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# Research on Distribution Efficiency of Automobile After-sales Spare Parts Based on System Dynamics

**TENG Jiayi[1] and Han Xiaolong[2]**

[1]Institute of Logistics Science and Engineering, Shanghai Maritime University, Shanghai 201306, Submission direction: Logistics Economy and Supply Chain Management; [2]Shanghai Institute of Logistics Science and Engineering, Shanghai Maritime University, Shanghai 201306

**ABSTRACT**

The distribution of aftermarket spare parts is an important part of automotive aftermarket parts logistics. The level of distribution efficiency is the key factor affecting customer satisfaction and the economic benefits of accessory companies. The paper uses the theory and modeling method of system dynamics to study the efficiency of the automobile after-sales spare parts distribution system, establishes a dynamic simulation model, and experiments and improves the model based on three important time elements in the system. Experiments show that shortening the delay time between nodes and adjusting the inventory adjustment time properly have positive practical significance for improving the distribution efficiency of aftermarket spare parts.

**Keywords:** spare parts logistics; system dynamics; simulation; distribution efficiency

***Correspondence to Author:**
Han Xiaolong
Shanghai Institute of Logistics Science and Engineering, Shanghai Maritime University, Shanghai 201306

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## 1 Introduction

The delivery requirements for automotive after-sales spare parts are to reduce the logistics cost as much as possible under the premise of providing fast, safe and punctual high-quality logistics and distribution services to end customers [1]. However, automotive after-sales spare parts have the characteristics of strong randomness and various types of demand. Excessive inventory of after-sales spare parts can improve the immediacy of spare parts distribution, but it also leads to an increase in inventory costs. Therefore, after-sales spare parts are guaranteed. Saving logistics and distribution costs under the premise of distribution efficiency has great practical significance [2].

In the aspect of auto parts distribution, in order to reduce the excessive capital occupied by auto spare parts inventory in the MTS mode, Ma Shihua [3] and others considered the importance of spare parts distribution, and re-planned the auto spare parts logistics network in the MTO environment. The resources are fully utilized to realize the integration and optimization of spare parts supply logistics. Qu Yuli [4] and other issues to convert the distribution network planning problem of auto spare parts into the location problem of DC, and re-planned the number and location of DCs of Shenlong Automobile Company.

The System Dynamics (SD) method focuses on causality, can find the inherent causes of certain phenomena from complex phenomena, and can also solve complex and time-varying systems with nonlinear and multiple feedbacks in case of insufficient data. Perform simulation and research [5]. Wang Chaofeng et al [6] applied system dynamics, and additionally considered horizontal scheduling and vertical emergency transportation in the service spare parts distribution system. The horizontal scheduling of the two base warehouses and the emergency dispatch of the central warehouse are more beneficial to meet the service requirements of spare parts. . Spengler et al. [7] used system dynamics to establish a complete spare parts supply production and recovery system to meet the requirements of fast response spare parts and minimize the cost of spare parts management. Based on the dynamic characteristics of spare parts logistics, Weipeng Wang [8] analyzed the mathematical principle of the supply and demand model of spare parts based on system dynamics, and gave the key parameters affecting the stability of the system. The system was optimized by SD simulation. Jin Tian et al. [9] applied SD theory to analyze the dynamic characteristics of the spare parts supply process, and evaluated and predicted the quantity of equipment and related expenses required for a certain military unit in a certain period in the future. Specific recommendations. Shi Guohong et al. [10] Sports SD method improved the vehicle logistics system, and verified that the new system has certain effects on improving the flexibility of the vehicle logistics supply chain and reducing the risk cost. In the field of after-sales spare parts for automobiles, the application of system dynamics is less, but in the distribution of auto parts, a perfect system is formed between the roles. Therefore, this paper intends to analyze the aftermarket spare parts from the perspective of system dynamics. The distribution system, using Vensim software for modeling and simulation, analyzes the impact of different factors on the efficiency of vehicle spare parts distribution, and provides a theoretical basis for improving its distribution efficiency.

## 2 Problem description and assumptions

### 2.1 Description of the problem

The automotive aftermarket spare parts distribution system studied in this paper consists of a headquarters spare parts center library (hereinafter referred to as the spare parts center library) and three base service stations radiating in different areas, that is, using the direct distribution mode of the headquarters for distribution. The aftermarket spare parts produced by the supplier enter the spare parts center library and are regularly delivered to the service station according to the order to meet the expected inventory of the service station. The customer's spare parts requirements first arrive at the grassroots service station and then communicated to the central repository via the service station in order to respond promptly to the customer's spare parts replacement requirements.

## 2.2 Conditional assumptions

(1) It is assumed that there is no return problem in the system, that is, the goods issued by the supplier are all qualified products; (2) the supplier is assumed to have no quantity restrictions on the supplied goods; (3) the service station and the spare parts center library are assumed to be adopted. Replenishment is carried out on a regular basis, in order to facilitate replenishment.

