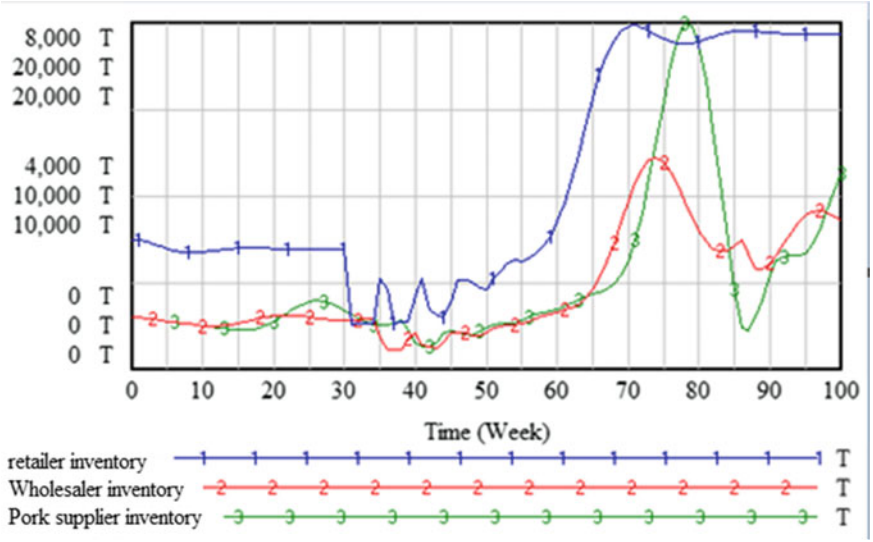

Fig. 3 Inventory changes under step demand 1

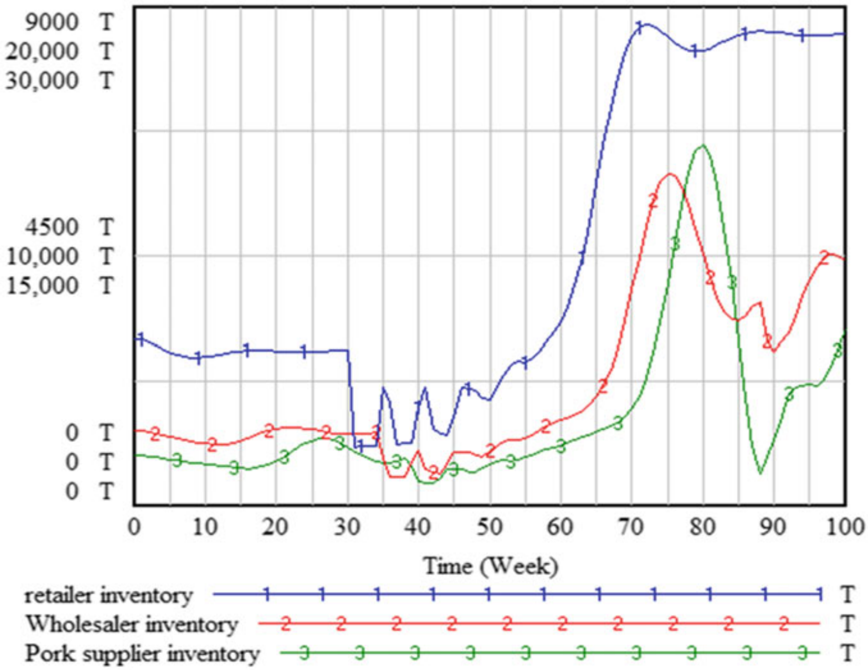

Fig. 4 Inventory changes under step demand 2

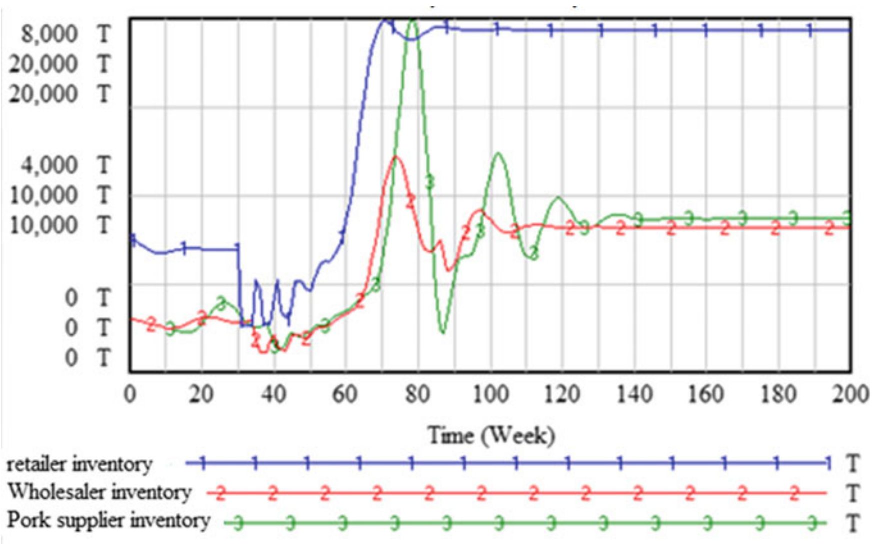

Fig. 5 Inventory changes under 200 weeks of simulation

significant improvement in both weeks around 80. However, the fluctuation of pork supplier inventory in Fig. 3 is relatively large, while that in Fig. 4 is relatively small. The results showed that when the demand for pork increased suddenly, the increase of 2000 could reduce the inventory of pork suppliers and alleviate bullwhip effect.

