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Research Article

Hybrid Modeling and Simulation of Automotive Supply Chain Network

Wen Wang, Weiping Fu, Hanlin Zhang and Yufei Wang
School of Machinery and Precision Instrument Engineering, Xi'an University of Technology, Xi'an, 710048, P.R. China

Abstract: According to the operation of automotive supply chain and the features of various simulation methods, we create and simulate a automotive supply chain network model with the core enterprise of two vehicle manufacturers, consisting of several parts suppliers, vehicle distributors and logistics service providers. On this basis of a conceptual model including the establishment of enterprise layer, business layer and operation layer, we establish a detailed model of the network system according to the network structure of automotive supply chain, the operation process and the internal business process of core enterprises; then we use System Dynamics (SD), Discrete Event Simulation (DES) and Agent Based Modeling (ABM) to describe the operating state of each node in the network model. We execute and analyze the simulation model of the whole network system described by Anylogic, using the results of the distributors' inventory, inventory cost and customer's satisfaction to prove the effectiveness of the model

Keywords: Automotive supply chain network, Hybrid modeling, Anylogic

INTRODUCTION

Automotive industry has more complex process and more complicate manufacturing technology compared with other industries. The administration of automotive supply chain is always regarded worldwide as the most complex and professional technology (Zhang and Zhao, 2010). With modeling and simulating, we can provide modeling support and corresponding methods for the reconstruction and optimization of automotive supply chain.

Methods suitable for supply chain modeling include: system dynamics (SD), discrete event simulation (DES) and agent-based modeling (ABM). Wang (2010) presented a colored timed hybrid Petri net and sets up a leagile supply chain system model of automotive enterprises and proved that the continuous-discrete hybrid model is more suitable for leagile supply chain system than Petri net model. Peng (2007) used SD software Vensim to build the supply chain network model, which is applied to the Hafei Automobile Industry Group. Pierreval *et al*. (2007) focused on the long-term decision of supply chain, used SD to build macro model of supply chain and the model is applied to a large French automotive company. Taking into account the diverse and unforeseeable nature of the auto industry, Hwang (2012) developed a comprehensive scenario for portraying future market maps, relying on Agent-Based Modeling (ABM) and the notion of complex systems.

Supply chain system is a complex adaptive system with characteristics of multilevel decision making, continuous and discrete hybrid state and dynamic structure changing. Using the above three modeling methods alone can only partially reflect the characteristics of the supply chain system. Therefore, we need to consider the combination of the three methods above to conduct hybrid modeling and simulation of supply chain system.

Focusing on the features of automotive supply chain network and the three modeling methods, we will select appropriate modeling methods and managing strategy for each node of the supply chain network, use Anylogic software to establish simulation model of the supply chain network and verify the effectiveness of the model through the analysis of the results of simulation.

STRUCTURE AND OPERATION PROCESS OF AUTOMOTIVE SUPPLY CHAIN NETWORK

Concept model of automotive supply chain network: We assume a five level automotive supply chain network in this study: supplier-logistics service provider - car manufacturer - customer - distributor, where the core enterprise, supplier, distributor and customer have multiple nodes. Different core enterprises have the same suppliers, the logistics service provider distributes components to the core enterprises and distributes vehicles to the distributors.

Corresponding Author: Wen Wang, School of Machinery and Precision Instrument Engineering, Xi'an University of Technology, Xi'an, 710048, P.R. China, Tel.: 13119109316

