Study on Supply Chain Replenishment Strategy based on Stochastic Petri Nets

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Abstract: The supply chain replenishment strategy is usually influenced by the supply chain structure, demand changes, supply sources, and inventory status. To achieve replenishment process refinement and effective implementation, a stochastic Petri net model based on influencing factors of uncertainty in supply chain warehousing replenishment was used to study supply chain warehousing replenishment strategies. The supply chain warehousing management process was designed by comparing it with the traditional enterprise warehousing process. The supply chain replenishment process was analyzed, and a replenishment strategy algorithm was designed. In keeping with the supply chain warehousing management process, the warehouse replenishment strategy model was constructed with the help of cargo priority management strategy. Finally, the replenishment strategy function was analyzed. Using the Petri net model to intuitively portray warehouse management process and describe the dynamic change of warehouse replenishment, this paper is expected to implement different warehouse replenishment strategies to solve the problem of out of stock supply chain warehousing caused by uncertainty.

1. Introduction

Online direct marketing promotes cooperation between dual-channel supply chains, requiring single producers and multi-channel vendors to form a joint inventory management [1]. Uncertain factors such as the level of production, supply capacity, logistics costs of warehousing and distribution, and changes in consumer demand have exacerbated the complexity of supply chain inventory management [2]~[4].Non-stationary demand is common in many industrial settings and accounting for the non-stationarity in the demand process significantly complicates the analysis of inventory policies[5]. According to Alptekingoglu's research, the market demand is random and independent, the efficiency of centralized warehouse management is higher than that of decentralized warehouse management [6].

Schmitt claimed that decentralized warehouse management effectively disperse supply risks in the event of supply disruption [7]. Considering the abovementioned random factors in the supply chain, some scholars can recommend responding to supply chain system risks by switching inventory control strategies, mixed-inventory emergency strategies, and mixed inventory dynamic management strategies[8]~[10].This view is more in-line with the current situation of multi-channel supply chain operations. In view of uncertain factors affecting the supply chain inventory, upstream and downstream companies are required to cooperate to achieve terminal demand satisfaction and total inventory cost reduction through joint replenishment [11].

The study of supply chain inventory and replenishment strategies at home and abroad mainly focuses on the optimization of storage layout, job flow optimization, and storage management effectiveness evaluation [12], [13]. Fan Jie et al. based their conclusions on single product storage inventory capacity through the division of T replenishment plan period to solve the warehousing dynamic batch integration optimization problem [14]. Lu Jizhou et al. analyzed the influencing factors of bullwhip effect in the upstream and downstream inventory of supply chain based on the information sharing mechanism and posited that the retailer's demand forecast in lead time affect the retailer inventory management and replenishment strategy [15]. Considering customer satisfaction and library capacity constraints, Zhou Jian established the TOC&M-IRP multi-product dual-channel replenishment model with supply chain replenishment, inventory and stock-out costs as the optimization objectives. Li Jiayin and other researchers rely on inventory replenishment and ordering strategies under the condition of inventory and put forward a retailer's two-level inventory optimization strategy [16].

Within the general practice of supply chain management, supply chain warehousing and replenishment strategies are affected by uncertainties such as channels, demand, and time. At present, scholars at home and abroad have studied inventory and replenishment of supply chain inventory models. However, there are relatively few studies on specific replenishment strategies. Therefore, this article fills that gap in the literature by taking the uncertain factors of supply chain inventory management as the starting point to discuss the replenishment problem of supply chain storage. First, combining the supply chain inventory control and replenishment process based on time constraints, the supply chain replenishment tactics algorithm is designed. Secondly, characterization of supply chain warehousing management processes is done using time-based colored Petri nets. Finally, functional analysis of supply chain replenishment tactics is performed.

2. Supply Chain Warehousing Process Analysis and Replenishment Strategy Algorithm Design

2.1 Supply Chain Warehousing Management Process Design

Compared to enterprise-level warehouse management that operates based on production or sales plans, there is a clear difference in the supply chain-level warehouse management over warehouse processes, inventory collaboration, and replenishment strategies. Supply chain warehousing management faces the following random conditions: first, the change of end consumer demand leads to the change of warehousing inventory and to the frequency and quantity of replenishment. Second, the supplier exists as a single supply source for warehousing. Random fluctuations in supply lead to changes in the time of delivery of replenishment warehousing and the number of products delivered. Third, measures to set up multiple inventory points for unexpected situations (stock storage outside a single supplier) result in different replenishment requirements under mixed inventory strategy.