# 3 System dynamics model construction

## 3.1 Determine the system boundary of the automobile after-sales spare parts distribution system

This paper extracts a part of the closed system in the automobile after-sales spare parts distribution system, and considers the major factors involved in the auto parts distribution system. It is concluded that the structure of the automobile after-sales spare parts distribution system under the direct distribution mode of the headquarters is as follows:

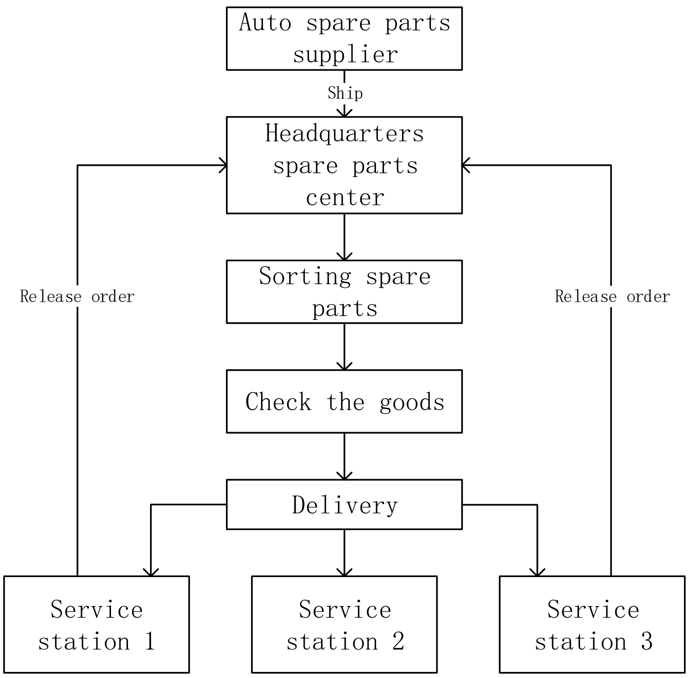


**Figure 1. Car after-sales spare parts distribution flow chart.**

As shown in Figure 1, the spare parts supplier delivers the goods to the central warehouse. After the central warehouse is sorted and shipped, the spare parts are delivered to the three basic service stations according to the order.

Combined with the automobile spare parts distribution system composition structure diagram and the modeling purpose of this paper, some minor and difficult to quantify variables are excluded, and the boundary of the SD model of the automobile after-sales spare parts distribution system is finally determined to include the order management system, inventory adjustment system and delivery. Management system.

### 3.2 Establishing a causal feedback model for automotive aftermarket spare parts distribution system

According to the feedback principle of system dynamics and the interaction of various factors in the distribution system, the causal relationship diagram of the automobile after-sales spare parts distribution system is drawn by vensim software, as shown in Fig. 2.

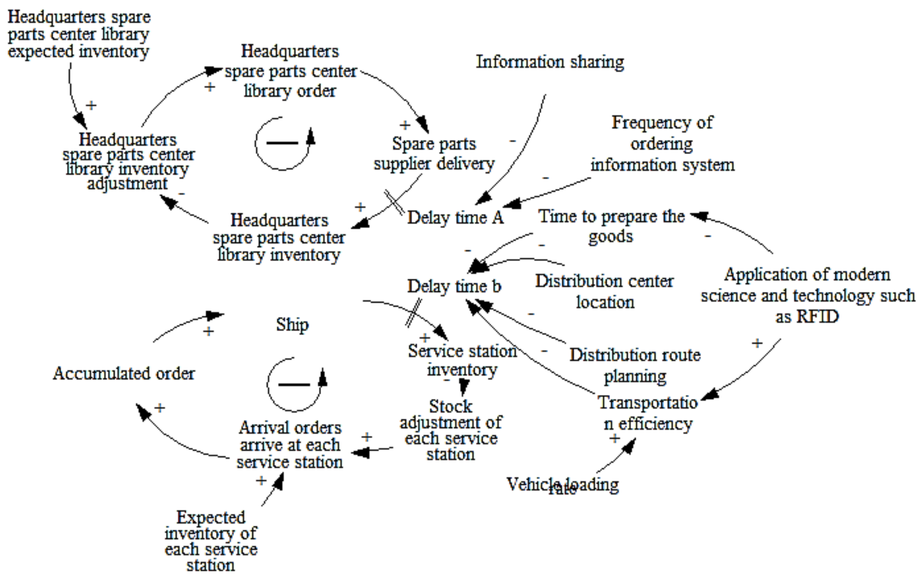


**Figure 2. Causal relationship diagram of automobile after-sales spare parts distribution system.**

In Figure 2, there are two negative feedback closed-loop systems, which represent the supplier-spare center library distribution link and the spare parts center library-service station distribution link, which clearly indicate the causal relationship between the variables. The delivery time from the supplier to the central repository and the central repository to the service station is delayed by a number of factors, namely delay time A and delay time b.

### 3.3 Drawing the flow chart of automobile after-sales spare parts distribution

According to the causal relationship diagram of Fig. 2, the primary SD flow chart of the automobile after-sales spare parts logistics distribution system constructed by vensim software is shown in Fig. 3. The figure shows the process of the spare parts reaching the central library and then reaching the grassroots service station, and indicates the process. The influencing factors of each link and the interrelationship between the factors, such as the number of spare parts A in transit, are affected by the ordering rate of the headquarters spare parts center library and the receiving rate of the headquarters spare parts center library.

