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Research on Demand-driven Leagile Supply Chain Operation Model: a Simulation Based on AnyLogic in System Engineering

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Abstract

With the development of economy and information technology, the competition between enterprises has already entered the period of "competition between supply chains". It is more and more impossible to satisfy the customer personalized and diversified demands with reducing the total cost. Using the system engineering concept, the system dynamics models of traditional supply chain and leagile supply chain are built in this paper. Through comparing the simulation results of these two kinds of supply chain, we show the advantages of leagile supply chain. The results hold that shorten the length of supply chain, share the information, cooperation and production delay can effectively weaken the bullwhip effect. By running the simulation model, we can determine the relationship among effect factors of leagile supply chain and observe the visual dynamic changes of supply chain. Thus, this result can provide decision supports to enterprises' leagile supply chain.

Keywords: Leagile supply chain; System engineering; Bullwhip effect; System dynamics; AnyLogic

1. Introduction

With the development of economy and information technology, more intense competition in market has emerged. The product life cycle continues to be shortened, and end customers prefer the personalized and diversified products. Therefore, these make it hard for the traditional supply chains to respond the uncertainty market. It has become the common understanding for most enterprises to consider the customer demands as the beginning of produce [1]. The research on supply chain has focused on the orders of end customers instead of products. The supply chain is not a stable structure, and the members enter or exit will affect the stability of supply chain. The dynamic characteristic of supply chain affects its efficiency of management, and the supply chain is a complex system. Compared with other analysis tools, simulation can be used in the dynamic supply chain system. Simulation is easy to construct a model, and its model based on system dynamics is intuitive and easy to understand. Simulation can be used in the actual supply chain with more persuasive and intuitive [2]. Researching on the simulation of supply chain

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and supply network in domestic and international, many scholars used Petri nets, multi-agent, system dynamics and other methods. And they usually use the simulation software, such as Swarm, Vensim, Witness, Repast, etc [3]. This paper adopts system dynamics based on AnyLogic, and builds the model of traditional supply chain and a relatively new concept -- leagile supply chain. Lean production was usually connected with reducing or eliminating all waste; Agile manufacturing usually strived the quick response to uncertainty market [4]. Combined these two kinds of supply chain and according to the general characteristics of leagile supply chain, a general structure model of leagile supply chain was proposed in this paper.

Using system dynamics and AnyLogic simulation tool, this paper compares the simulation results of these two kinds of supply chain, and discusses the advantages and applicability of leagile supply chain.

2. Traditional Supply Chain Driven by Customer Demand

2.1. Summary of traditional supply chain driven by customer demand

In traditional supply chain enterprises make sales forecasts based on a source of demand information from downstream enterprise. And then, according to inventory condition, each node in the supply chain makes the inventory decisions, order decisions and production decisions independently. However, with the economic globalization and the rapid development of information technology, the marketing competition is getting intense. The customer demand manifests the characteristic of personalized and diversified, and product life cycle continues to be shortened. Therefore, the manufacturing companies have to respond quickly to the changes in uncertain market demand. Keeping the low cost, quick response to the customer demand and to meet the demand of customers are key factors to determine the success or failure of an enterprise business. But in the supply chain management driven by customer demands, the traditional supply chain has become very slow to respond to the changes in market and control of the product cost.

The shortages of traditional supply chain mainly are shown in the following areas:

(1)Information cannot be shared in the supply chain

For the traditional supply chain, each enterprise makes production orders based on the orders from the direct downstream enterprise in the supply chain. According to their own inventory condition, each node enterprise in the supply chain makes the inventory decisions and order decisions independently. This kind of operation mode gradually magnifies the fluctuation of orders from downstream to upstream in the supply chain. Demand information is not authenticity, resulting in an increase in inventory of each enterprise in the supply chain.

(2)The length of supply chain

The general structure of traditional supply chain mainly includes five parts: Raw materials suppliers—Manufactures—Distributors—Retailers—End customers. Many scholars think that the length of supply chain is one of the important factors of the bullwhip effect. When the length of supply chain extended, the demand information is magnified repeatedly and released significantly.

(3) Demand prediction

Traditional supply chain is facing with multilevel demand prediction, so the information of orders and inventory level that companies get will deviate from the real needs. And this deviation will continue to be magnified from downstream to upstream in the supply chain [5].