Based on traditional warehousing management processes, this article extends the supply chain warehousing management process, as shown in Figure 1, for supply chain warehousing management oriented to upstream and downstream multi-agents and random inventory demand changes. Other stocks are introduced before the warehouse storage link as an emergency stock transfer reserve [9] in addition to the supplier stock routine replenishment. Warehousing stores the goods for level classification, determines the replenishment priority, and sets the threshold control for inventory status. Once the reorder point for replenishment is reached, the number of goods and the number of required trays at the time of picking and sorting must be set to handle inventory changes; the replenishment plan for storage must determine the source of replenishment through replenishment time control according to the downstream demand.

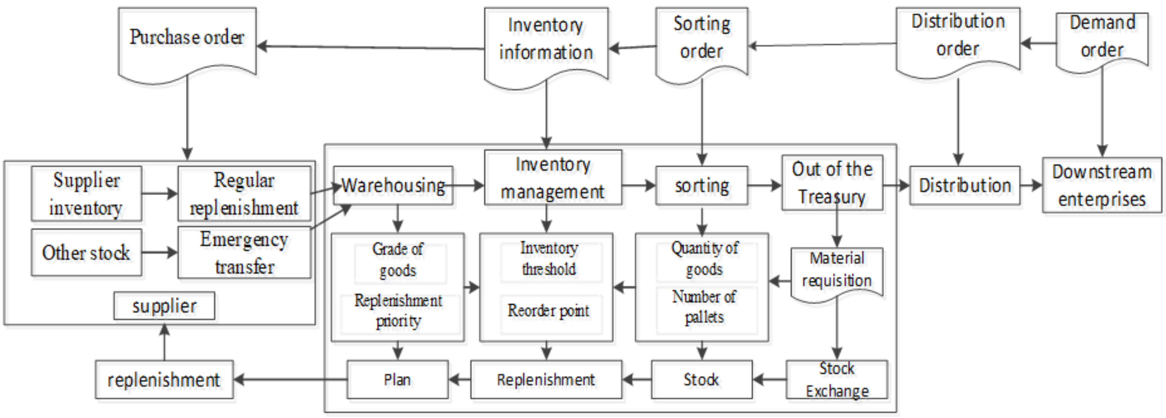

Fig. 1 Schematic diagram of supply chain warehouse management

2.2 Supply Chain Replenishment Characteristics Analysis

Based on the large variety of warehousing goods, according to key customers and the nature of goods, the priority of goods in the warehouse and further replenishment priorities will help optimize the inventory management and replenishment response. In general, the replenishment priority of goods satisfying the constraint of high consumption rate and low inventory level is the highest, and the safety stock threshold is triggered by giving priority to the replenishment of key cargoes to avoid delay in the delivery of key customer orders. The priority of replenishment depends on the following factors: 1) the consumption rate of goods, 2) safety stock level, 3) minimum stock level, 4) value of goods, 5) emergency response capacity, and 6) ease of purchase of goods. Among them, the first three indicators are the basis for calculating inventory standards, and the latter three are related to the characteristics of the goods themselves and the suppliers. The most important link in the supply chain warehousing management process is to determine the reorder point, which is affected by the minimum inventory level and the safety stock level. The determination of reorder point is mainly influenced by the minimum inventory level of goods and the level of safety stock. When the results obtained by the previous first three indexes are the same, the priority of the replenishment should be determined according to the second comparison of the last three indicators.

Different inventory status requires different supply chain warehousing replenishment plans, thus in this paper different colors are used to denote the variation in warehousing inventory status. The supply chain warehousing inventory status affects the replenishment planning arrangement, that is, the supply chain warehousing inventory threshold setting and the replenishment shipment time setting are related, as shown in Figure 2. As inventory reaches the minimum point, the warehouse replenishment schedule is triggered. This article does not consider the time taken by suppliers to receive purchase orders in warehouses.