By observing Figs. 3 and 4, it can be found that in the case of step demand, the images of inventory levels at all levels and replenishment at all levels have obvious fluctuations in the case of a sudden increase in demand, but with the increase in time, the fluctuation amplitude begins to be significantly reduced compared with the initial sharp oscillation. To further analyze this phenomenon, the simulation time was extended to 200 weeks and 300 weeks, respectively, for simulation, and the inventory fluctuation in Figs. 5 and 6 are obtained.

Comparison of inventory changes after changing the simulation time, volatility can be observed after a period of time, amplitude recovery from higher volatility weakened until smooth, thus manifests the rapid growth in demand suddenly the dangerous situation, system has a certain robustness, volatility, when the system can adjust themselves in order to maintain the stability of the system.

5 Conclusion

According to design relevant suggested four-point optimization simulation results for the optimization of supply chain, respectively, from the integration of simplified nodes to reduce the bullwhip effect of cascade multilevel demand amplification and

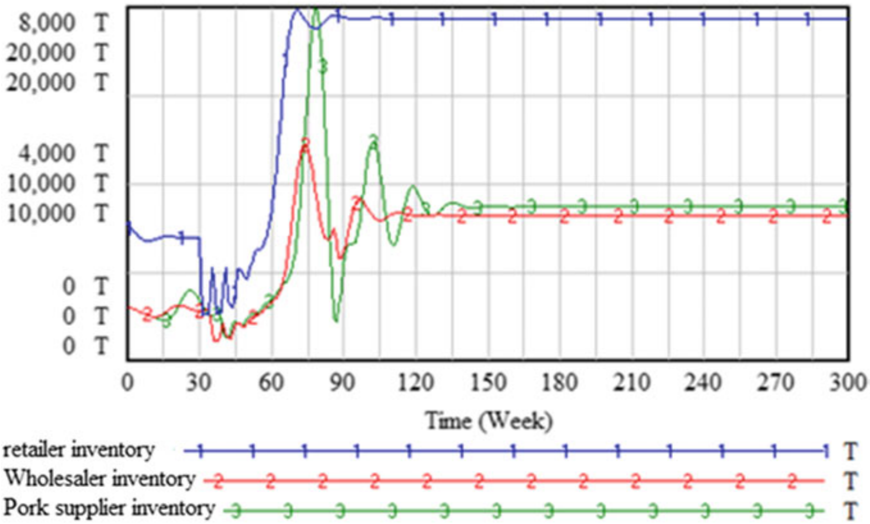

Fig. 6 Inventory changes under 300 weeks of simulation

distortion, to support the breeding reduce delay cultivation, and strengthen the cooperation mechanism to eliminate bullwhip effect brought by the information transfer is not transparent and national reserve effectively on the application of the four aspects of the meat.

The model in this paper is to simplify the nodal enterprises involved in the actual PSC and extract the relevant nodal links that are obvious to the supply and demand changes, so as to analyze the relationship between the supply and demand changes and the price. However, part of the data used in the simulation is difficult to obtain accurate values, which is mainly obtained through system debugging by referring to relevant data and simulation, or through reasonable analysis based on the actual situation. There are certain errors, which affect the accuracy of the model.

Acknowledgements This research work is partially supported by the Scientific Research Project of the Educational Department of Liaoning Province 2019 of China (Project Codes: lnqn201916), Shenyang Social Science Project 2020 of China (Project Codes: SYSK2020-09-14, SYSK2020-09-32), Project Plan of China Logistics Learned Society and China Logistics and Purchasing Federation 2020 (Project Codes: 2020CSLKT3-187, 2020CSLKT3-188), Logistics Reform and Teaching Research Project 2020 of China (Project Codes: JZW2020205)

References

1. Qiu, H.Q., Chen, W.Y.: Study on the inventory cooperative strategy of dual-channel supply chain in fresh agricultural products. Math. Pract. Theor. **49**(09), 1–10 (2019). (in Chinese)
2. He, J., Liu, W.X.: Simulation of aquatic products supply chain information transfer based on system dynamics. Food Industry **40**(09), 302–306 (2019). (in Chinese)
3. Chen, W., Shen, Y., Tian, Y.: Modeling and simulation of fresh agriculture products supply chain based on system dynamics. Logistics Eng. Manage. **40**(12), 101–104 (2018). (in Chinese)
4. Hu, L.H., Liu, T.: Research on supply chain risk for fruit and vegetable products in big Xiangxi. J. Huaihua Univ. **38**(07), 74–79 (2018). (in Chinese)
5. Wei, J., Liu, W.H.: Fresh agricultural products logistics inventory simulation analysis based on system dynamics. Storage Process **18**(02), 130–134 (2018). (in Chinese)