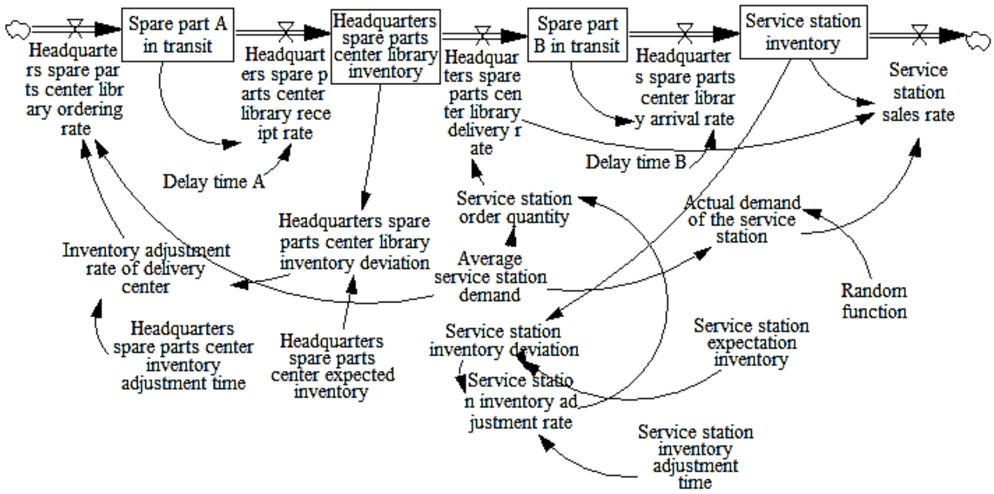


**Figure 3 .Flow chart model of the primary automobile after-sales spare parts logistics distribution system.**

The auto aftermarket spare parts distribution system model of this paper contains three service stations. Through analysis, the complete flow chart of the automobile after-sales spare parts distribution is shown in Figure 4. It shows the distribution process of the headquarters spare parts center library to three service stations. For the sake of the intuitiveness of the flow chart, each variable is represented by a symbol as show in Table1.

**Table1. Variable symbol table.**

| Variable category | Variable name | symbol |
|---|---|---|
| Stock variable | Spare part A in transit | D1 |
| | Headquarters spare parts center library inventory | I1 |
| | Spare part B in transit | D21;D22;D23 |
| | Service station inventory | I21;I22;I23 |
| Rate variable | Headquarters spare parts center library ordering rate | R1 |
| | Headquarters spare parts center library receipt rate | R2 |
| | Headquarters spare parts center library delivery rate | R31;R32;R33 |
| | Headquarters spare parts center library arrival rate | R41;R42;R43 |
| | Service station sales rate | R51;R52;R53 |
| Auxiliary variable | Headquarters spare parts center library inventory adjustment rate | HINR |
| | Headquarters spare parts center library inventory deviation | HINV |
| | Average service station demand | SAN1;SAN2;SAN3 |
| | Actual demand of the service station | SRN1;SRN2;SRN3 |
| | Service station order quantity | SO1;SO2;SO3 |
| | Service station inventory deviation | SINV1;SINV2;SINV3 |
| | Service station inventory adjustment rate | SINVR1;SINVR2;SINVR3 |
| | Random function | test1;test2;test3 |
| constant | Delay time A | LT1 |
| | Delay time b | LT21;LT22;LT23 |
| | Headquarters spare parts center inventory adjustment time | T1 |
| | Headquarters spare parts center expected inventory | HDINV |
| | Service station expectation inventory | SDINV1;SDINV2;SDINV3 |
| | Service station inventory adjustment time | T21;T22;T23 |
| | Headquarters spare parts center library ordering cycle | z |

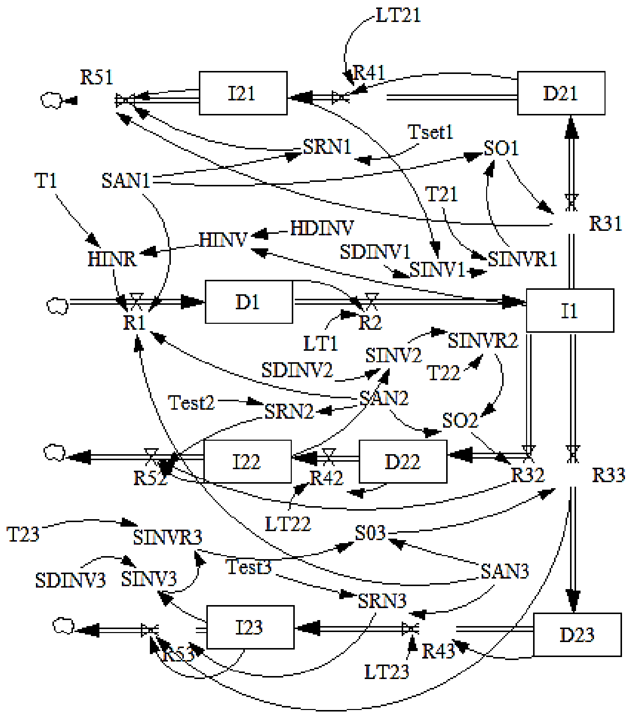


**Figure 4 .Flow chart model of complete automobile after-sales spare parts logistics distribution system.**

In Fig. 4, the in-situ spare part B indicates that the headquarters spare parts center library is respectively delivered to the service parts 1, 2, and 3, and the delay time b indicates the delay time during the delivery of the headquarters spare parts center library to the service stations 1, 2, and 3. Taking the ordering rate of the spare parts center library as an example, it affects the quantity of spare parts in transit and the receiving rate and inventory of the spare parts central warehouse, but it is also affected by the average demand of each service station. The average demand of the service station affects The actual demand of the service station, in turn, affects the sales volume of the service station. In order to ensure the timely response of the spare parts demand, after the service station adjusts the inventory, it must place an order to the central warehouse to ensure sufficient inventory, so as to form a well-functioning distribution system. . According to Figure 4, the SD equations between the variables in the automotive after-sales spare parts logistics distribution system are mainly included: 1) Headquarters spare parts center library inventory: INTEG (headquarters spare parts center library receiving rate - headquarters spare parts center library delivery rate, Headquarters spare parts center library inventory initial value); 2) Service station inventory = INTEG (headquarters spare parts center library arrival rate - service station sales rate, service station inventory initial value); 3) in-service spare parts A = INTEG (headquarters spare parts Center library ordering rate - Headquarters spare parts center library receiving rate, 0); 4) In-transit spare parts B = INTEG (Headquarters spare parts center library delivery rate - Headquarters spare parts center library arrival rate, 0); 5) Headquarters spare parts center collection Freight rate = DELAY 1 (spare part A in transit, delay time A). The relationship between the variables is embodied in the equation. For example, Equation 1 indicates that the stock of the spare parts center warehouse at the headquarters is obtained by solving the integral of the delivery rate minus the delivery rate, and the initial value of the inventory is given according to the actual amount. Due to the large number of equations, it is limited to the length of the list.

