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Distributed Multi-level Inventory Algorithms for Automotive Maintenance Spare Parts Based on Centralized Control Model

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Abstract

In order to increase the inventory of automotive maintenance spare parts, this article takes automobile maintenance spare parts as the research object, and proposes a distributed multi-level spare parts inventory algorithm based on centralized control to address the problems of low satisfaction of the automotive maintenance spare parts warehouse and poor effectiveness of spare parts inventory control. . The characteristics of automobile maintenance spare parts supply, vehicle maintenance spare parts supply and vehicle maintenance spare parts inventory management are introduced, and the current status of automobile maintenance spare parts inventory management is analyzed. Using the conditions of centralized ordering and mutual allocation, the functions of inventory cost and estimated inventory cost were calculated. A mathematical model for centralized ordering and mutual spare parts inventory was established. Through the establishment of a model, the research of distributed multi-level inventory algorithm for automobile maintenance spare parts is completed to realize inventory optimization. The experimental results show that the algorithm not only has the advantage of high satisfaction rate of automobile maintenance spare parts library, but also improves the efficiency and control ability of spare parts inventory turnover.

Keywords: *centralized control; automobile maintenance spare parts; distributed; multi-level inventory*.

1. Introduction

The concept of spare parts begins with modular design of products. Spare parts are parts and components that can replace the vulnerable parts in machine equipment. According to different uses, spare parts can be roughly divided into two categories: one is that in order to maintain the normal operation of production equipment and promote the continuity of production process, enterprises must reserve a certain number of spare parts of production equipment, which is called maintenance spare parts; the other is that after the sale of their own products, in order to ensure the normal operation of such products after sale, it is necessary to maintain a certain number of spare parts to provide maintenance or replacement services for users. Such spare parts are called service spare parts. Maintenance spare parts inventory in service spare parts of automobile service enterprises is selected as the research object[1-2].

With the continuous development of Internet technology, many related scholars have proposed a variety of distributed multi-level inventory algorithms for vehicle maintenance spare parts. Reference [3] proposed a distributed multi-level inventory algorithm for automobile maintenance spare parts based on industry chain cloud service platform. Aiming at the cooperative demand of spare parts business of chain cooperative service platform in manufacturing industry, a cross-node inventory cooperative solution was proposed and a near-term demand forecasting calculation model was established. Combining the application of real-time collection and processing of historical transaction data and inventory data of distributed node enterprises, the effectiveness of inventory control scheme was guaranteed. MapReduce framework was used to optimize the calculation process of model parameters and improve the operation speed. The genetic algorithm was used to obtain the optimal solution of the model, the results of the model were pushed to the downstream dealer enterprise group, and the dynamic generation of orders was controlled by feedback information. The model was applied to the cloud service platform of the automobile industry chain, which reduced the response time of the industry chain, but the algorithm had high inventory and high cost of spare parts. Reference [4] proposed a distributed multi-level inventory algorithm for automobile maintenance spare parts based on virtual center. In automobile spare parts maintenance and support, the inventory control of automobile maintenance spare parts was one of the effective ways to improve the efficiency of automobile equipment support. A two-level inventory model was established to optimize the cost of inventory management, and a distributed multi-level inventory control strategy for automobile maintenance spare parts was given. Reference [5] proposed a distributed multi-level inventory algorithm for automobile maintenance spare

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parts based on non-preemptive maintenance priority. Considering the influence of non-preemptive maintenance priority on the maintenance process of faulty parts, the availability evaluation model and initial inventory optimization model of automobile maintenance spare parts under non-preemptive maintenance priority were established. The objective function of non-preemptive priority allocation scheme in multi-level support system was constructed, and the genetic algorithm was used to optimize the priority allocation scheme. Finally, the distributed multi-level inventory of automobile maintenance spare parts was optimized. The above two algorithms had the problem of low satisfaction rate of spare parts warehouse, which reduced the efficiency of support. Reference [6] presented a distributed multi-level inventory algorithm for automobile maintenance spare parts based on system dynamics. A dynamic model of multi-level inventory cooperative management system composed of suppliers, distribution centers and stores was constructed from the point of view of dynamic system. Through sensitivity analysis, the inventory adjustment cycle, demand forecasting weight and safety of automobile maintenance spare parts were determined. By improving the parameters such as full inventory days, an optimized multi-level inventory system dynamics model of automobile maintenance spare parts was finally obtained. The algorithm had the problem of low turnover efficiency of spare parts inventory.

In summary, a distributed multi-level inventory algorithm for automobile maintenance spare parts based on centralized control is proposed. The overall research framework of the algorithm is:

(1) The characteristics of automobile service spare parts inventory are analyzed;

(2) The current situation of inventory management of automobile service spare parts is analyzed;

(3) The mathematic models of spare parts inventory in centralized ordering and mutual allocation are constructed respectively, and the research on distributed multi-level inventory of automobile maintenance spare parts is completed.

(4) The experimental results and analysis. The validity of the distributed multi-level inventory algorithm for automobile maintenance spare parts based on centralized control through the test of spare parts inventory and spare parts warehouse satisfaction rate is verified, and the turnover rate of spare parts inventory of the proposed algorithm is discussed.

(5) Conclusions.