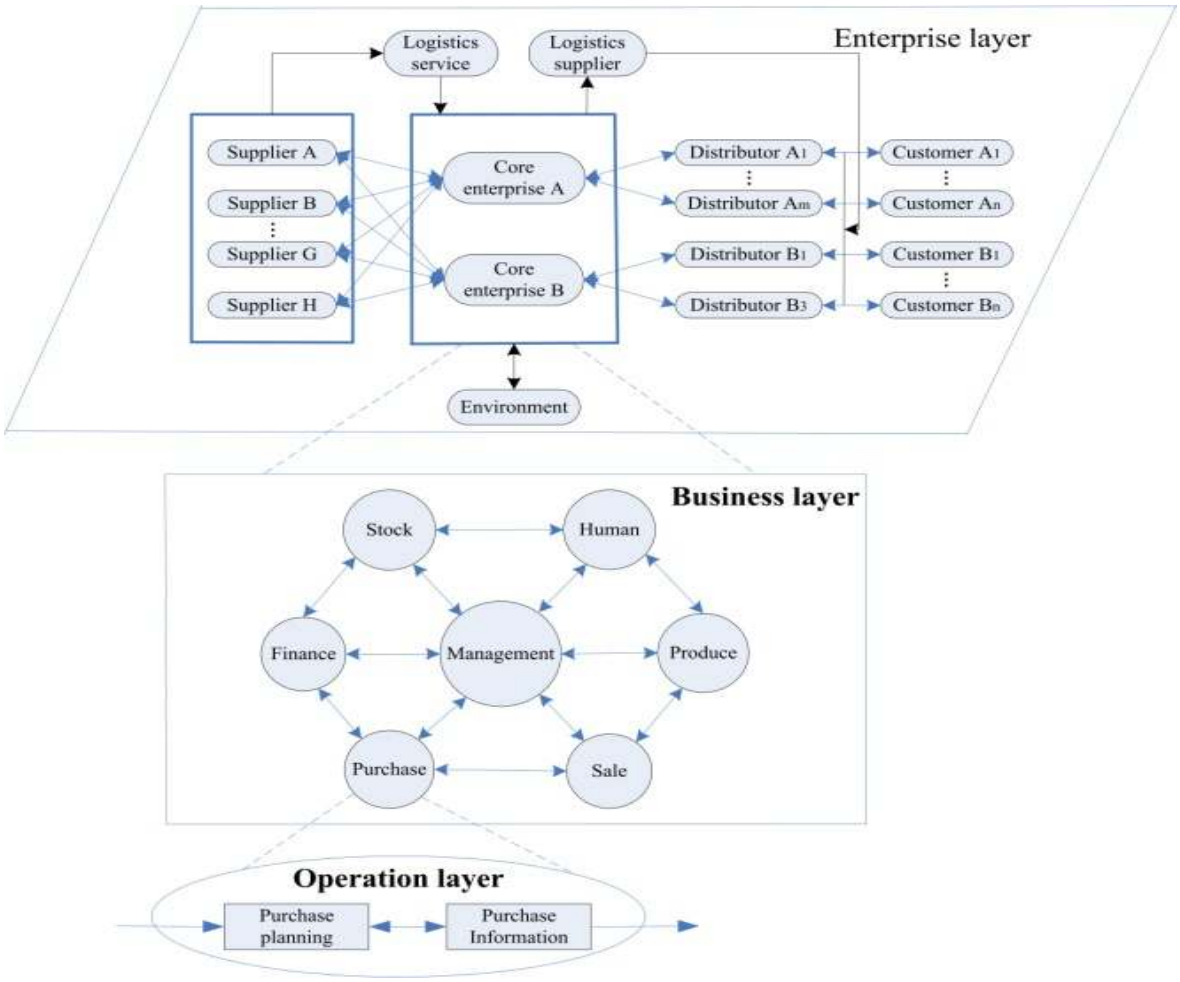


Fig. 1: Conceptual model of supply chain networks

The hierarchy of supply chain network is very strong, which can be divided into enterprise layer, business layer and operation layer (Ren *et al*., 2002; Govindu, 2006). The business layer is the top level, composed of all member enterprises in the supply chain network, mainly reflects business contacts between enterprises and a variety of behaviors during these contacts; the business layer is the middle layer, mainly reflects the internal business of each node enterprise, such as sales, production, procurement, finance etc; operation layer is the lowest layer, shows specific operation processes implementation in the business layer. The car manufacturer is the core enterprise, initiator and manager of the supply chain. The organization structure of the core enterprise, strategies adopted by various departments as well as the cooperation strategies of supply chain play a decisive role to the performance and stability of supply chain network. Therefore, this study mainly studies the business and operation of the core enterprise's business layer and operation layer.