2.2. Simulation of Traditional Supply Chain Driven by Customer Demand

This paper based on the operation mechanism of traditional supply chain, simulate the process of five-stage supply chain using the Economic Order Quantities (EOQ) model. Retailer's inventory is decided by the sales rate and distributor delivery rate. Distributor's inventory is decided by distributor delivery rate

and manufacturer delivery rate. And Manufacturer's inventory is decided by manufacturer delivery rate and production rate. For the raw materials suppliers, manufacturers, distributors and retailers in the supply chain, the ordering strategy and production strategy are the same, as shown in Fig.1. Take the manufacturer as an example. In order to achieve the lowest cost of inventory, the inventory-order strategy can be expressed as

$$Q^* = \sqrt{\frac{2C_D D}{c}} \quad (1)$$

Here, is ordering cost, is inventory cost, and D is demand.

The demand information is not shared in the supply chain, so each enterprise gets the demand prediction directly from its downstream enterprise. This simulation used the distributor's six-month moving average of the orders to predict the demand. When getting the expected inventory, the manufacturer submits orders to the upstream suppliers. And then, the upstream suppliers ship the goods to the manufacturer. This paper assumes the upstream suppliers have the supply capacity, production delay and logistics delay. According to that, the system dynamics model is proposed in this paper, its structure figure is shown in Fig.2:

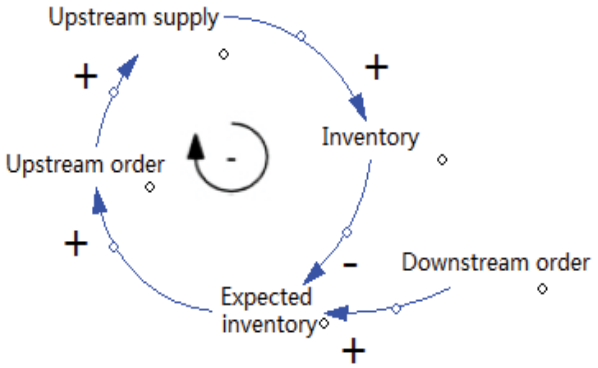

Fig.1. Influence diagram of manufacturer (Vensim)

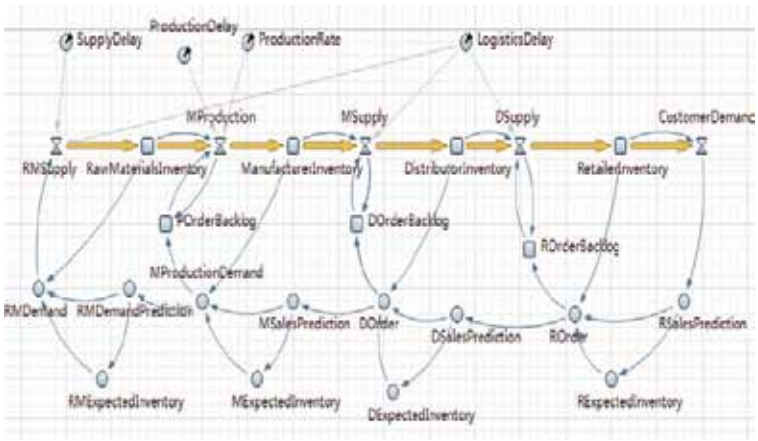

Fig.2. System dynamics model of traditional supply chain in AnyLogic

The dynamic demand in market is presented as the stochastic volatility of end customer demand in this model. Random function: Demand Rate=uniform_discr(1000,3000). The changes of demand rate are shown in Fig.3:

Fig.3. Customer demand

The changes of each enterprise's inventory in the supply chain are shown in Fig.4.(a). And the changes of each enterprise's orders are shown in Fig.4.(b).