## 4 Simulation experiment

### 4.1 Case Model Simulation

In the distribution system, the relationship between many parameters is difficult to quantify, but the structure of the SD model is based on the feedback loop. Even if the lack of data makes the estimation of the parameters difficult, as long as the estimated parameters fall within its tolerance, The trend of system behavior can still be studied by the method of system dynamics [11]. Before the simulation starts, the paper sets the simulation time for calculating the time variable of the model to 60 days according to the basic data in the spare parts distribution system of a car company. The step size is 0.5 days, and the simulation results are stored once a day. The initial values of the variables in the model are shown in Table 2.

**Table 2 .Constant initial value setting.**

| variable | Initial value | unit | variable | Initial value | unit |
|---|---|---|---|---|---|
| $I_1$ | 2000 | box | $T_{21}$ | 1 | day |
| $I_{21}$ | 25 | box | $T_{22}$ | 1 | day |
| $I_{22}$ | 20 | box | $T_{23}$ | 1 | day |
| $I_{23}$ | 15 | box | HDINV | 2500 | box |
| $LT_1$ | 4 | day | $SDINV_1$ | 30 | box |
| $LT_{21}$ | 0.25 | day | $SDINV_2$ | 25 | box |
| $LT_{22}$ | 0.25 | day | $SDINV_3$ | 20 | box |
| $LT_{23}$ | 0.25 | day | $SAN_1$ | 90 | box/day |
| $T_1$ | 2 | day | $SAN_2$ | 70 | box/day |
| z | 3 | day | $SAN_3$ | 50 | box/day |

The model checking function of Vensim software can determine that the model can run normally. The simulation results of the main variables in the model are as follows:

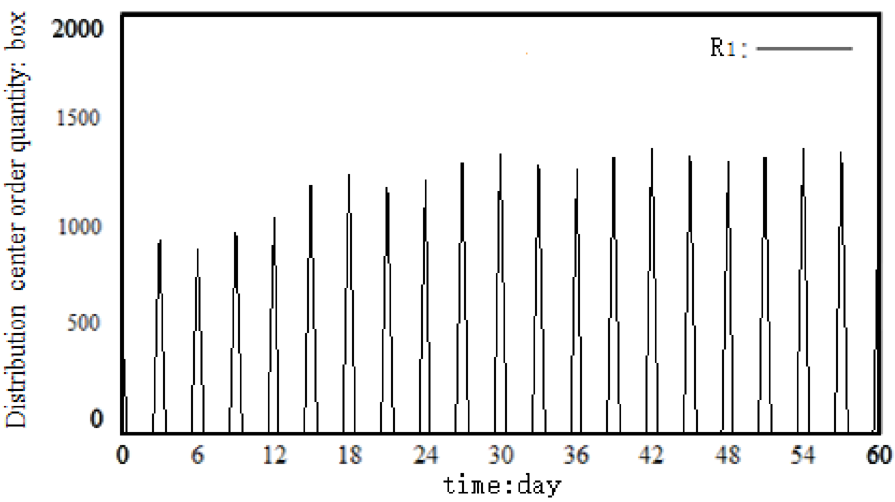


**Figure 5. Spare parts center library ordering rate.**

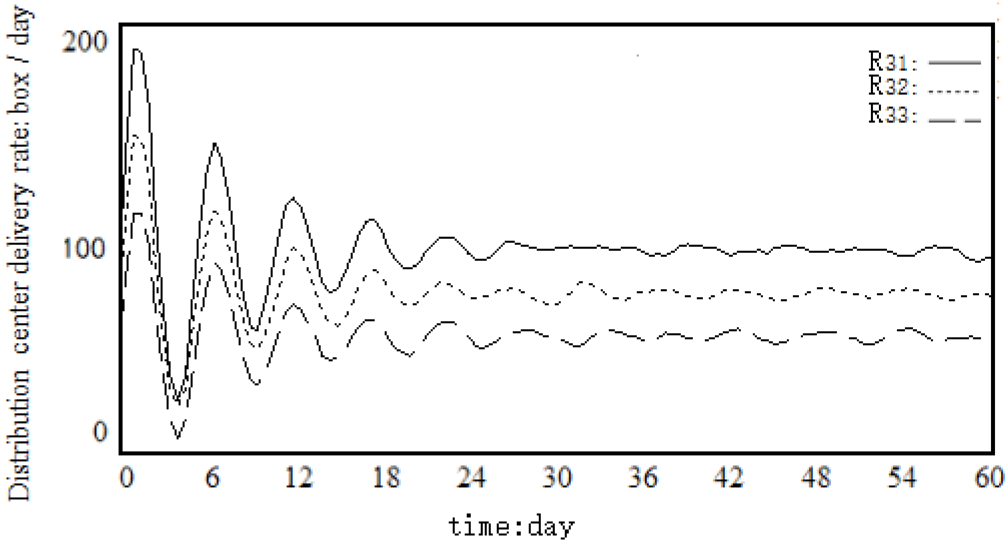


**Figure 6. Spare parts center library delivery rate graph.**

Figures 5 and 6 are the order rate graphs of the spare parts center library within 60 days and the delivery rate graphs sent to the three base station service stations. Because the setting of the goods in transit delay in the model will cause the graph to fluctuate greatly in the initial stage of the simulation and tend to stabilize after a period of time. It can be seen from Figure 6 that the shipment rate from the spare parts center library to the three service stations fluctuates around 90, 70, and 50 boxes per day, and the fluctuation range is small, indicating that the distribution system is stable in the model.