A car is made up of tens of thousands of components, each car company has at least hundreds of suppliers, but it is difficult to reflect so many components and suppliers directly in the model. In this study, we assume that a car consists of eight main parts: engine assembly, body assembly, transmission assembly, brake system, electrical system, transmission, suspension and tire (Yu, 2009; Jia, 2002). Correspondingly, parts suppliers are divided into eight categories, there are a number of parts suppliers in each category available for core enterprises' choosing. We assume that there are two core enterprises A and B, producing two different brands of car. All parts of these two core enterprises are supplied by these eight categories of suppliers and the same categories of suppliers can have cross with each other. Each core enterprise have a number of independent distributors. Parts and vehicle distribution service of core enterprises are provided by the same logistics service provider.

The conceptual model of automotive supply chain network system is shown in Fig. 1.

Detailed model of core enterprise in automotive supply chain network: Core enterprise is the key node

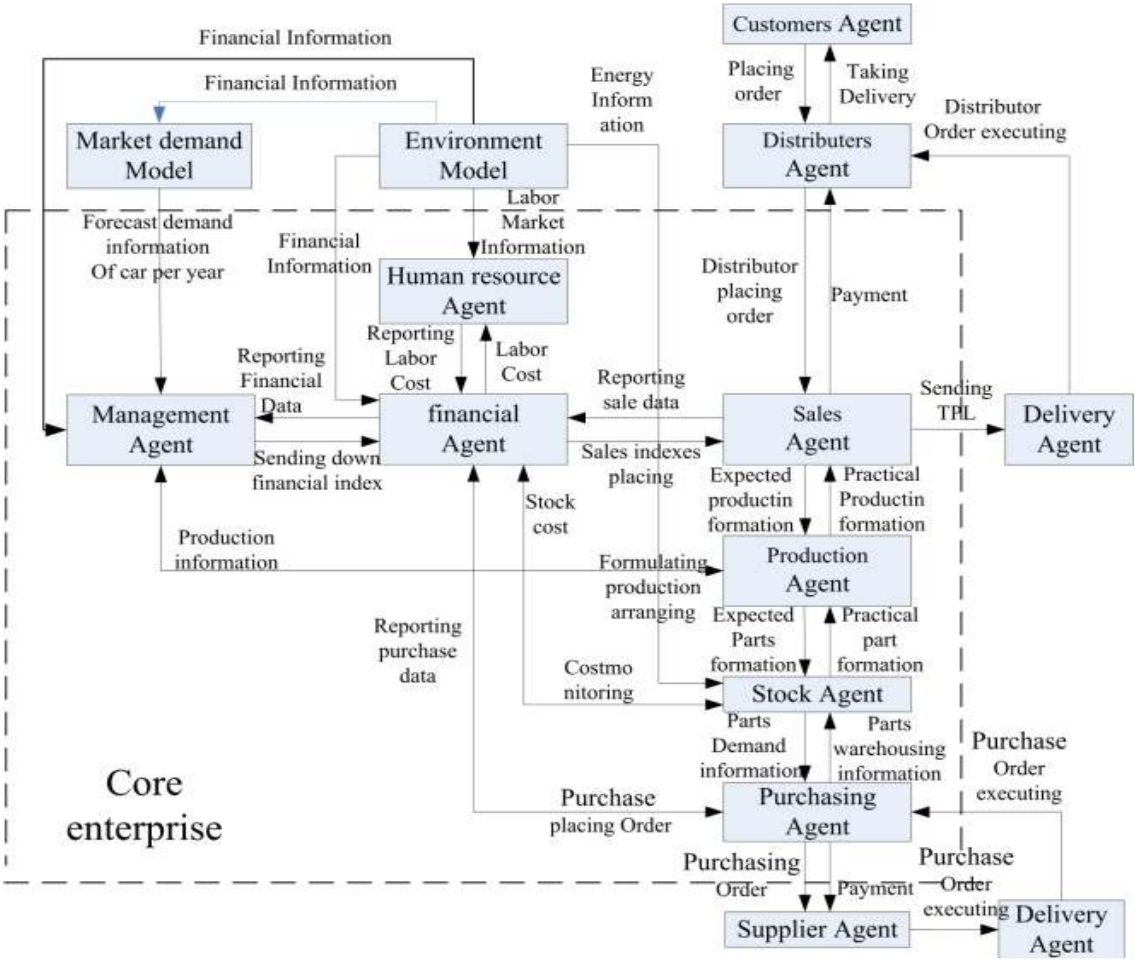


Fig. 2: Frame diagram of detailed model

deciding the operation of the entire supply chain network. This study focuses on product flow, information flow, capital flow in various kinds of business and related strategies; meanwhile, we fully consider the supply chain environment related to these various kinds of business, such as the financial environment, labor market environment, energy environment and market demand environment. We assume that the core enterprise take the strategy, Assembly to Order (ATO), it only has parts inventory, not whole car inventory. And we assume that each core enterprise has detailed model as shown in Fig. 2.