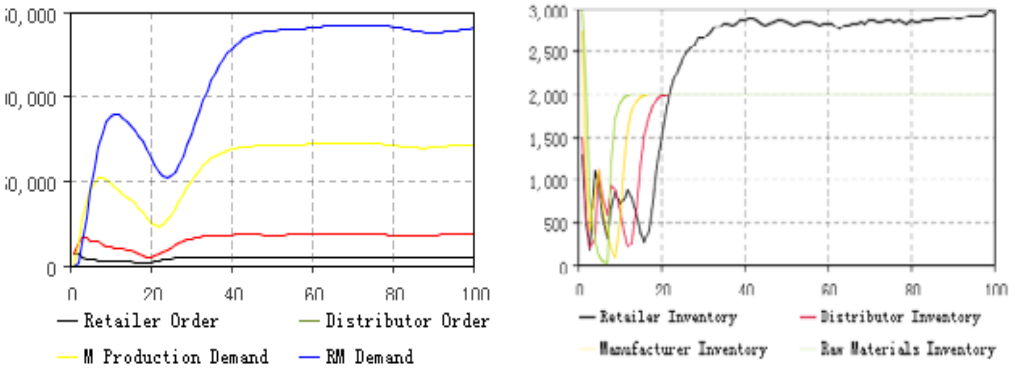

Fig.4. (a) Orders of each enterprise; (b) Inventory of each enterprise

The results of this simulation obviously show that demand information is magnified in traditional supply chain, namely "Bullwhip effect". Fig.4.(a) illustrates the changes of demand orders from the downstream to upstream in the supply chain. We can find that the demand orders are magnified in the upstream enterprise. Fig.4.(b) illustrates the changes of the inventory from downstream to upstream in the supply chain. At the beginning, the inventory of each enterprise changes violently. Because demand information is not shared in the supply chain, each node makes decisions depend on the orders from the downstream enterprise, and the orders have delays between the downstream enterprise and upstream enterprise, this forms the forecast deviation. The diversified customer demands in this model show only changes of demand quantity, if consider the changes of the product itself, the overstock of inventory cannot continue to be sold. And this will make more inventory costs.

3. Leagile Supply Chain Driven by Customer Demand

3.1. Summary of leagile supply chain

"Leagile" is a combination of "lean" and "agile" approaches combined at the decoupling point for optimal supply chain management [6]. The purpose of the lean concept, inspired by the just in time (JIT)

approach from Japanese Toyota production management [7], is to reduce all kinds of waste (inventory, unutilized capacity, bad quality, obsolete, etc.) in order to minimize cost. The purpose of the agile concept is to quick response to a volatile market request. In order to be agile, the supply chain needs to be flexible, and can respond to end customer demands.

Lean supply chain can't quick respond to end customer personalized demands, thus, leagile supply chain which combined the advantages of lean production and agile manufacturing has been proposed in manufacturing industry. Naylor et al considered that leagile strategy combines lean strategy with agile strategy and realize the quick response to the changeable demand of downstream enterprises and batch process of upstream enterprises by fixing decoupling position in supply chain [8]. Mason-Jones et al proposed a leagile model where the lean and agile systems operate at different points in a manufacturing supply chain. A key element of this model is a "decoupling point", which separates the lean processes from the agile processes in the supply chain. The lean processes are on the upstream side of the decoupling point, and the agile processes are on the downstream side. The decoupling point also acts as a strategic point for buffer stock, and its position changes depending on the variability in demand and product mix [9]. R.Stratton and R.D.H Warburton considered it is easy to produce deviations when the lean system makes forecast to the market demands, therefore, they proposed the combination of lean supply chain and agile supply chain to adjust to the uncertainty of market [10].

As the analysis of last chapter, we conclude that traditional supply chain is difficult to solve the bullwhip effect, high cost of inventory, and slow response to market. So this paper designs leagile supply chain to solve these problems. Leagile supply chain has many forms, and this paper only discusses the simulation of its general characteristics. Compared with traditional supply chain, leagile supply chain has the following advantages:

(1) Sharing Information

With the development of electronic commerce and information systems, the core manufacturer realizes sharing information in the stages of supplier management, product design and development, materials procurement, production, and sales. Sharing information is the basis of implementation in the leagile supply chain management. Through sharing information in the supply chain, it can reduce the risks caused by information asymmetry and incomplete, and it can strength the cooperation between enterprises and improve the ability to response the market [11]. The enterprise in leagile supply chain is no longer managing inventory based on the forecast of direct demand, and therefore it can reduce inventory effectively.

(2) Shorten the Length of Supply Chain

Leagile supply chain starts its production based on the customer demand, and its procurement, production and sales are all around the orders of end customers. So this kind of supply chain adopts direct selling mode. The direct selling mode can ignore the distributors and retailers, and directly face to the end customers. Therefore, leagile supply chain will get the advantages of low cost and high efficiency. This mode is the core competence of leagile supply chain. This paper ignores the distributors and retailers in the model of leagile supply chain.