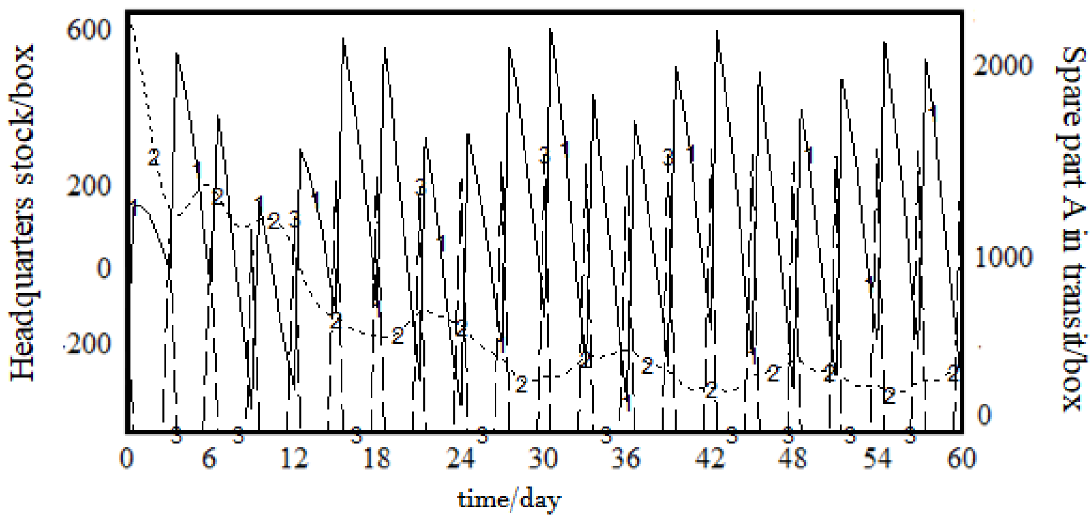


**Figure 7.Sspare parts center library order receipt curve.**

In Fig. 7, curves 1, 2, and 3 indicate the spare parts A, the spare parts center library inventory, and the spare parts center library order rate. As can be seen from Figure 7, the spare parts center library is regularly ordered. When the spare parts center library is ordered, the number of spare parts A in the way increases, and after the ordering activity is over, the delivery activities are still going on, but the number of spare parts A in the beginning begins to decrease, indicating the spare parts. Gradually reach the spare parts center library, and the curve 2 is always maintained at more than 0 boxes, indicating that the inventory of the spare parts center library is relatively stable, which can ensure timely meeting the ordering requirements of the service station.

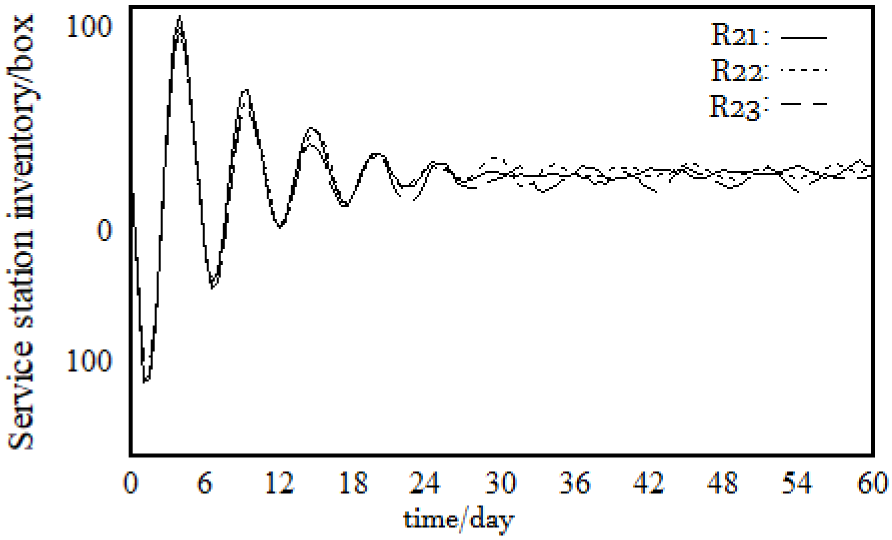


**Figure 8. Three service station inventory graphs.**

It can be seen from Figure 8 that the inventory of the three service stations fluctuates around 25, 20, and 15 boxes, and the stocks are properly stocked, and the immediacy of the supply of spare parts can be guaranteed, and the customer satisfaction will not be affected by the shortage of goods.

### 4.2 Improvement strategy and results analysis

The distribution of after-sales spare parts of automobiles has the characteristics of timeliness. The delivery time plays a vital role in the whole distribution system, and it greatly affects the level of distribution efficiency. To improve the distribution efficiency, the delay time should be shortened as much as possible. Therefore, the paper In combination with the actual situation, the delay time is mainly improved.