The business operation process of supply chain network is roughly shown as follows. Customers visit distributors to check the performance and price of products, if they meet their needs, customers make their orders; according the inventory, orders, sales strategy, distributors meet the customers' orders, or place their own orders to sales department of car manufacturers; after receiving distributors' orders, according to sales strategy of car manufacturers, the sales department transfer the car orders to production department and work out a backlog of orders of current period and forecast orders of next period; after receiving orders, according to capacity and quantities of production, production department sends parts demand instruction to stock department; after receiving the information, according to its inventory strategy, stock department sends parts to production department; after receiving parts, production department organizes manufacturing and send cars to sales department; after receiving cars, according to its distribution strategy, the sales department send cars to distributors in sequence of their orders; after receiving cars, distributors deliver them to customers according to orders and send the rest to storage; according to the demand of production department and ordering strategy of stock department, purchasing department sends orders to parts suppliers; after receiving orders from car manufacturers, suppliers organize delivery with logistics service providers according to its inventory and if the supplier has business with two car manufacturers at the same time, then its delivery to different car manufacturers is arranged according to its distribution strategy; after purchasing department receiving parts, it transmits those to inventory department; financial department

settles accounts with other departments at regular intervals; human resource department arrange increase or decrease of staff according to the demand of other departments; management department summarizes the operation of various departments, views profits and modifies management strategy. Car manufacturers evaluate suppliers and distributors regularly and choose more suitable ones.

SIMULATION MODEL OF AUTOMOTIVE SUPPLY CHAIN NETWORK

Anylogic software and selecting of modeling methods: Anylogic is a software developed by Technologies (Year) basing on Java language, consisting of the three most commonly used modeling methods: SD, DES and ABM. According to the functions of Anylogic and the characteristics of automotive supply chain network node enterprises and various interior departments of core enterprises, we select appropriate modeling methods, for example, each node enterprise and various interior departments of core enterprises use ABM, strategy layer of enterprises and tactics layer of departments use SD, logistics and production of operation layer use DES.

Simulation model of automotive supply chain network basing on anylogic: Before establishing a simulation model, we have to offer a supply chain network framework to the model. First, we create a model "Supply Chain Network" in project bar of Anylogic. Then we build customer, distributor, sales,