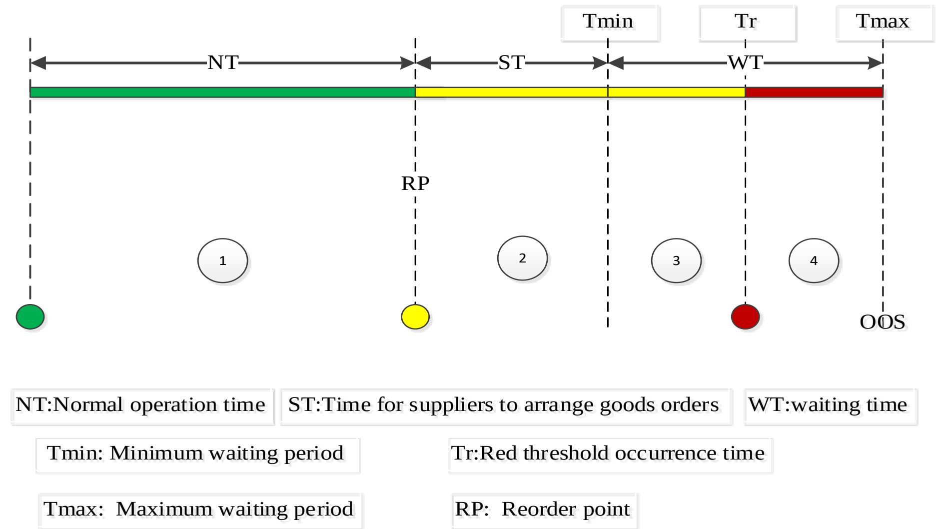

Fig. 2 Flow chart of inventory status threshold setting and replenishment time

3. Supply Chain Replenishment Model Design based on Stochastic Petri Nets

The Petri net model has mathematics and graphic expression capabilities; when applied to the supply chain system modeling for system performance analysis and system optimization, it has proved that its network is an effective tool for supply chain modeling. Supply chain replenishment management is not enough to optimize the structure itself, but it also requires better control of the replenishment process. General Petri nets are more difficult to accurately show the random phenomena in supply chain warehousing and replenishment management. Therefore, the characteristics of various Petri nets are comprehensively analyzed, and the improved timed colored

Petri nets are used to portray the supply chain warehousing process. Model key links for replenishment and analysis of supply chain replenishment strategies.

3.1 Description of Supply Chain Warehousing Management Process

To distinguish between conventional inventory and safety stock, a single warehouse that does not differentiate the traditional space layout is divided into two sections: regular warehouse and emergency stock preparation warehouse. The conventional warehouse refers to the normal supply cargo storage area, and its goods and packaging colors are <a>, <b>, respectively; emergency stock storage warehouse refers to the safety stock storage area, and the color of its goods and packaging are marked with <e>, <h>. Here, <a> and <e>, <b> and <h> may be the same product and packaging but are set for easy identification of different warehouses. The cargo data recorded in the distribution and transportation equipment and warehouse management system is marked with colors <c> and <k>, respectively.

The supply chain warehousing management process begins with the distribution order and leads to inventory change through picking; it then generates distribution tasks based on delivery demand orders and picking orders and initiates replenishment planning based on inventory changes; the final task is to downstream distribution and transportation. The main links and process structure of supply chain warehousing management based on Petri nets are shown in Figure 3, in which the red inventory threshold is triggered when the inventory consumption is rapid, and the warehousing system is required to perform emergency replenishment processing.

The production order P0 is generated and the warehouse manager collects a certain amount of goods <a> and corresponding packages <b> from the warehouse P2 according to the picking list P1. When the T0 transition (receiving) triggers, the distribution task P4 is completed. At the same time, the warehousing system calculates the consumption rate P3 of the stock of goods and packaging, the cumulative consumption of goods and the number of bags P5. When the batch of goods <a> is consumed in a certain quantity, a transition T1 (inventory) occurs; the goods <a> and packaging <b> data are entered through the storage system and are recorded on the existing inventory P7. At the same time, the transport equipment <c> is prepared for delivery P6. The red threshold is controlled based on the number of stocks recorded in P7. Once the existing stock exceeds the safety stock level (Ss), the red threshold is triggered to generate the transition T18 (emergency replenishment), and the number of replenishment stocks triggered when the emergency replenishment P26 is noted.