2. Materials and methods

2.1. Inventory Characteristics of Automotive Service Spare Parts

2.1.1. Demand for automotive service spare parts

When repairing a certain equipment, parts used to replace aging or worn parts are called spare parts. In order to shorten the repairing time, a certain number of spare parts are usually kept in the warehouse. These preserved parts are called spare parts. As the most important link in the sales supply chain of automobile manufacturing enterprises, the service of 4S automobile shops brings huge profits to automobile enterprises. The flow direction of service spare parts is from 4S shops to customers. From the perspective of 4S shops, there are three main demands for automobile service spare parts: the first is that customers need to carry out vehicle repair and daily maintenance, cosmetology and so on every fixed cycle or journey; the second is that after a traffic accident, the corresponding vehicles need to be repaired. A certain number of accident spare parts are required. Thirdly, the owners with special requirements need certain spare parts. Some customers will require 4S shops to refit the automobile or customers themselves to carry out refitting and daily simple maintenance. Generally speaking, there is no big difference between the spare parts for the first type of demand and the general products. The number of customers' car purchases is known, and the frequency of daily maintenance is relatively stable. Therefore, it is easy to predict. While the spare parts for the second type of demand are very uncertain, because the occurrence of accidents is discontinuous and uncertain. This brings great difficulties to spare parts prediction. This uncertainty will be transmitted along the upstream and downstream of the supply chain [7], thus increasing the difficulty of spare parts control in automobile manufacturers and 4S shops. Generally, statistical methods are more accurate in demand analysis.

2.1.2. Supply of automobile service spare parts

Usually, a car contains at least 6,000 kinds of parts and components. With the development of science and technology, the models of cars are changing with each passing day, and new models are constantly introduced. All parts and components cannot be produced by the whole car factory. Many automobile manufacturers mainly produce automobile engines and pay attention to the research and development of car bodies, for example, Japan's Toyota, Germany's Volkswagen, etc., other parts are mainly supplied by suppliers.

According to the types of suppliers, there are two main types: one is the factory entrusted by the automobile manufacturing enterprises; the other is the long-term supplier of spare parts, such as Bosch, Wanxiang, Delphi and so on. According to the geographical location of spare parts supply, there are three main categories: the first category is imported parts, although domestic automobile development is faster, the development capacity of new products in a real sense is less, so more than half of the spare parts need to be imported from abroad, the logistics route of imported parts is more complex, and the cycle is relatively long; The second category is self-made parts, automobile manufacturing enterprises with core R&D capabilities will manufacture relevant core components by specialized departments to improve core competitiveness and reduce costs; the third category is domestic parts supplied by domestic suppliers, the order lead time is shorter and the logistics cost is relatively low..

2.1.3. Characteristics of inventory management of automobile service spare parts

Above all, we can see from the demand and supply of automobile service spare parts that the demand of spare parts is uncertain and the supply mode is diverse. In addition, the inventory of automobile service spare parts has the following outstanding characteristics:

(1) Spare parts have a wide variety of inventory and different prices.

Because there are many kinds of spare parts that make up automobiles, there are also many kinds of service spare parts that need to be provided by 4S shops. The price difference is massive. The price of more valuable spare parts can reach more than 90,000 yuan, while the price of cheap spare parts is only a few yuan.

(2) Long life cycle

Compared with general products, the life cycle of auto repair spare parts is much longer. The life cycle of a typical product is its duration, from the launch of a new product to the exit of the market, it is a life cycle. The life cycle of a car is the life cycle of the car plus the life cycle of the parts it uses. For example, after an automobile is launched into the market, it will exit the market after about 10 years. If the life of the vehicle is 15 years, the duration of the automobile is 25 years.

(3) Service spare parts need to meet a higher level of service

Service spare parts are mainly to provide services to customers. The important sign of judging service level is to look at the response time of customers' needs, to make the fastest response in the shortest time, solve the customer's problems, not only to obtain profits but also to win customers' trust, so as to establish the brand image of the company [8]. Generally speaking, if a private car is repaired, it will affect the daily travel of customers and bring inconvenience to personal life during the repair period; if the vehicle of logistics company needs to be repaired, it will affect the operation of the whole company; if it is repaired for medical, fire and other emergency vehicles, it may also affect life and property safety. Therefore, the automobile service spare parts should have a faster response speed, and then meet the higher level of service.

(4) Long inventory turnover time

The demand for service spare parts is not only the daily maintenance, but also the failure of the automobile product. With the development of science and technology, the quality of automobiles is getting better and better. The probability of failure is also reduced. The inventory turnover rate of service spare parts is lower than that of general consumables. At present, Shanghai General Motors is the best after-sales service in China. Its annual inventory turnover is three times, while that of automobile companies like Huachen is only 2 times.

(5) Reverse Logistics

For expensive and repairable automotive service spare parts, spare parts suppliers will provide maintenance services. For these spare parts, first of all, they will be repaired in 4S shops. If they are not repaired properly, they will be repaired in regional maintenance center. At the same time, they will replace spare parts for customers. If the repair of the regional repair center is not good, it will be returned to the factory for repair, and the repair will be completed as local stock. This reverse logistics process is more complex, mainly for expensive repairable automotive service spare parts, the inventory management of these spare parts is also very important.

(6) Low selectivity of inventory content

For the whole automobile factory, there are as many as 20,000 kinds of automobile spare parts, while the inventory of automobile service spare parts for after-sales service is relatively less selective. After fixed spare parts are selected in production, the spare parts needed in service are determined. For example, in production, five of the 20 types of spare parts that meet the requirements are selected, and the types of spare parts for after-sales service are five. The selectivity of the inventory contents is relatively small.

2.2. Current Situation of Inventory Management of Automotive Service Spare Parts

Audi, BMW, Chery three automobile brands are chosen to understand the operation of their service spare parts, and make a specific description[9,10], as shown in Table 1. CDC refers to the central distribution center, RDC refers to the regional distribution center, where the retail only lists 4S shops, not including maintenance stations.