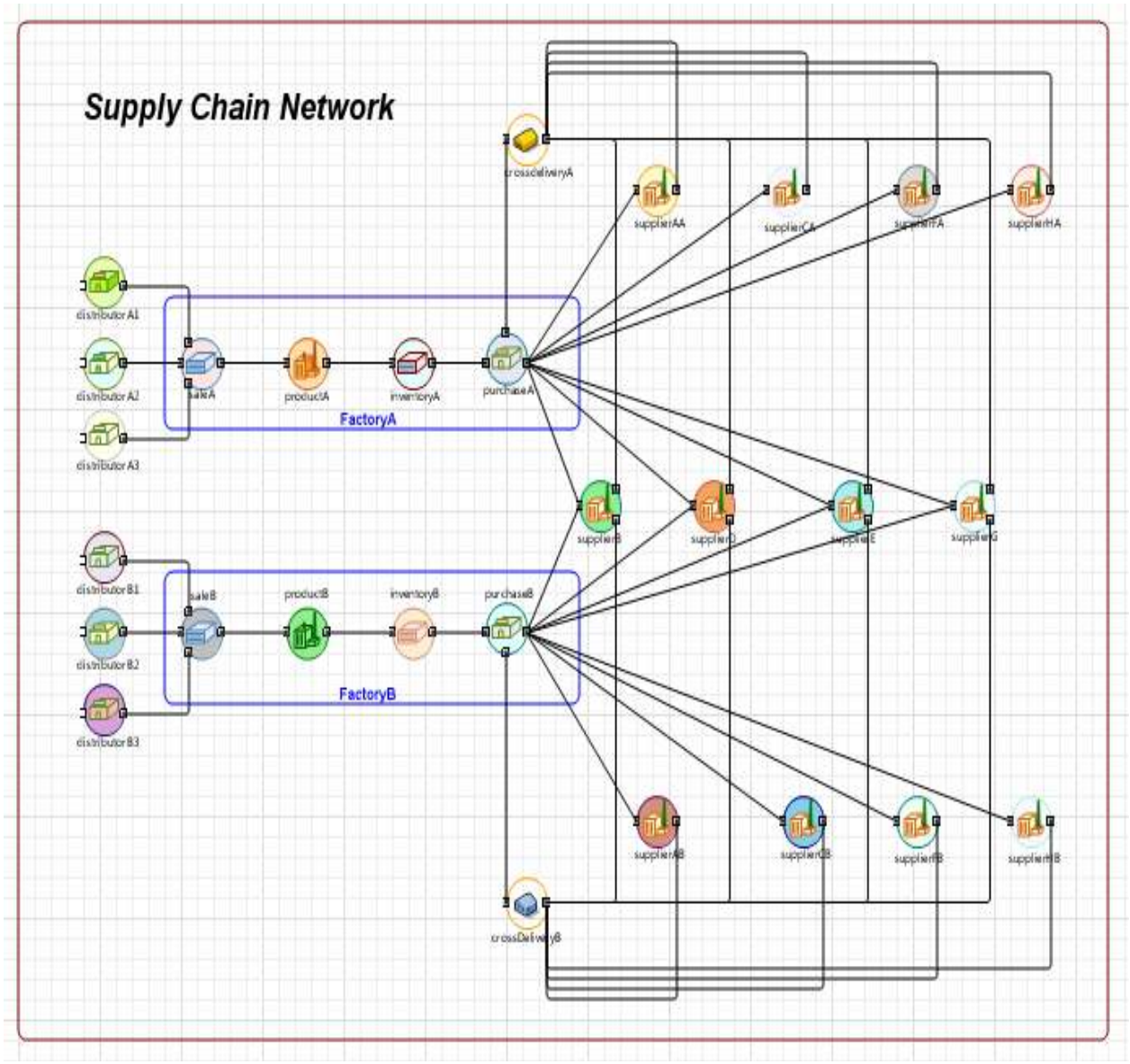


Fig. 3: Anylogic based model framework of supply chain netwok

production, inventory, purchasing, supplier, distribution, environmental and other active object class and select "agent" option in the "conventional" property bar of active object bar. Thus, these active object class turns into agents, which have characteristics of agent. We create icon and add ports for all agents, then drag all agents to top activity object class Main and use connecter to link agents having information exchange with others. Framework of automotive supply chain network simulation model is shown as Fig. 3.

In this study, the model mainly includes two kinds of information, flow of goods and materials and information flow, the express of these two kinds of information needs establishment of objects with elements that transmits and operates data. Each agent has two or three ports and ports connected with others can complete information transmission through connector. Thus, we create three java classes in the model: Demand, Order and Shipment. Demand is the demand of customer; order and shipment are information between distributors and sales department of core enterprise, various interior departments of core enterprise and purchasing department of core enterprise and suppliers.

A illustration of automotive supply chain network model: Owing to space, here we take production agent as example to introduce the specific simulation model.

Here is the operating process of production agent. At the beginning of each day, production department of core enterprise first check whether there are uncompleted orders the day before and get intraday orders from sales department. If there are uncompleted orders, production department have to continue production and take parts that orders that day need from stock to buffer for use, in principle of FIFO (first in, first out) to meet orders. When production department finishes a batch of products, it will send them to the temporary storage buffer of sales department and sales department will arrange shipment according to distribution strategy. At the end of a day's production, the uncompleted orders will be set into backlog. Production agent just runs in this cycle. The flow chart of its operation layer is shown as Fig. 4.

Production agent gets product demand from sales agent, gets parts from stock department and arranges its production according to its producing strategy, then sends cars to sales department. After that production department predicts output of next stage according to output of this stage and adjusts its production rate. The SD model of production agent created in Anylogic is shown as Fig. 5.