(3) Order Guidance

The leagile supply chain starts its production based on the orders of end customers. The same or similar functional units are separated from the production process of leagile supply chain, and used lean production by the unified or standard method. And then, based on the orders of end customers, the core manufacturer produces or assembles the standardized module and specialized module as new products. This kind of approach can reduce the complexity of production, improve the efficiency of production, shorten the lead time, and satisfy the needs of end customers greatly.

(4) Close Cooperation between Enterprises

Leagile supply chain requires suppliers or the warehouses of suppliers to locate around the core manufacturer to shorten the transportation time of logistics. Through evaluating the quality, service, cost,

supply capacity and technological innovation, the core manufacturer selects some certain suppliers to keep close cooperation.

3.2. Simulation of leagile supply chain driven by customer demand

3.2.1. Structural model of leagile supply chain

With the rapid replacement of products, personalized demand of end customers, and instability of market, this paper constructed a generalized structural model of leagile supply chain based on its main characteristics, and divided the whole supply chain into "pull" and "push" supply chains [12]. Moreover, this paper adopts modularization of productions, customization and postponement strategy. The structural model of leagile supply chain is shown in Fig.5:

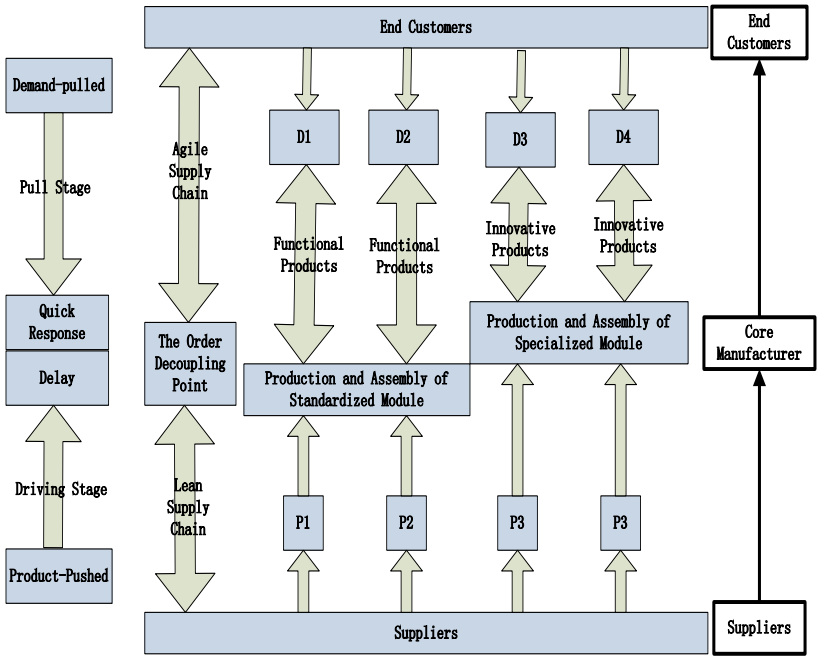

Fig.5. Structural model of leagile supply chain

According to Fig.5, the supply chain is driven by orders from end customers, and the production process of customized and diversified products can be divided into two processes: standardized module and specialized module. Bounding by the order decoupling point, the supply chain can be divided into lean supply chain phase and agile supply chain phase. The downstream of the order decoupling point is the phase of demand-pulled, core manufacturer makes a production plan according to orders of end customers, at the same time sends the order information to every raw-materials and parts suppliers with no delay (or relatively low delay). There are two kinds of suppliers: standardized module supplier and specialized module supplier, the former one supply high-standardized parts that commonly used in all production with no differences, so standardized module supplier could adopt lean production to achieve economies of scale with low cost and waste. And the specialized module supplier could adopt agile manufacturing according to different orders of end customers, respond market rapidly to achieve economies of scope. Standardized module and specialized module suppliers manufacture their own part simultaneously and supply it to core manufacturer to assemble or further manufacture.

3.2.2. Simulation of leagile supply chain driven by customer demand

Based on the structural model above, in this model the supply chain consists of 4 main nodes, that is, standardized module supplier, specialized module supplier, core manufacturer and end customer, with no distributor and retailer. In this supply chain all sections share information, in this model that can be expressed as: customer demand = orders of standardized module = orders of specialized module. The system dynamics flowchart is shown in Fig.6.

Since the specialized module is produced according to orders, so there would have delay existed in production. Specialized module supplier has its own warehouse, it is close to core manufacturer geographically or build public warehouse to make the supply more rapid and reduce logistics cost. According to orders of core manufacturer, the supply of specialized module = delay(min(order of specialized module, production rate), production delay). And in every unit of time the change of specialized module inventory = the supply of specialized module – supply rate.