Table 1. Logistics Status of Service Spare Parts for Four Automobiles

Automobile brand		Audi	BMW	Chery
Inventory structure	Layer number	3	2	3
	Number of CDC	1	1	1
	Number of RDC	7	3	15
	Number of 4S shops	150	70	310
Inventory control method		Fixed order quantity	Fixed order quantity	Fixed order quantity
Is spare parts classified management?		ABC classification	ABC classification	ABC classification
Vehicle factory procurementLead time	Imported CKD parts	Three months	Three months	Three months
	Domestic parts	Two months	Two months	Two months
4S shop's lead time		One week	One week	One week

In order to shorten the demand response time, the main distribution mode is from the central distribution center to the regional distribution center and then to 4S shops, as shown in Figure 1.

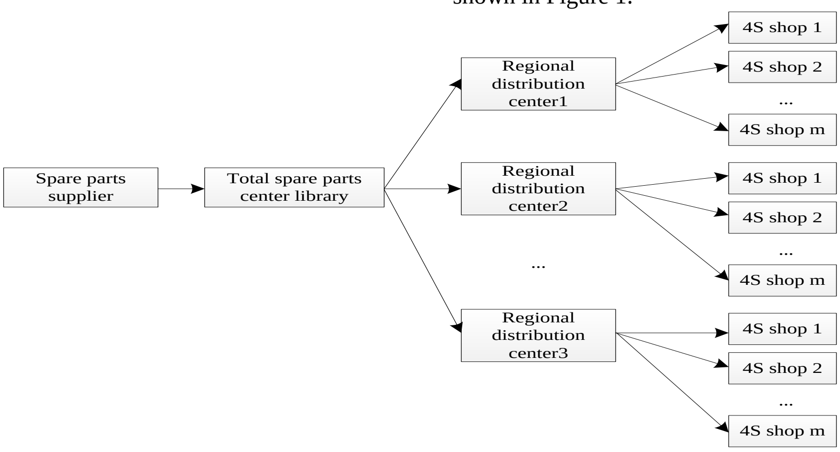


Figure 1. Existing supply mode of automobile service spare parts

As can be seen from Figure 1, the automobile manufacturing enterprises have a general central distribution center throughout the country. At the same time, they are divided into several regional distribution centers according to the region. Each regional distribution center serves 4S shops within its service scope. This method has faster demand response speed, and the specific process is as follows:

(1) 4S shops in a certain area draw up orders according to their market forecast and their own stock situation, and submit the orders to the regional distribution center serving them. If the stock of automobile service spare parts in the regional distribution center is sufficient, it will be distributed to 4S shops. If it is not enough, it is necessary to submit the order to the central distribution center in conjunction with the order of each 4S shop and its own inventory.

(2) If the total quantity of service spare parts in the central distribution center of the automobile manufacturing enterprise is sufficient, it will be distributed to the regional distribution center. If the spare parts are insufficient, the procurement plan will be formulated according to the actual situation of the headquarters [11,12], and the order will be submitted to the supplier to order, and the supplier supplies to the central distribution center.

(3) The central distribution center distributes the goods through sorting, packing and other procedures according to the order requirements of the Regional Distribution Center. After receiving spare parts, the Regional Distribution Center distributes the goods according to the order requirements of the 4S shop it serves.

2.3. Research on Distributed Multi-level Inventory of Automotive Maintenance Spare Parts Based on Centralized Control

2.3.1. Core ideas

The core idea of the centralized control strategy is to set up an inventory coordination center in the spare parts management department of the headquarters of automobile manufacturing enterprises. Based on the real-time centralized storage of spare parts demand and inventory information in each region, the centralized control of the inventory in each sub-warehouse is carried out by the coordination center, or the ordering from external suppliers is unified, or inventory is transferred between different regions within the company. Each regional warehouse is responsible for the spare parts supply of service stations nationwide under the unified dispatch of the headquarters coordination center. This inventory coordination center enables the entire company to physically disperse distributed inventory, forming a virtual centralized inventory.

2.3.2. Mode of operation

Under the guidance of the above ideas, the centralized control strategy operates in the following ways. An inventory coordination center has been set up in the spare parts management department of automobile manufacturer headquarters. Instead of sending spare parts demand information to the major regional warehouses, the regional service stations order spare parts directly from the headquarters [13]. The headquarters coordination center inquires the company’s real-time inventory database immediately after receiving the orders from the service stations. The geographic location of the service station and the inventory situation of the major regional warehouses designate the corresponding large regional warehouses to supply them. The Headquarters Inventory Coordination Center should monitor the inventory situation of each regional warehouse in real time, coordinate the order business with the spare parts suppliers when the total stock of the company has dropped to the company’s general order point, take charge of the inventory replenishment of the downstream major regional warehouses, and the spare parts suppliers will send the spare parts directly to the regional sub-warehouse under the coordination of the Headquarters Coordination Center: When some large-scale sub-warehouses need to replenish and the existing total inventory of the entire company has not yet fallen to the company’s total order point, it should compare the expected inventory costs under the order situation with the expected inventory costs under the transfer situation, if the former is smaller than the latter, then for centralized ordering, if the latter is smaller than the former, the stocks are reasonably allocated between the major sub-warehouses to avoid the company’s overall inventory backlog and partial shortages. At this time, the original spare parts central warehouse of headquarters no longer undertakes the replenishment business to the subordinate major sub-warehouses. Its responsibilities are similar to those of other large sub-warehouses. It is responsible for the spare parts supply of its peripheral service stations under the dispatch of the headquarters inventory coordination center. The improved supply mode and supply process are shown in Figure 2 and 3.