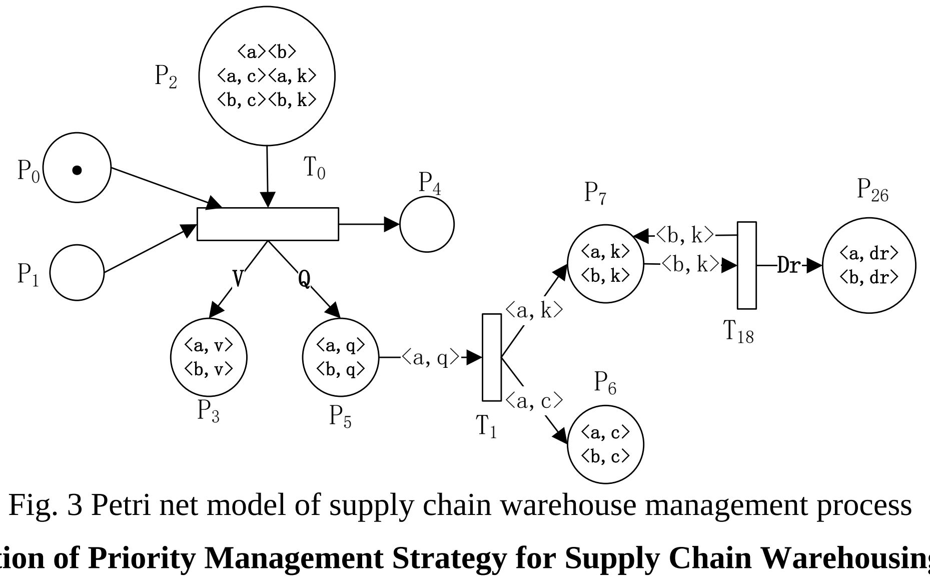

Fig. 3 Petri net model of supply chain warehouse management process

3.2 Construction of Priority Management Strategy for Supply Chain Warehousing Goods

The ordering strategy determines the priority of different replenishment orders according to the importance of the stocks. Therefore, it is necessary to strengthen the discussion on the priority management of the goods in the warehousing management process. The priority management of the extracted goods is analyzed in detail, and the Petri model is shown in Figure 4.

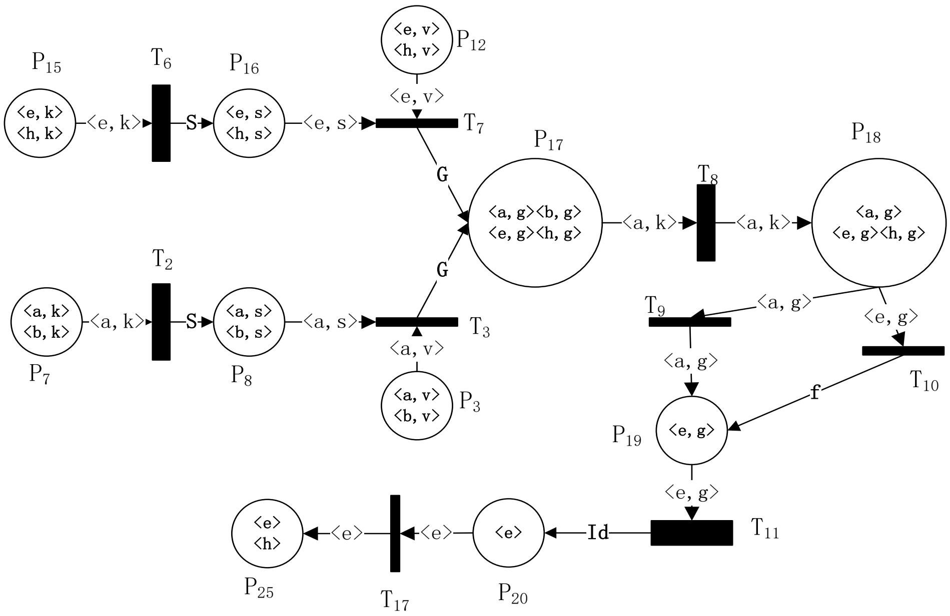

Fig. 4 The Petri model of cargo priority management strategy

P8 indicates that the warehouse is normally in stock, P16 indicates safety stock in the emergency stock warehouse, and T2 and T6 triggers represent normal inventory consumption and safety stock consumption, respectively. According to the number of P8 or P16 stocks and the consumption rate of <a> and <e>, when the stock change triggers the transition T3, the stock support time P17 of various items is calculated through the G function. Once the function G value is obtained, T8 is triggered to select the P18 value (G). At this stage, one of the trigger sequences {T9, T10} is determined based on the remaining inventory quantity. When the inventory <a> can still be maintained for a period of time, the transition T9 occurs. Otherwise, transition T10 occurs, and calculate time that safety inventory <e> can maintain. thereby calculating the minimum value P19 of the G value. Finally, by triggering T11, the extraction function Id corresponds to the minimum value P20 of the function G, while the data are recorded in P25 by the occurrence of the transition T17.