Standardized module is commonly used in all products with no differences or very similar, using lean production, relative to standardized module the delay is low. Generally the supplier needs to hold a certain amount of inventory and needs to predict the future supply situation, in our SD model the prediction is based on the moving average of last 3 months. The expected inventory = demand prediction * expected duration of inventory. In every unit of time in SD simulation the change of standardized module inventory = delay(min (production demand, production rate), production delay)– supply rate. In this model, it is assumed that a finished product is assembled or produced by the two kinds of module according to the proportion of 1:1.

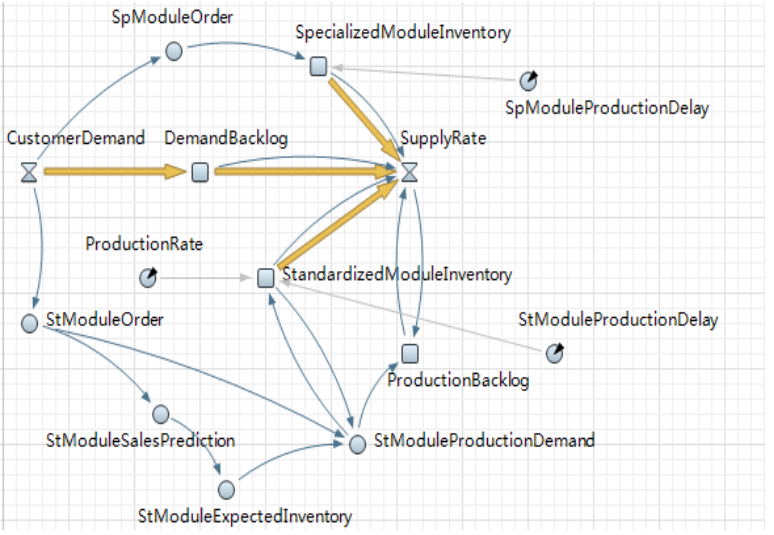

Fig.6.System dynamics model of leagile supply chain in AnyLogic

3.2.3. Simulation results and analysis

The inventory of two modules is shown in Fig.7.(a) and the status of production demands is shown in Fig. 7.(b). The production demand of specialized module is determined by orders from end customers, that is, the demand rate (Fig.3). Because of the production and supply delay of both standardized and specialized module supplier (generally the delay of specialized module supply is higher than standardized module supply), at the beginning the specialized module supplier has demand but could not meet the order of core manufacturer immediately. Because of production delay, core manufacturer could not assemble more finished products, so the demand and supply of standardized module is low either. Accordingly the demand of standardized module decreased in a short time and soon increases and stabilized when specialized module production tends to be steady and matches the standardized module. The fluctuation of standardized module production demand is relatively low and the inventory soon stabilized. Compared with traditional supply chain, the bullwhip effect of leagile supply chain is not so obvious.

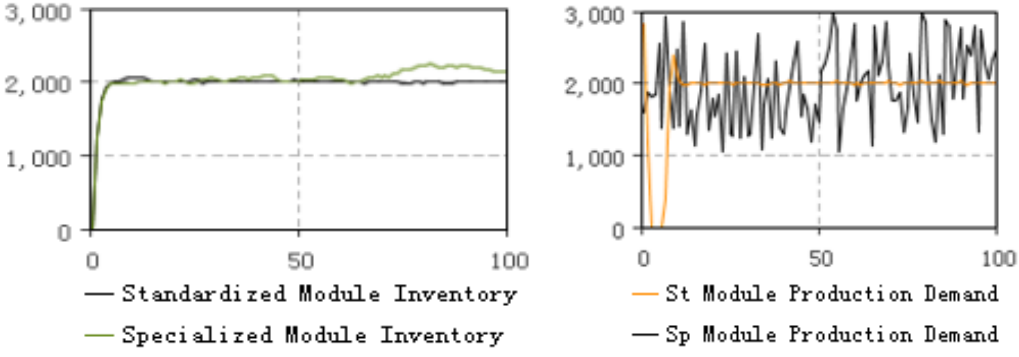

Fig.7. (a) Inventory status; (b) Production demand status

The productivity of core manufacturer depends on orders of demand. So standardized module and specialized module, either of the two modules is in scarcity would cause diminution of the production of

finished product, then the supply of another module supplier seems excessive compared with the supply of finished product, accordingly causing inventory backlog. In all inadequate supply capacity of either side would lead to inventory backlog of the other side.