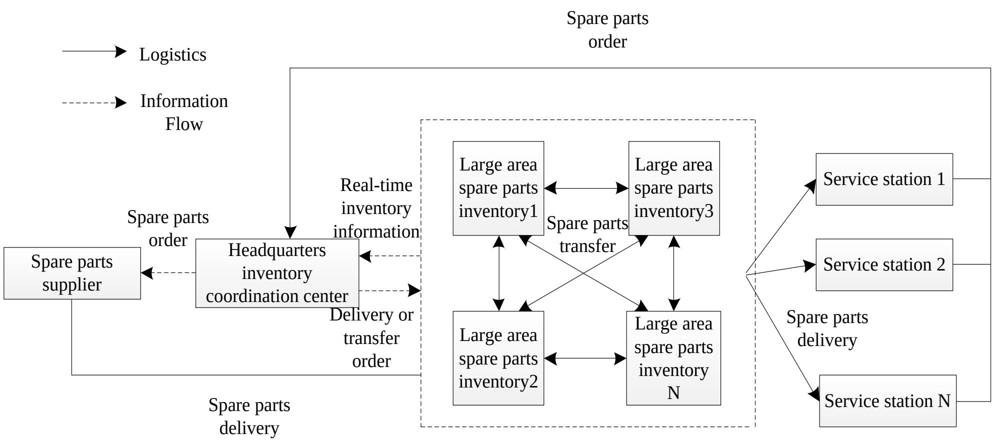


Figure 2. The improved supply mode of automobile spare parts

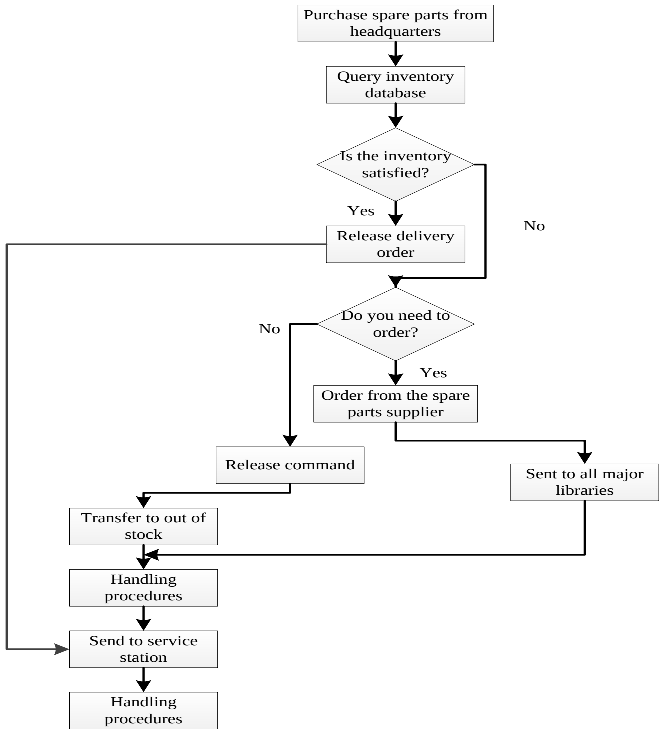


Figure 3. Improved Supply Process of Automobile Spare Parts

The spare parts inventory coordination center company's headquarters plays a very important role. Its main functions include: collecting spare parts purchase orders from service stations nationwide, assigning corresponding large-scale warehouses to supply spare parts to service stations; purchasing spare parts from suppliers when the company's overall inventory is insufficient; processing the information and control parameters needed in order together with spare parts suppliers and establishing the standard mode and business process of order processing. assisting spare parts suppliers in real-time understanding of the inventory and consumption of major downstream sub-warehouses, and making preparations for production; consulting with each sub-warehouse to determine the relevant parameters of inventory control, such as regular or continuous replenishment strategy of major sub-warehouses, safe inventory, order point, order quantity and allocation amount, etc. [14]; real-time monitoring of spare parts consumption and inventory in each region, dynamic automatic replenishing according to the spare parts consumption and inventory situation in each region; ordering the spare parts supplier and assisting to deliver the goods to the warehouse on time; when the company's overall inventory is insufficient, it is necessary to transfer the inventory among the regions, carrying out the inventory allocation between regions.

The above centralized control strategy breaks the situation of independent decision-making and self-governing of each regional warehouse in the management of its own inventory, strengthens coordination and cooperation among various regions, and then links physical distributed inventory into a virtual centralized inventory, effectively resolving various problems in existing modes of automobile spare parts supply.

2.3.3. Advantages of centralized control strategy

(1) Effective control of bullwhip effect in spare parts supply chain

In order to ensure the smooth implementation of the centralized control strategy, it is necessary to collect the data information of the spare parts supply chain into the Headquarters Inventory Coordination Center in real time. Through the real-time aggregation of data information, the company headquarters can grasp the demand and current inventory information of its downstream regions in real time, and can make decisions according to the demand and inventory situation of downstream regions in time. Ordering spare parts suppliers or allocating inventory among different sub-warehouses is the way to deal with this problem. It can reduce the fluctuation caused by the transmission of data information in the spare parts supply chain [15]. With the centralized storage of historical information, and through scientific analysis methods, we can more accurately predict the future demand of some spare parts and reduce the error of demand forecasting. In this way, the bullwhip effect caused by the non-sharing of demand information and the independent operation of inventory in spare parts supply chain system can be effectively controlled.