3.3 Supply Chain Replenishment Strategy Model Construction

The replenishment strategy means that the supplier and neighboring warehouses adopt corresponding strategies when different stock thresholds are triggered. The specific Petri model is shown in Figure 5. Among them, the right part corresponds to Step 2 - Step 4 of the supply chain replenishment strategy algorithm; the left side represents the recording process when the red threshold is triggered; the T31 transition occurs, and the inventory red threshold P37 is calculated. P23 indicates that the warehouse lacks the inventory goods, and P38 indicates the out of stock quantity. Only storing a certain quantity of goods in the warehouse P0 and no longer having the out-of-stock number record in P2 causes the transition T32 to generate a new record P39.

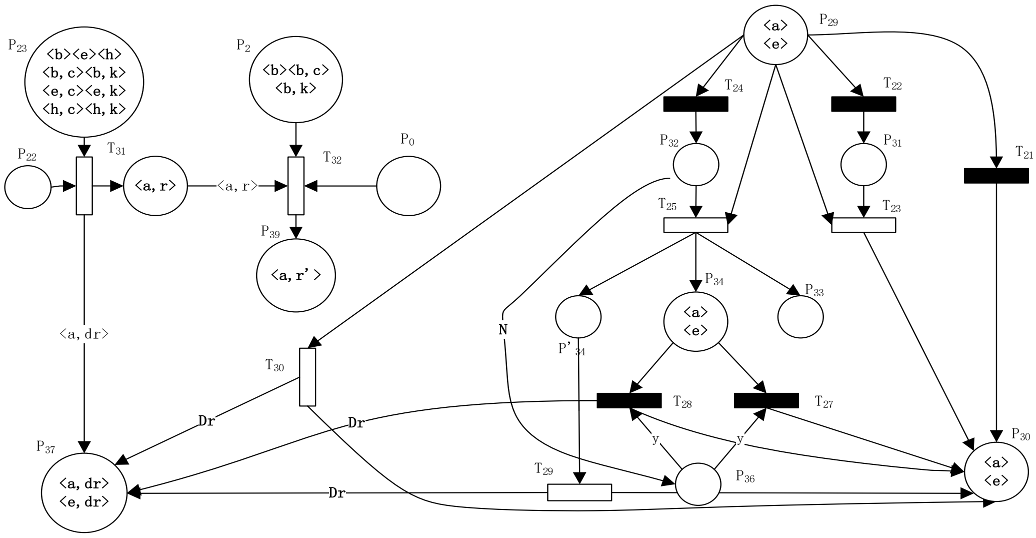

Fig. 5 Petri net model of supply chain replenishment strategy

4. Analysis of Warehouse Replenishment Policy Function based on Stochastic Petri Net Supply Chain

The above stochastic Petri net model is established based on a certain period of time, in which the color represents any number of tokens to avoid confusion of the digital model and represents the evolution of the mark; the main process of supply chain storage is dynamically changed through T. This paper uses mathematical functions to quantify the dynamic change process of transitions in the Petri net, which reflect the state of the transition more clearly.

For warehouse storage of goods, the storage time calculation constraint is set to the duration of the inventory at a certain consumption rate within the constraint time t. Assuming that X is a collection of goods, A is a subset of X (A ⊂ X), A indicates that the priority goods are selected in the constraint time t, and the highest priority cargo type is determined by the replenishment priority. Let T be the set of time t during which the warehouse is in normal operating condition. Specific parameters include: consumption rate V, Minimum inventory levelSmin, Safety stock levelsSs, priority management of goods $\mathrm{Rpr}(\mathrm{Rpr} = x^{*}\})$, The first three parameters change over time.

Set the inventory goods x duration function G at time t. There are:

$$G(x,t) = S(x,t)/V(x,t) \tag{1}$$

Use function F to describe the order of goods priority management, including:

$$F{:}\ X * T{-}{>}\ X, F(A,t) = \{x^{*}/\mathrm{Min}_{A} G(x,t) = G(x*,t)\} \tag{2}$$

Set consumption rate V function:

$$V{:}\ X * T -> IR + \tag{3}$$

where for the parameter x:$V(x,t) = wx/d0$

The consumption rate of the parameters changes with time, for example: within the time [d0+t], 3 kinds of goods are to be delivered, so$V(x, d0 + t) = [\sum_{1}^{3} wx(pt)]/d0 + t$. The time (d0 and d0+t) occurs at T0. The consumption quantity function was set to Q, and the quantity of inventory-consumed goods changed with the delivery quantity within a certain period of time. There are:$Q{:}\ X * T -> IN$, and

$$Q(x,t) = \sum_{1}^{npt} wx(\Omega) \tag{4}$$

where npt denotes the quantity of products delivered at this time, Wx is the weight of the parameter x.