The inputs of model are Sale Order Rate, Expected WIP, Parts Provide Rate, they are order demand from sales agent, WIP expected and parts supply rate fromstock department, respectively. The outputs are Expected Production Rate and Finished Production,

Fig. 4: Flow chart of production agent

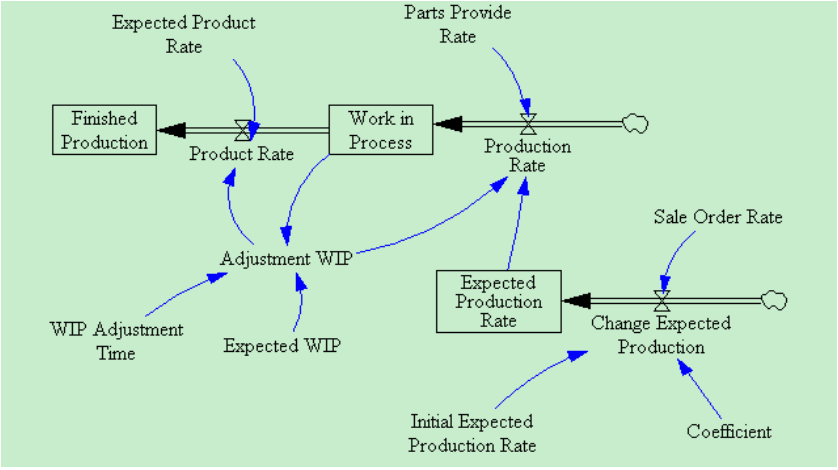


Fig. 5: The SD model of production agent

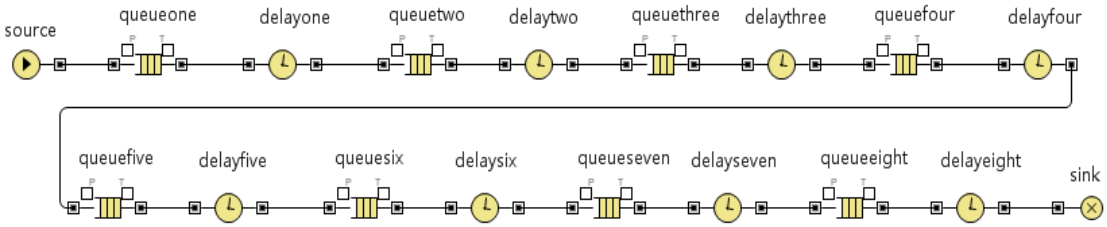
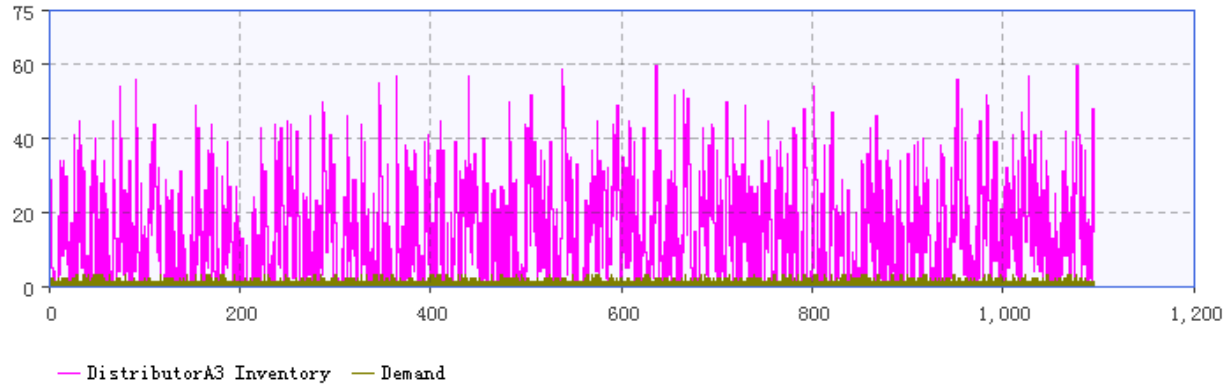
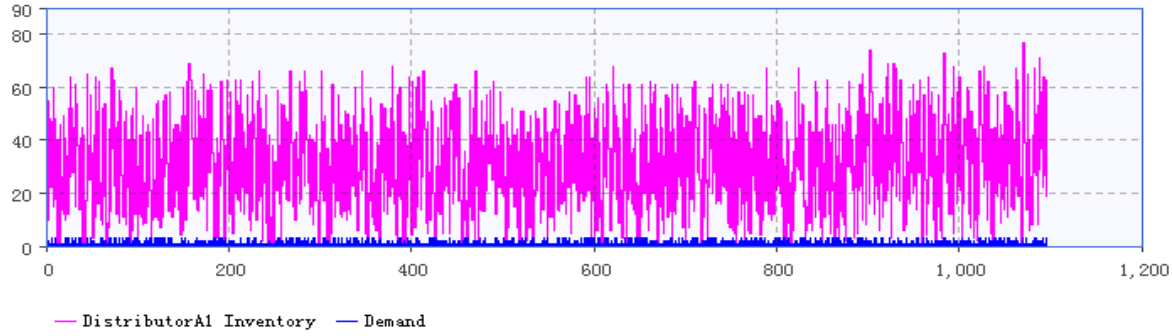