(2) Exerting the Scale Advantage of Centralized Inventory Management

In order to meet the requirements of rapid response to customer demand, it is difficult for automobile manufacturers to achieve centralized physical management of service spare parts inventory, which makes the advantages of centralized inventory management difficult to play. But centralized control strategy makes physically dispersed distributed inventory become virtual centralized inventory, and centralized inventory management can be realized through information sharing. Setting up the headquarters' spare parts inventory coordination center, consulting with the major sub-warehouses to formulate inventory control strategies, and implementing replenishment and allocation of the sub-warehouses by the coordination center, can give full play to the scale advantage of centralized inventory management[16].

(3) Strengthening coordination and cooperation among nodes

In the implementation of centralized control strategy, supply chain-based business process reengineering is a key link, which can solve the multi-organizational collaboration problems involved in multi-level inventory management. Through business process reengineering among spare parts supply chain nodes, coordination and cooperation among nodes are strengthened, seamless connection between nodes is effectively realized, so as to achieve the goal of optimizing spare parts inventory control.

(4) Reducing the uncertainty of suppliers

Spare parts suppliers can timely understand the inventory and consumption of the latter according to the spare parts demand and inventory information centralized in the headquarters of automobile manufacturing enterprises, timely replenishment of raw materials, shorten the lead time of supply, and then improve the ability of supplying for automobile manufacturing enterprises. And automobile manufacturers can also track the implementation of spare parts suppliers' orders, get timely feedback from suppliers, and reduce the loss of shortage. At the same time, the management level and competitiveness of spare parts suppliers have been improved correspondingly.

2.3.4. Model construction

(1) Model description

Supposing an automobile manufacturer has a regional spare parts warehouse in the whole country (the original headquarters spare parts central warehouse is regarded as one of these warehouses), which is responsible for the spare parts supply of service stations throughout the country. With continuous inventory replenishment strategy, the headquarters coordination center monitors the whole company's spare parts database in real time. When the inventory of some large-scale warehouses drops to the ordering point, and the existing total inventory of the whole company also drops to the company's total ordering point, the headquarters coordination center adopts centralized ordering strategy, and the headquarters coordination center provides spare parts suppliers with the strategy of centralized ordering. In order, the supplier delivers the spare parts directly to the different warehouses; when the stock of some large warehouses falls to the order point, and the total stock of the whole company has not yet fallen to the company's total order point, it is necessary to calculate the expected inventory cost in the case of ordering and allocation separately. If the former is less than the latter, the set is adopted. If the latter is smaller than the former, the mutual allocation strategy will be adopted, and the other regions will allocate to the regions requiring orders under the dispatch of the headquarters coordination center.

For an automobile repair spare part, the following assumptions are made:

The demand of differentiated warehouse k is D_k in every week, which obeys the normal distribution of $N(\mu_k, \sigma_k^2)$, and the demand is independent and identical distribution every week. So if the time period t is taken into account, the demand D_k of t period obeys the $N(\mu_k, \sigma_k^2)$ normal distribution, $k = 1, 2, 3, ..., N$; the lead time of spare parts supplier supplying to differentiated warehouse k is L_k. For the reason of warehouse capacity, regional warehouse k allows the maximum warehouse capacity of the spare parts to be V_k, and the company sets the service level of spare parts to be p, that is, the probability that the demand can be met directly from the local warehouse. and the service level of spare parts set by the company is p1, that is, the probability that the demand can be met directly from the local warehouse. The objective of inventory optimization is to determine the inventory control parameters, i.e. the total order point of the company and the order point, and order quantity or allocation quantity of the different warehouses, so as to make the expected inventory costs of the spare parts of the whole company are minimal in the time period T under the condition of given spare parts service level p and given the system time period T to be considered[17].

(2) Symbol definition

Firstly, the symbols in the model and their meanings are listed.

I_{kT} is the initial inventory of the spare parts of regional warehouse k in period T, D_k denotes the weekly demand of the spare parts in regional warehouse k in period T, which obeys the $N(\mu_k, \sigma_k^2)$ normal distribution, D_{kT} denotes the demand of the spare parts in regional warehouse k in period T, which obeys the $N(\mu_k, \sigma_k^2)$ normal distribution, and $P_{kT}(x)$ denotes the probability that the demand of the spare parts in regional warehouse k in period T is x. L_k represents the lead time from supplier to regional warehouse k. D_{Lk} represents the demand of regional warehouse k for the spare parts within the lead time L_k, which obeys the $N(L_k\mu_k, L_k\sigma_k^2)$ normal distribution. r_k represents the order point of regional warehouse k, Q_k represents the order quantity from regional warehouse k to supplier. Q1 indicates the order quantity of regional warehouse k to suppliers, and the allocation quantity between regional warehouse k and other regionals when allocating to each other. P indicates the unit purchase price of the spare parts when the company orders to suppliers. CO indicates the transaction costs of that headquarters coordination center orders to the spare parts suppliers on behalf of the regional warehouses that need to order, including telecommunications, contract notarization and travel expenses at the time of ordering. CT indicates that the business processing costs of that the headquarters coordination center handles the transfer business in each time when transferring to each other. Cin_k means that the business processing expenses of that regional warehouse k handles the spare parts storage in each time. $Cout_k$ means that the business processing expenses of that regional warehouse k handles the spare parts out of the warehouse in each time. CH_k indicates the storage expenses of the spare parts in unit time in regional warehouse k, including warehouse usage fee, warehouse keeper's salary, insurance premium, tax, interest on occupied funds, etc. CS_k states the loss fee of unit spare parts in the case of shortage of warehouse k, including penalty for breach of contract, loss to users, loss of sales opportunity profit, etc., due to company's shortage during the three guarantees period. Ct represents the transportation cost of bit spare parts and unit distance, d_{kj} represents the transportation distance from k to regional warehouse j, Q_{kj} represents the allocation amount between k and regional warehouse j, CO_{kT} and CD_{kT} respectively represents the expected inventory cost of k in period T under centralized order and mutual allocation, TCO_T and TCT_T respectively represents the expected inventory cost of the whole company in period T when centralized orders and mutual transfers are made.