The functions related to parameter x that trigger the red, yellow, and green thresholds are as follows:

$$\mathrm{Dr}(<\mathrm{x},\mathrm{k}>) = \begin{cases} 1, \mathrm{If} < \mathrm{x},\mathrm{k} > \text{set number } \leq \mathrm{Ss} \\ 0, \quad \mathrm{If\ not} \end{cases} \tag{5}$$

$$\mathrm{Dv}(<\mathrm{x},\mathrm{k}>) = \begin{cases} 1, \mathrm{If} < \mathrm{x},\mathrm{k} > \text{set number } \leq \mathrm{Smin} \\ 0, \quad \mathrm{If\ not} \end{cases} \tag{6}$$

$$\mathrm{Ds}(<\mathrm{x},\mathrm{k}>) = \begin{cases} 1, \mathrm{If} < \mathrm{x},\mathrm{k} > \text{set number } \geq (\mathrm{Smin} + \mathrm{Ss}) \\ 0, \quad \mathrm{If\ not} \end{cases} \tag{7}$$

The function S is used to calculate the inventory level (Ss+ Smin), S changes with time, define S:

$$\mathrm{S}: \mathrm{X} * \mathrm{T} -> \mathrm{IN}: \mathrm{S}(\mathrm{x},\mathrm{t}) = \mathrm{Ss}(\mathrm{x},\mathrm{t}) + \mathrm{Smin}(\mathrm{x},\mathrm{t}) \tag{8}$$

The function Id corresponds to the minimum value of the function G, which defines:

$$\mathrm{Id}: \mathrm{IR}+ -> \mathrm{A}: \mathrm{Id}(\min) = \{< \mathrm{x} * >\} \tag{9}$$

The function f determines the minimum value of the additional complex colors <x, g> and <y, g>. x and y are given parameters, so there are:

$$\mathrm{f}(<\mathrm{x},\mathrm{g}>, <\mathrm{y},\mathrm{g}>) = \begin{cases} <\mathrm{x},\mathrm{g}>, \mathrm{If} < \mathrm{x},\mathrm{g}> \leq < \mathrm{y},\mathrm{g}> \\ <\mathrm{y},\mathrm{g}>, \quad \mathrm{If\ not} \end{cases} \tag{10}$$

According to the change of the inventory status of the supply chain storage management process, the mathematical models representing different scenarios are added to the corresponding Petri nets to build an integrated model. Through the consumption rate V of different goods, the consumption quantity Q is determined by the speed of stock consumption, the quantity of remaining goods in stock and judges the inventory level according to the three-color threshold $(\mathrm{Ss} + \mathrm{Smin})$to determine how long the goods can last$\mathrm{G}(\mathrm{x},\mathrm{t})$. At the same time, the goods are divided into different priorities, rational arrangements for replenishment plans, weakening the influence of uncertain random factors, and avoiding the consumption of safety stocks, thereby reducing or avoiding the occurrence of supply chain warehousing management interruption.

5. Conclusion

Currently, with the diversification of the supply chain structure, there are uncertainties in the warehousing and distribution demands and warehousing supply requirements. Therefore, it is of great practical significance to implement supply chain-level warehouse management to respond to the dual-uncertain decision-making environment of supply and demand. Supply chain warehousing management is subject to the priority of the cargo and the level of inventory shortage response's ability, and different storage replenishment strategies must be formulated. Since the Petri net model can intuitively portray the warehousing process and describe the dynamic changes of replenishment system and consider the uncertainties of the supply chain warehousing ordering strategy, this paper adopted the stochastic Petri net to study the replenishment strategy of the supply chain storage.

Changes in the supply chain structure affect the change in supply chain warehousing management requirements and will also lead to changes in the supply chain warehousing process. Therefore, the supply chain warehousing process and replenishment strategy designed in this paper will change with the increase of random influencing factors; at the same time, the constraint function in the establishment model will change randomly. Therefore, future studies must consider the following: 1) how to empirically analyze the established model to verify the research conclusions; 2) how to automatically generate a computer control program for formalized modeling rules in further study of the model function,; and 3) how to integrate transportation distribution, information processing and warehouse management together to form a holistic study of supply chain storage management system.

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