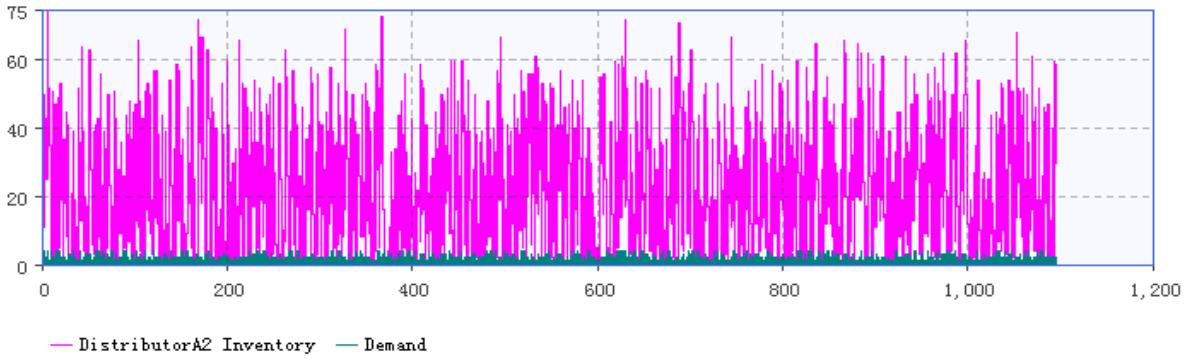
Fig. 6: Assembling process of production agent



(a) Ordering strategy is (40, 75)



(b) Ordering strategy is (40, 80)



(c) Ordering strategy is (40, 90)

Fig. 7: Distributors' inventory under different ordering strategy

they are predicted production of next stage and storage rate of sales department's temporary inventory. The production starts when production agent receives parts from stock agent. Though automotive assembly is a continuous operation on production lines, but it is a discrete process in detail, so we use DES to simulate automotive assembly. Figure 6 is model of automotive assembly's process using standard library of Anylogic. In Fig. 6, source is the spring of assembly process and we set speed and quantity of cars in line in its property bar. Assume that a car assembly line has eight work stations for the eight kind of parts' assembling. Queue is the quantity of cars waiting for assembly in this station and delay is assembly time. The capacity and time of each queue and delay can be adjusted according to actual situation.

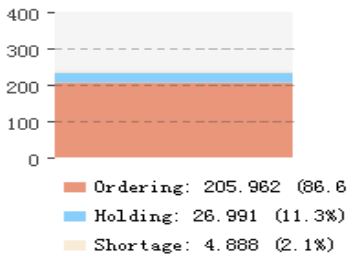
According to the description of production agent as Fig. 4, we establish a function checkOrders to check whether there are orders and send parts demand instruction to stock agent. Production agent receives parts from stock agent through the attribute "when accept" of production agent's stock port. When orders are more than the production capacity of production department, production agent asks stock agent for parts in terms of the production capacity and the rest are set as backlog for production next day. The function checkOrders is assumed to be performed at eight o'clock every morning.