According to the analysis of the above simulation results, combined with the important factors affecting the distribution system, the paper proposes three improvements:

Option 1: Adjust the delay time A (supplier-spare center library) to improve the transportation deployment capacity of the spare parts center library in the procurement process;

Option 2: Adjust the inventory adjustment time of the spare parts center library, and improve the tally, stocking and shipping capacity of the spare parts center library in the storage chain;

Option 3: Adjust the delay time bj (spare parts center library - service station), improve the cargo distribution and deployment capacity of the spare parts center library in the delivery link. The scheme takes the service station 1 as an example, that is, adjust the delay time b1.

Based on the above-mentioned distribution efficiency evaluation perspective, considering that the model variables are limited, the improvement results of the above schemes are evaluated by the following indicators:

**Table 3. Improvement strategy evaluation indicators and calculation methods.**

| Indicator name | Calculation formula |
|---|---|
| Spare parts center library maximum stock | |
| Spare parts center library minimum inventory | |
| Spare parts center library inventory fluctuations | Maximum stock value - minimum stock value |
| Spare parts center warehouse average inventory | Inventory average |
| Spare parts center library out of stock rate | Out of stock during calculation period / average stock during the period |
| Service station 1 maximum inventory | |
| Service station 1 minimum inventory | |
| Service station 1 inventory fluctuations | Maximum stock value - minimum stock value |
| Service station 1 average inventory | Inventory average |
| Service station 1 out of stock rate | Out-of-stock days during calculation / total days during the period |
| Service Station 1 submits the order to the receiving cycle | Spare parts center library ordering period + delay time A + delay time b1 |

Since the above mentioned model will be disturbed at the beginning of the operation and the numerical deviation is large, the improvement strategy calculation starts from the 31st day and tries to avoid the result difference caused by the numerical fluctuation.

**4.2.1 Adjusting the delay time A**

Without changing the values of other variables in the model, the delay time A was adjusted from 4 days to 2 days and 6 days respectively. After the model was tested, the simulation was performed and the output stocks were compared:

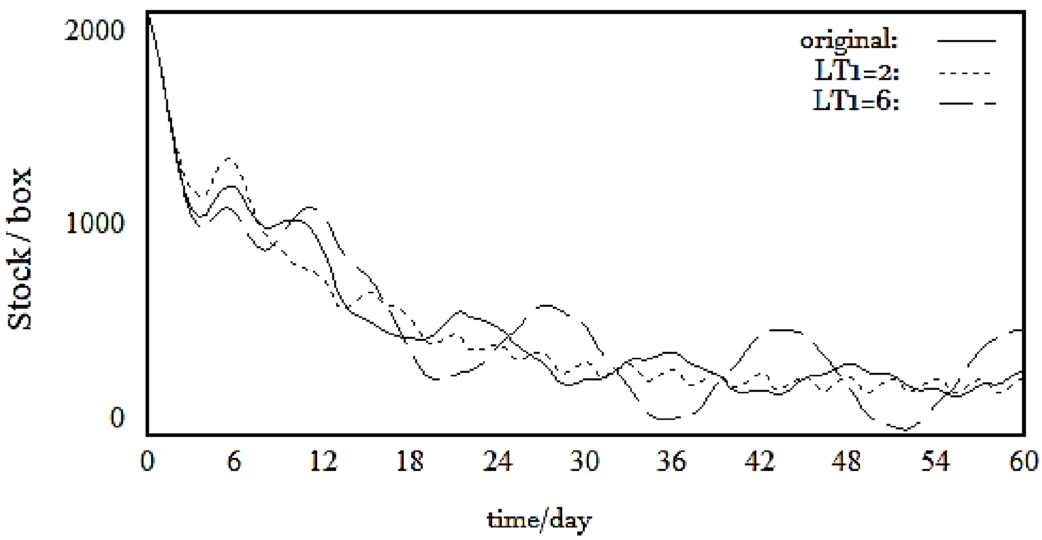


**Figure 9. Spare parts center library inventory comparison curve.**

Comparing the fluctuation amplitude and speed of each curve in three cases, it can be seen that the inventory quantity is directly affected by the delay time A. When the delay time A is reduced from 4 days to 2 days, the inventory fluctuation becomes smaller; when extended to 6 days, Large fluctuations in inventory are not conducive to inventory management.