(3) Model establishment

A mathematical model for centralized inventory control of regional spare parts warehouses under the unified management of headquarters coordination center is established. When establishing the inventory model, the following costs are considered: transaction cost of order, purchase cost, warehouse storage cost of maintaining spare parts inventory, loss cost of shortage caused by shortage, business processing cost allocated between different warehouses and transportation cost of spare parts when allocating. There are two cases: one is the situation of centralized ordering to spare parts suppliers through the headquarters coordination center in each region requiring ordering; the other is the situation of inventory allocation to regions requiring replenishment under the scheduling of the headquarters coordination center.

In the case of centralized ordering, it is necessary to determine the optimal order quantity of different warehouses so as to minimize the expected inventory cost of the whole company during the period T. Inventory costs include transaction costs, purchase costs, warehousing business processing costs, storage costs, as well as out-of-stock loss costs. Because of the centralized order of the whole company, transaction costs and purchase costs can be considered from the perspective of the whole company, while warehousing business processing costs, warehousing and storage costs and out-of-stock loss costs vary with the different regional warehouses, so it is necessary to calculate the regional warehouses as a unit, and then aggregate and count them into the whole company. Transaction cost and purchase cost are the inventory cost under the condition of centralized order of the whole company.

Inventory costs related to regional warehouses are calculated using the following formulas (1).

So in the case of centralized order, the total expected inventory cost function of the whole company in period T is as follows:

$$TCO_T = CO + P\sum_{k=1}^{N} Q_k + \sum_{k=1}^{N} CO_{kT} \tag{2}$$

Considering the constraints of centralized ordering, the maximum storage capacity of spare parts in each region is allowed to be V_k, and the following constraints are obtained:

$$I_{kT} + Q_k \le V_k \tag{3}$$

The mathematical model of spare parts inventory in centralized ordering is as follows:

$$MinTCO_T = CO + P\sum_{k=1}^{N} Q_k + \sum_{k=1}^{N} CO_{kT}$$
$$s.t. I_{kT} + Q_k \le V_k \tag{4}$$

In the case of mutual allocation, it is necessary to determine the optimal allocation amount of different warehouses so as to minimize the expected inventory cost of the whole company during the period T. Here, the inventory cost includes the disposal cost of allocation business, the disposal cost of inward and outward warehousing business, the transportation cost of spare parts when allocating each other, and the storage cost and the loss cost of shortage. Because it is allocated by the company's headquarters coordination center, the allocation of business processing costs can be considered from the perspective of the whole company, while the processing costs, storage costs, shortage loss costs and transportation costs vary with the different regional warehouses, so it is necessary to calculate the regional warehouses as a unit. Then, the inventory cost under the whole company's allocation can be obtained by summarizing and counting the disposal cost of the whole company's allocation business.

$$\begin{aligned} CO_{kT} &= \delta(Q_k)\times Cin_k + CH_k \times T \times \sum_{D_{kT}\le I_{kT}+Q_k} [(I_{kT}+Q_k-D_{kT})\times P_{kT}(D_{kT})] \\ &+CS_k \times \sum_{D_{kT}\le I_{kT}+Q_k} [(D_{kT}-I_{kT}-Q_k)\times P_{kT}(D_{kT})] = \delta(Q_k)\times Cin_k CH_k \times T \times \\ &\int_0^{I_{kT}+Q_k} (I_{kT}+Q_k-x)\times \frac{1}{\sqrt{2\pi T\sigma_k}} + CS_k \times \int_{I_{kT}+Q_k}^{\infty} (x-I_{kT}-Q_k)\times \frac{1}{\sqrt{2\pi T\sigma_k}} \end{aligned} \tag{1}$$

Where, $\delta(x)=\begin{cases}1, x>0\\ 0, x\le 0\end{cases}$, then, the inventory cost of the whole company in period T is calculated, and the inventory cost of each regional warehouse is added into the transaction cost and purchase cost of the whole company.

The inventory costs associated with the regional sub-repositories can be calculated as formulas :

$$CT_{kT} = \sum_{j=1}^{N}[\eta(Q_{kj} \times Cout_k) + \sum_{j=1}^{N}\delta(Q_k) \times Cin_k] + \sum_{j=1}^{N}(\delta(Q_k) \times Q_{kj} \times Ct \times d_{kj}) + CH_k \times T \times \sum_{D_{kT} \le I_{kT}+Q_k}[(I_{kT}+Q_k-D_{kT}) \times P_{kT}(D_{kT})] + CS_k \times \sum_{D_{kT} \le I_{kT}+Q_k}[(D_{kT}-I_{kT}-Q_k) \times P_{kT}(D_{kT})] = \sum_{j=1}^{N}[\eta(Q_{kj} \times Cout_k) + \sum_{j=1}^{N}\delta(Q_k) \times Cin_k] + \sum_{j=1}^{N}(\delta(Q_k) \times Q_{kj} \times Ct \times d_{kj}) + CH_k \times T \times \int_0^{I_{kT}+Q_k}(I_{kT}+Q_k-x) \times \frac{1}{\sqrt{2\pi T\sigma_k}} + CS_k \times \int_{I_{kT}+Q_k}^{\infty}(x-I_{kT}-Q_k) \times \frac{1}{\sqrt{2\pi T\sigma_k}} \tag{5}$$

Where, $\eta(x) = \begin{cases} 1, x < 0 \\ 0, x \ge 0 \end{cases}$. Next, the expected inventory cost of the whole company in the period T is calculated, and the inventory cost of each regional warehouse is summed up and included in the allocation business processing cost of the whole company.