ANALYSIS OF AUTOMOTIVE SUPPLY CHAIN NETWORK MODEL SIMULATION

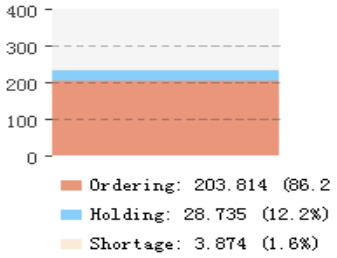
Owing to space, we only analyze inventory and cost of distributors and customers' satisfaction. Figure 7 is time series of distributors under different maximum and minimum (S, s) ordering strategy. Figure 8 is stacking chart of distributors' inventory cost, where Ordering, Holding and Shortage represent the average of ordering cost, holding cost and shortage cost respectively.

Comparing Fig. 7 and 8, Fig. 7a has the minimum inventory range, but its inventory shortage happens for the most times; Fig. 7c has the maximum inventory range, but it is most impossible to have inventory shortage. This illuminates that when enterprises reduce order quantity to cut down inventory cost, it is most possible for the inventory shortage. Figure 8a has the highest ordering cost and shortage cost, meanwhile the lowest holding cost; Fig. 8c has the lowest ordering cost and shortage cost, but its holding cost is the highest.

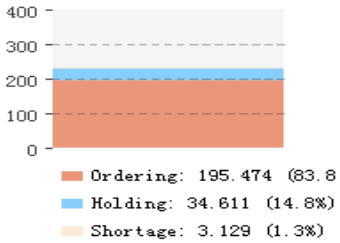
This shows that after reducing the maximum inventory, order quantity of each time and inventory holding cost reduce, but total inventory cost increases because the order number increases causing the increase of ordering cost. The simulation results are consistent with the actual situation, proving that the model is reasonable and effective.



(a) Ordering strategy is (40, 75)



(b) Ordering strategy is (40, 80)

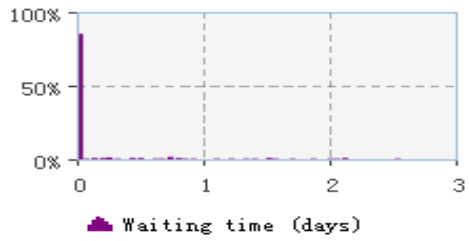


(c) Ordering strategy is (40, 90)

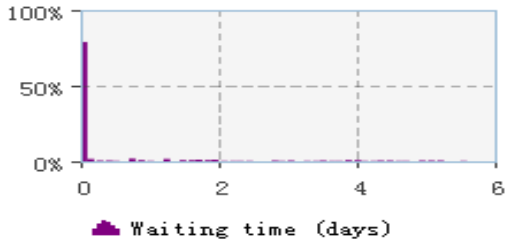
Fig. 8: Distributors' inventory cost under different ordering strategy

Customer satisfaction is a very important indicator in supply chain management, which can be measured through customer waiting time. The customer waiting time is time from ordering to receive cars. The longer customers wait, the lower customer satisfaction becomes and vice versa.

Figure 9 is time plot of customer waiting time. In Fig. 9a, the delivery delay of sales agent and supplier are (1.5, 2), (2.5, 3), respectively and in Fig. 9b, they are (2, 2.5), (3, 3.5). We can clearly see that, in Fig. 9a the days that waiting time is 0 take up about 85 percent of the total number and in Fig. 9b it is about 70 percent. The shorter the waiting time is, the higher customer satisfaction becomes. Therefore, when delivery time is shorted, waiting time will be shorted, so customer satisfaction will be higher. This is consistent with the actual situation, proving that the model is reasonable and effective once again.



(a) Transportation delay are (1.5, 2), (2.5, 3)



(b) Transportation delay are (2, 2.5), (3, 3.5)

Fig. 9: Customer waiting time after increase the transportation delay

CONCLUSION

In this study, considering the structure and operation features of automotive supply chain network, we use a method combining SD, DES and ABM to establish a simulation model of automotive supply chain network basing on Anylogic and give examples and some simulation results. The analysis of simulation results shows that the automotive supply chain network simulation model is reasonable and effective. Further research will focus on perfecting the model.

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