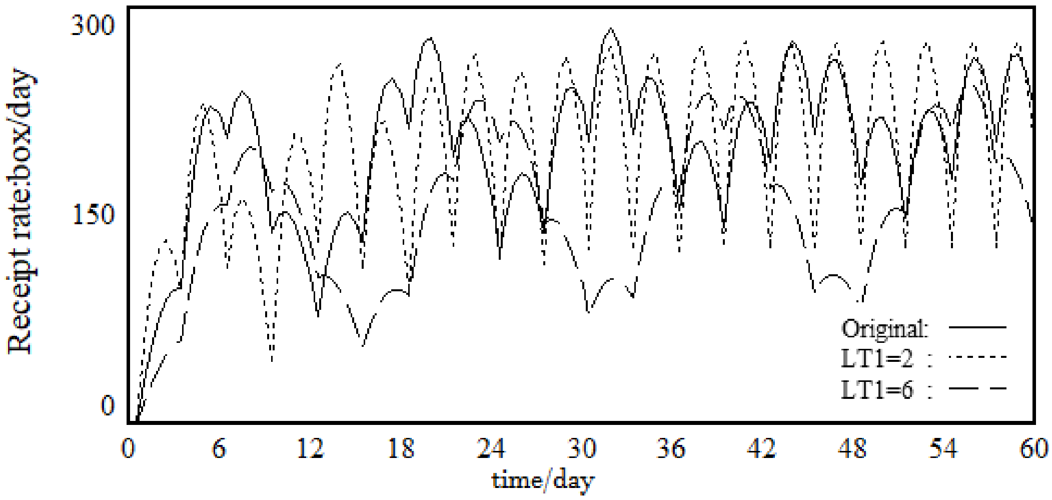


**Figure 10. Spare part center library receipt rate comparison curve**

As shown in FIG. 10, when the delay time A is 2 days, the receiving rate of the spare parts center library is also relatively stable compared with the other two cases. According to the simulation data, the approximate values are obtained, and the results of each evaluation index are shown in the following table:

**Table 4. Evaluation of the results of each indicator after adjusting the delay time A.**

| Indicator name | $LT_1$=6 | $LT_1$=2 | $LT_1$=4（original） |
|---|---|---|---|
| Spare parts center library maximum stock | 498 | 331 | 389 |
| Spare parts center library minimum inventory | 23 | 197 | 178 |
| Spare parts center library inventory fluctuations | 475 | 134 | 210 |
| Spare parts center warehouse average inventory | 266 | 252 | 273 |
| Spare parts center library out of stock rate | 0 | 0 | 0 |
| Service station 1 maximum inventory | 31 | 31 | 31 |
| Service station 1 minimum inventory | 23 | 23 | 23 |
| Service station 1 inventory fluctuations | 8 | 8 | 8 |
| Service station 1 average inventory | 26 | 26 | 26 |
| Service station 1 out of stock rate | 0 | 0 | 0 |

As can be seen from the above chart, shortening the delay of supplier delivery to the spare parts center library will not affect the inventory of the service station, and can reduce the average inventory of the spare parts center library, reduce inventory fluctuations, and cause no shortages. Reduce inventory holding costs in the case of inventory.

#### 4.2.2 Adjusting the spare parts center library inventory adjustment time

In the case where the values of other variables in the model are unchanged, the inventory adjustment time of the spare parts center library is adjusted from 2 days to 1 day and 5 days, and the model is tested and simulated. The relevant evaluation indicators are as follows:

**Table 5. Evaluation results of the indicator results after adjusting the spare parts center library inventory adjustment time**

| Indicator name | $T_1$=2（original） | $T_1$=1 | $T_1$=5 |
|---|---|---|---|
| Spare parts center library maximum inventory (box) | 389 | 2245 | -1472 |
| Spare parts center library minimum inventory (box) | 178 | 334 | -2490 |
| Spare parts center library inventory fluctuations (box) | 210 | 1911 | 1018 |
| Spare parts center warehouse average inventory (box) | 273 | 1353 | -2073 |
| Spare parts center library out of stock rate | 0 | 0 | 100% |

By comparing the output results, a graph showing the inventory of the central repository after adjusting the inventory adjustment time is as follows:

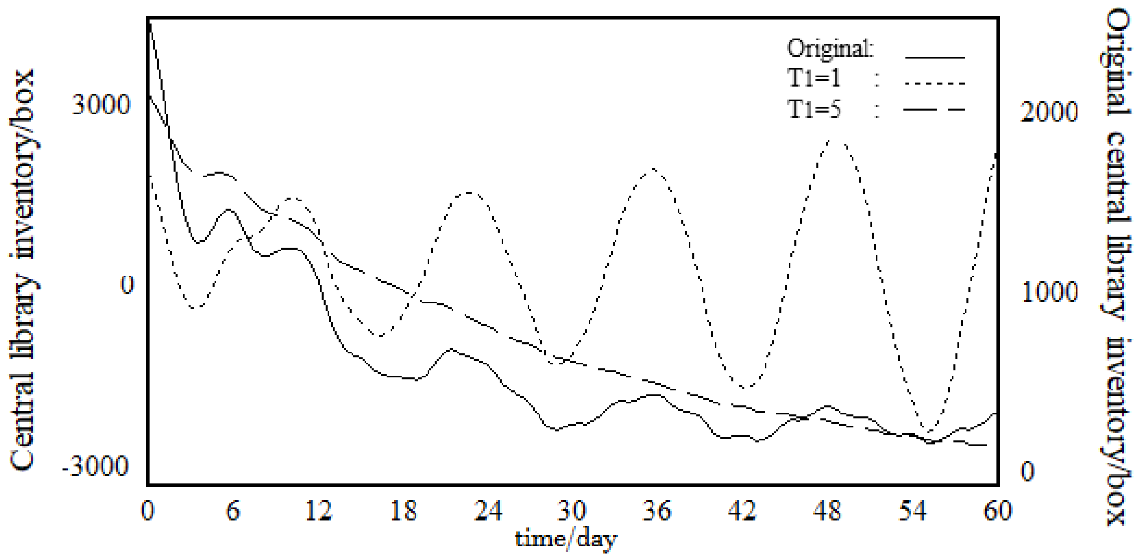


**Figure 11. Adjust the inventory of the central repository after the spare parts center library inventory adjustment time.**

It can be seen from Fig. 11 that when the inventory adjustment time of the spare parts center library is reduced to 1 day, the fluctuation of the inventory quantity curve becomes larger, and the shortage of inventory management increases the difficulty of inventory management and operation cost; when the inventory adjustment time of the spare parts center library is adjusted to 5 days The inventory continues to decline, which is likely to cause out of stock.