Therefore, in the case of allocation, the total expected inventory cost function of the whole company in period T is as follows:

$$TCT_T = CD + \sum_{k=1}^{N} CT_{kT} \tag{6}$$

Considering the constraints of allocation, the maximum storage capacity of spare parts is allowed to be V_k by the sub-storage of spare parts in each region, so that the import amount of warehouse k can be satisfied:

$$0 < I_{kT} + Q_k \le V_k \tag{7}$$

The inventory transferred from the warehouse shall not be lower than its ordering point after deducting the amount transferred, and the amount transferred from the warehouse k shall be satisfied:

$$-(I_{kT} - r_k) < Q_k < 0 \tag{8}$$

The mathematical model of spare parts inventory allocated to each other is as follows:

$$MinTCT_T = CT + \sum_{k=1}^{N} CT_{kT}$$
$$s.t.\begin{cases} 0 < I_{kT} + Q_k \le V_k \\ -(I_{kT} - r_k) < Q_k < 0 \end{cases} \tag{9}$$

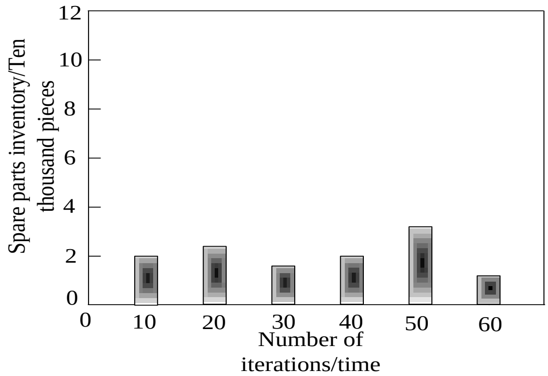
Based on the constructed data model, the spare parts inventory optimization algorithm is obtained as:

$$P(t) = \frac{\sum_{k=1}^{N} CT_{kT}}{V_k} \tag{10}$$

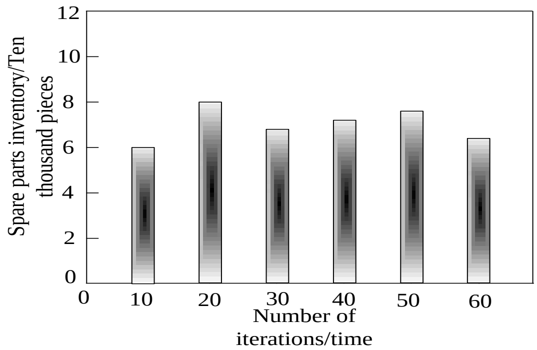
By deriving formula (14), the research of distributed multi-level inventory algorithm for automobile maintenance spare parts is realized.

3. Results

In the experiment, CPU with memory of 3G is selected, the running system is Windows 7, and the running software is MATLAB. In order to verify the validity of the proposed method, the stock of automobile maintenance spare parts is tested. The higher the inventory of automobile maintenance spare parts is, the more the cost is. The test results are shown in Figure 4.



(a) Test results of inventory of automobile maintenance spare parts based on the proposed algorithm



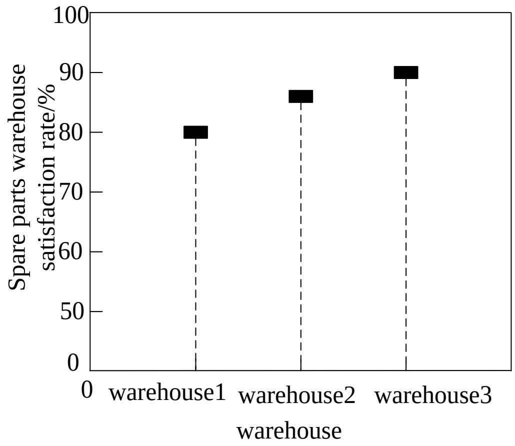
(b) Test results of inventory of automobile maintenance spare parts based on the algorithm in reference [3]

Figure 4. Contrast results of inventory of automobile maintenance spare parts.

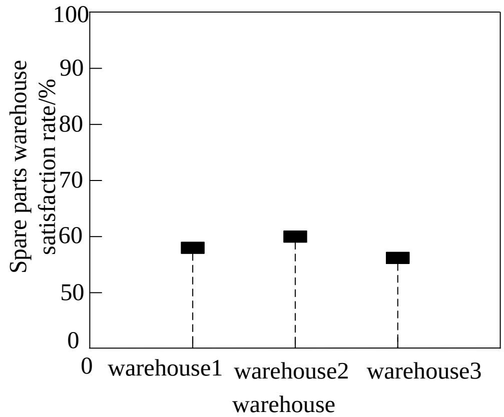
Analysis of Figure 4 shows that in the 60 iterations, the inventory of automobile maintenance spare parts controlled by the proposed algorithm is between 20,000 and 40,000 pieces. In the 30th and 60th iterations, the inventory of spare parts is less than 20,000 pieces. In the 60 iterations by using the algorithm in reference [3], the total inventory of spare parts is between 60,000 and 80,000 pieces. In the 20th iteration, the inventory of spare parts is the largest, which is 80,000 pieces. By contrast, when the proposed algorithm is used to control the inventory of spare parts, the inventory is smaller and the cost is lower, which can accurately guarantee the inventory control of spare parts and improve the control ability.

On the basis of inventory measurement of automobile maintenance spare parts, three warehouses are designed, which are warehouse 1, warehouse 2 and warehouse 3. Satisfaction rate of spare parts warehouse is tested. The test results are shown in Figure 5.