Leagile supply chain uses postponement strategy, and the production delay of specialized module is higher than standardized one. According to the analysis above, the supplier of standardized module adopts the strategy of mass production and manages inventory based on prediction And for different order demands of finished product, its product is same and interchangeable, so when the supply of specialized module tends towards stability, the inventory of standardized module maintains at a certain level, and it is not so sensitive to demand change compared with specialized module. So the supply of standardized module can relatively easily meet the demands, or can be considered that the production of standardized module is constant and common compared with specialized module. In order to make-to-order and match the standardized module, the response speed and supply capacity of specialized module are quite significant for the whole supply chain. The production of specialized module is based on orders, if its response and supply capacity were not sufficient, in our model for specialized module supplier we increase the delay to 3 times step and decrease the production rate to 1500 per time step, the inventory and production demand would change into the status shown in Fig.8.(a) and Fig.8.(b) respectively. According to our assumption that a finished product is assembled or produced by the two kinds of modules according to the proportion of 1:1, since the production of specialized module requires higher agility, if the production and supply capacity were not sufficient, it would cause fluctuation of the inventory and demand of whole supply chain. So from the results of simulation, the operation of a leagile supply chain is good or bad, to a great extent depends on the response speed of specialized module, which may become a “bottleneck” in the whole manufacturing process.

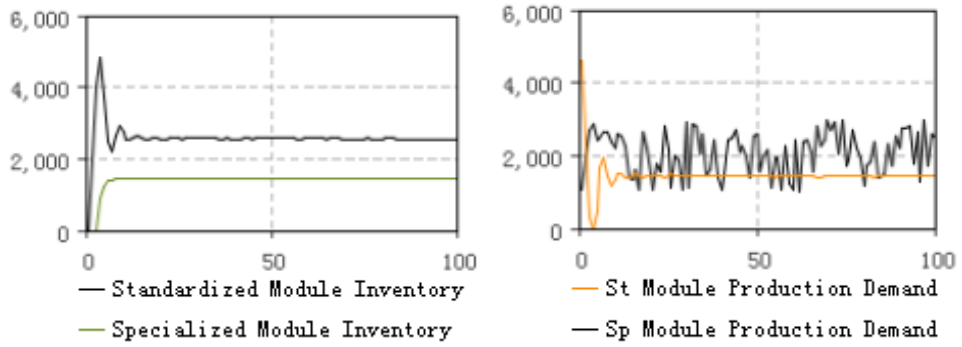

Fig.8. (a) Inventory status with insufficient capacity; (b) Production demand status with insufficient capacity

4. Conclusion and Discussion

Through comparing the simulation and results analysis of traditional supply chain and leagile supply chain, the advantages of leagile supply chain are mainly shown in the following points:

(1) Inventory. The core manufacturer of leagile supply chain starts its productions based on orders from customers, so generally it has no or low inventory of raw material or subassembly that can reduce its inventory cost. Furthermore, core manufacturer can reduce the supply risk by establishing close long-term partnership with suppliers in supply chain.

(2) Quick response to market demand. A leagile supply chain adopts modular manufacturing and postponement production strategies to produce based on personalized and diversified needs of end customers. As a result it can achieve much more customer satisfaction.

(3) Shorten the Length of Supply Chain. Generally in leagile supply chain the adoption of Third-party logistics can avoid the defects of diseconomy and high cost of traditional first party logistics. Full use of

the advantages of third-party logistics and distribution systems can reduce costs, shorten lead time to the end customers. Moreover, since the length of supply chain is one of the main factors that affects bullwhip effect, shorten the length of supply chain can effectively reduce the amplification of demand.

In conclusion, leagile supply chain is a new conception that proposed in the context of diversified and personalized customer demands, it can quickly response fast changing demands, and modularize all kinds of personalized products as much as possible. So that it can still have the advantages of low cost of mass production. This paper proposed the general structural model of leagile supply chain. At present, the Mass Customization mode adopted by Dell and BMW is also a type of leagile supply chain, with the ever growing personalized demand and the progress of production capacity, there would appear many types of leagile supply chain, but still have the characteristics analyzed above, their products can be seen as an assembly of a variety of standardized modules and specialized modules. Leagile supply chain can meet the needs of current and future production and market, and it has greater prospects for development and research.

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