It can be concluded that inventory adjustment time may be too large due to too fast adjustment; inventory adjustment time is too long, although it will improve the stability of the distribution system, but will delay the replenishment time and affect the timeliness of the system. .

### 4.2.3 Adjusting the delay time b1

Keep the values of other variables in the model unchanged, and adjust the delay time of the spare parts center library to service station 1 from 0.25 days to 1 day. The model is tested and simulated to obtain the relevant indicators of the spare parts center library and service station 1. The evaluation is as follows:

**Table 6. Evaluation results of the indicator results after adjusting the delay time b1**

| Indicator name | $LT_{21}$=6 | $LT_{21}$=4（original） |
|---|---|---|
| Spare parts center library maximum stock | 14438 | 389 |
| Spare parts center library minimum inventory | -18674 | 178 |
| Spare parts center library inventory fluctuations | 33112 | 210 |
| Spare parts center warehouse average inventory | -384 | 273 |
| Spare parts center library out of stock rate | 48% | 0 |
| Service station 1 maximum inventory | 23570 | 31 |
| Service station 1 minimum inventory | -19247 | 23 |
| Service station 1 inventory fluctuations | 42817 | 8 |
| Service station 1 average inventory | 159 | 26 |
| Service station 1 out of stock rate | 0 | 0 |

By comparing the output results, a graph showing the inventory amount of the service station 1 after adjusting the delay time b1 is as follows:

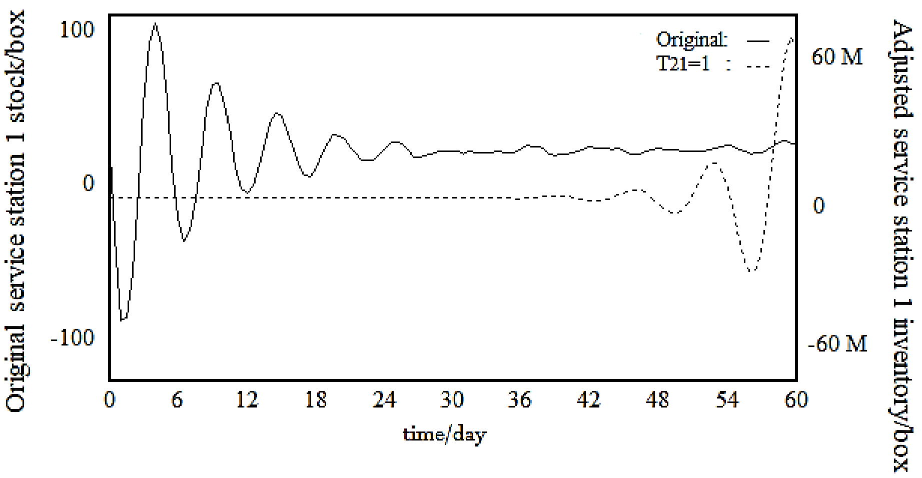


**Figure 12. Service station 1 inventory curve when adjusting delay time b1**

The delay time b1 indicates the transit time of the spare parts center library to the service station 1, reflecting the distribution efficiency of the spare parts center library, and the shorter the delay time b1, indicating that the more timely the delivery, the less likely the service station is out of stock. As can be seen from the above chart, when the delay time b1 is extended to 1 day, the inventory fluctuation of the service station 1 is very large, there will be a shortage of goods at a certain time, and the inventory backlog when the goods are not out of stock is also very serious, and the spare parts are caused. The inventory of the central repository fluctuates and the entire distribution system is very unstable.

## 5 Improvement measures and recommendations

Through the analysis of the above simulation experiment, the influence law of the main parameters of the distribution ability on the stability and inventory of the after-sales spare parts distribution system of the automobile is obtained. Starting from the perspective of three simulation experiments [12], according to the elements in Figure 2 The causal relationship between the two can be considered to optimize the distribution efficiency of the automobile after-sales spare parts distribution system from the following aspects:

(1) Shorten the delay in the delivery of suppliers to the spare parts center library.

By reasonably selecting the geographical location of the spare parts center library, comprehensive consideration of the integrity of the spare parts supplier, the spare parts center library and the grassroots service station, so that the planning of the three is optimal, so as to shorten the delay time of distribution between the nodes.

(2) Maintain proper inventory adjustment time.

With the rapid development of modern technology, the application of logistics technology and equipment plays an increasingly important role in logistics and distribution. Enterprises should take their needs and rationally apply logistics information systems and logistics equipment to facilitate adjustment of appropriate inventory adjustment time. Improve distribution efficiency and corporate profits.

(3) Reduce the delay time for the spare parts center library to arrive at the service station.

Reasonably plan the distribution route and vehicle loading, reasonably plan the vehicle loading and routing according to the location of the spare parts center library and the service stations and the purchase demand of different service stations, reduce unnecessary time delays, and improve the distribution system. The level of integration of roles, the overall planning of the system, so that each node achieves the best efficiency.

## 6 Conclusion

The effective operation of the automobile after-sales spare parts distribution system is an important link to support the after-sales service of the automobile. Effective system optimization is beneficial to reduce the cost of emergency delivery and improve the service response speed. This paper analyzes the automobile after-sales spare parts logistics system consisting of a spare parts center library and three service stations, establishes the SD model, and obtains the entry point of the optimized distribution system through simulation. Next, factors such as distribution cost, labor cost and service station sales rate can be added to further research and optimize the distribution efficiency of the automobile after-sales distribution system, and improve the distribution efficiency of the automobile after-sales spare parts from more angles.

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