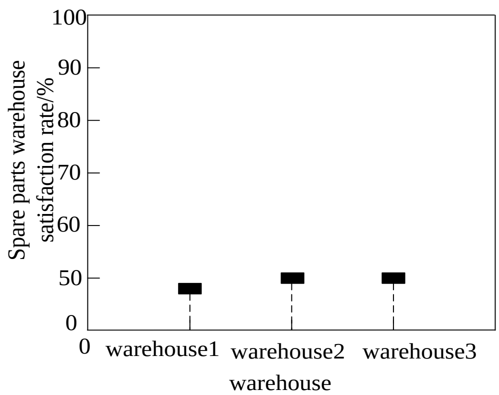
Figure 5 shows that in the proposed algorithm, the warehouse satisfaction rate of spare parts in warehouse 1 and warehouse 3 is 80% and 90%. In the algorithm of reference [4], the satisfaction rate of spare parts in warehouse 1 and warehouse 3 is lower than 60%, and the satisfaction rate of spare parts in warehouse 2 is 60%. In the algorithm of reference [5], the satisfaction rate of spare parts in warehouse 1 and warehouse 3 is lower than 50%, and the satisfaction rate of spare parts in warehouse 2 is 50%. By comparison, the proposed algorithm has a higher satisfaction rate of automobile maintenance spare parts in warehouse and improves the efficiency of support. The above two experiments verify the effectiveness of the proposed algorithm.



(a) Test results of the satisfaction rate of spare parts warehouse based on the proposed algorithm



(b) Test results of the satisfaction rate of spare parts warehouse based on the algorithm in reference [4]

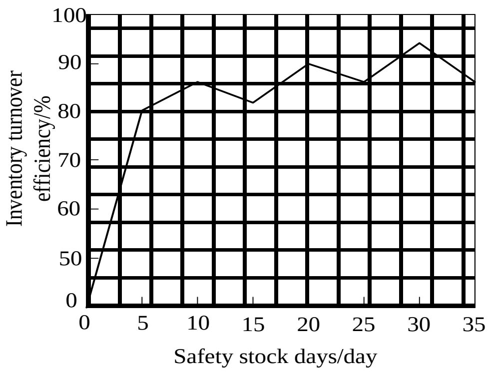


(c) Test results of the satisfaction rate of spare parts warehouse based on the algorithm in reference [5]

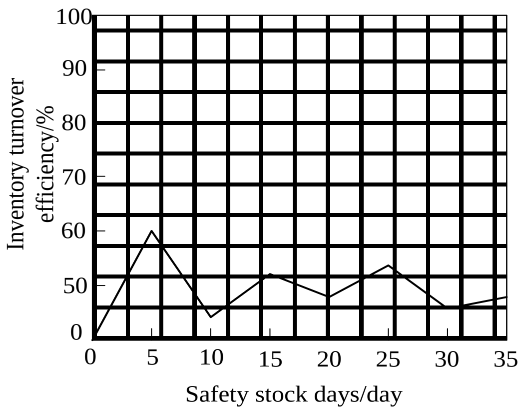
Figure 5. Contrast results of Satisfaction Rate of Spare Parts Warehouse with Different Algorithms

4. Discussion

On the basis of the above experiments, the validity of the proposed algorithm is further discussed. The safety inventory days and inventory turnover efficiency of automobile maintenance spare parts are discussed. The discussion results are shown in Figure 6.



(a) Inventory turnover efficiency of automotive maintenance spare parts based on the proposed algorithm



(b) Inventory turnover efficiency of automotive maintenance spare parts based on the algorithm inreference [6]

Figure 6. The discussion results of inventory turnover efficiency of automobile maintenance spare parts based on different algorithms

Analysis of Figure 6 shows that in the proposed algorithm, the inventory turnover efficiency of spare part is 80% when the safe inventory days of automobile maintenance spare parts are five days; the inventory turnover efficiency of spare part is 90% when the safe inventory days are 20 days; the inventory turnover efficiency of spare part exceeds 90% when the safe inventory days are 30 days, indicating that the average inventory turnover efficiency of spare parts between 80% and 100%. In the algorithm of reference [6], the inventory turnover efficiency is 60% when the safe inventory days of automobile maintenance spare parts are five days, and it is the lowest. The overall inventory turnover efficiency of spare parts is between 0% and 60%. By comparison, the proposed algorithm has higher inventory turnover efficiency of automobile maintenance spare parts and greatly reduces the storage cost.

5. Conclusions

With the expansion of automobile service business, the scale of automobile service companies has developed fast from several initial regions to national automobile service enterprises. With the intensification of competition in the industry, the selling price of automobiles has gradually become transparent, the price has been declining, and the profit margin of the whole automobile sales of automobile enterprises has gradually decreased. The automotive industry as a whole has gradually paid attention to the automotive after-sales service market, which is the third barrel of gold in the automotive industry. On the other hand, as consumers' rational consumption consciousness gradually strengthens, in order to occupy the market, vehicle manufacturers have to put forward higher requirements on the quality of after-sales service. Maintenance service is an important part of automobile after-sales service, and service spare parts are the material guarantee of maintenance service. In order to supply the service stations all over the country with repair spare parts quickly, the automotive service enterprises have to pay more attention to it. Aiming at the above problems, the inventory of automobile maintenance spare parts and the satisfaction rate of spare parts warehouse are tested respectively, and good experimental results are obtained. The inventory turnover efficiency of automobile maintenance spare parts is further discussed. The experimental results and discussion results verify the effectiveness of the proposed method as a whole, and at the same time improve the control capability of spare parts inventory.

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