Research on Bullwhip Effect Management in Supply Chain Based on System Dynamics

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Abstract. Since the development of the Beer games in the last century, beer games and the bullwhip effect they reflect have attracted extensive attention and discussion from scholars. This paper will explore the causes of bullwhip effect, includes oscillation, amplification effect, and phase lag in supply chain management. With the help of system dynamics, the beer game model is constructed and the bullwhip effect is visually observed. From the perspective of supply chain structure and management, this paper makes a comparative analysis of the inventory of supply chain management strategies, thus finding the direction of supply chain management optimization-accelerating flow, and helping supply chain managers and practitioners to developmental models.

Keywords. Bullwhip effect, Supply chain, System dynamics.

1. Introduction
The Beer game was invented by Professor Jay Forrester, the creator of system dynamics, in the late 1950s. The Beer game was used to help supply chain managers and practitioners to better understand the bullwhip effect in supply chain management, which is oscillation, amplification effect, and phase lag.

Since its appearance, the game has been widely spread around the world. Thousands of people have played the game, including students majoring in logistics management, enterprise buyers, managers, and government officials. Although the game is very simple and most of the players have received professional training, their performance is often poor and very similar: as the market demand starts to step up, starting with retailers, inventories in all links of the supply chain begin to drop rapidly and are out of stock. After that, orders in all links increase. As the goods cannot be delivered in time, the further shortage leads to an increase in orders. With the improvement of supply capacity, inventories in all sectors began to grow and exceed the expected inventories. After that, orders were cut in all sectors, and inventories slowly decreased. In other words, the whole supply chain was short of supply in the medium term and seriously overstocked in the later period.

Bullwhip effect widely exists in supply chain management, especially in high-speed growth industries, such as the electronics industry. Besides, most commercial products have a business cycle, that is, the alternation of off-season and peak season, the Bullwhip effect is strong during peak season. Therefore, the research on the bullwhip effect can effectively improve the performance of supply chain management and help people understand the problems of supply chain management, instead of simply attributing it to human errors (psychologists call it "basic attribution errors").

2. The Mechanism of the Bullwhip Effect
Oscillations, amplification effects, and phase lags are widespread in the supply chain. Generally speaking, the amplitude of oscillation is amplified step by step from the downstream to the upstream of
the supply chain, and each upstream in the supply chain tends to lag behind the downstream.

2.1. Oscillation
The high similarity between the Beer game process and the result shows that it is the internal structure of the supply chain that causes the bullwhip effect. A large number of studies have shown that oscillation occurs in a negative feedback loop with time delay, as shown in figure 1.

![Figure 1](image1.png)

**Figure 1.** Structure and behavior of the oscillation system [1].

The system state takes corrective actions towards the target. Due to the existence of time delay, the system still takes corrective actions after reaching the target, resulting in over-adjustment of the system and further triggering corrective actions in the opposite direction. The types of oscillation are mainly damped oscillation, finite cycle, and chaos. An important characteristic of oscillation is attenuation. Many systems exhibit damped oscillation and reach local stability after a while. A typical ringing is shown in figure 2.

![Figure 2](image2.png)

**Figure 2.** Changes of retailer inventory in beer game.

Excessive corrective actions lead to system oscillation. Therefore, oscillation can be avoided, while the amplification effect and phase lag are inevitable.

2.2. Amplification Effect
The stock management structure in system dynamics provides a convenient tool for us to identify the amplification effect. Assuming that an enterprise has 100 sets of production equipment, to meet future order needs, the company decided to expand its production capacity to 130 sets. The average service life of this equipment is 10 years. The stock adjustment time is set at 3 years. The formula applied is as follows:

- Stock Adjustments = Expected Stock - Stock.
- Stock Adjustment Rate = Stock Adjustment Amount/Stock Adjustment Time.
- Loss Rate = Stock/Life Cycle.
- Acquisition Rate = Stock Adjustment Rate + Loss Rate. The change of the system is shown in figure 3.
The adjustment process of the stock has resulted in a clear amplification effect. The expected stock increase by 30% leads to a 100% increase of the acquisition rate. Therefore, the amplification ratio (the ratio of the maximum rate of change of the input to the maximum rate of change of the output) is 100%/30%=3.33. By analogy, the amplification effect is transmitted step by step along the supply chain. Secondly, the amplification effect is temporary. The amplification effect can be well explained by the stock flow. Due to the delay in production and transportation, the enlargement of demand will inevitably lead to the reduction of inventory. To increase inventory, the order quantity must be greater than the delivery quantity, which will produce the enlargement effect, which means the system structure determines the necessity of the enlargement effect. Another important reason for the amplification effect is the "competitive game" (Nash) or "prisoner's dilemma" (Albert Tucker) of downstream enterprises' orders. When there is a shortage, if we do not increase the order quantity and other downstream enterprises increase the order quantity, the other party will get more quota supply and we will lose the supply, then we must increase the order quantity to deal with the unknown shortage risk (Croson, R [1], K. Donohue [3], E. Katok, and J. Sterman 2014). Due to the lack of a correct evaluation of the system structure and dynamics, downstream enterprises can only adopt the cluster mentality, that is, all downstream enterprises adopt the same behavior to increase the order quantity, further aggravating the amplification effect. Similarly, when there is a shortage, customers may place the same orders or inquiries to multiple retailers, which makes the retailer's estimation of market demand "distorted and exaggerated". When orders are received downstream, a large number of "phantom orders" will be canceled, resulting in excess inventory and overcapacity in the upstream. Phantom orders played an important role in the overshoot and collapse of the telecom equipment supply chain, resulting in losses, layoffs, and stock price declines for Lucent, Nortel, Cisco, and JDS Uniphase (Gonçalves 2002 [5], Shi 2002 [6]).

Due to the existence of "competitive game", when there is a shortage, only when all participants in the supply chain adopt "rational" ordering can the "bullwhip effect" be reduced more effectively. This further proves the difficulty of reducing the "bullwhip effect" and the importance of supply chain partners.

2.3. Phase Lag
The Beer games can well explain the phase lag. The typical results of the beer game are shown in figure 4.

![Figure 4](image-url)
Among them, the fluctuation ranges from small to large is retailers, wholesalers, distributors, and manufacturers.

The phase lag is manifested by the shortage of supply and the surplus of inventory in each link of the supply chain. The existence of a delay in each supply chain link leads to phase lag.

The peak of the order rate lags behind the change in market demand. The adjustment of the order quantity to the inventory gap reaches the maximum value after the inventory reaches the minimum value, and the inventory reaches the minimum value when the supply quantity finally rises to be equal to the market demand. The systematic structure of the stock determines the inevitability of phase lag.

Delay is a process in which the output lags behind the input in some way. Delays include material delays and information delays. The material delay is expressed as the material is not immediately available; Information delay is manifested as the immediacy of information and time delay of decision-making.

3. Modeling and Simulation of Beer Game Based on System Dynamics

According to the structure of retailers, wholesalers, distributors, and manufacturers in beer games and the heuristic rules of anchor adjustment, we use Vensim software to build a system dynamics model. Stock flow chart and causality chart, as shown in figure 5.

Figure 5. System dynamics model of the beer game.

Note that this figure ignores the backlog of orders and supply lines.

The following parameters are set for each supply chain link: The predicted smoothing time is 1.82 weeks. Stock adjustment time: 3.85 weeks. Initial inventory: 12 boxes. Delivery delay: 3 weeks. The Expected delay: 3 weeks. The formula is as follows (Take retailers as an example, other supply chain links can be deduced by analogy):

Retailer Inventory = INTEG (Wholesaler Delivery Rate - Market Demand Rate, 12).
Retailer Sales Forecast = SMOOTH (Market Demand Rate, Retailer Forecast Smooth Time) Retailer Expected Inventory = Retailer Expected Delay * Retailer Sales Forecast.
Retailer Order = MAX (Retailer Sales Forecast + Retailer Expected Inventory / Retailer SAT - Retailer Inventory / Retailer SAT, 0).
Wholesaler Delivery Rate = DELAY3 (Retailer Order, Wholesaler Delivery Delay).
Market demand rate = IF THEN ELSE (Time > 4, 8, 4).
The simulation step length is 100 weeks.
Note that some articles use their delivery rate to forecast sales smoothly, which is unreasonable. The
The rational principle is to forecast sales smoothly according to the next order. The simulation results are shown in figure 4.

The bullwhip effect has caused serious oscillation and high cost destroyed the trust of supply chain partners, lead to the blame and suspicion of supply chain partners, and further exacerbated the bullwhip effect. When there is a shortage, the upstream supply chain has to make quota delivery to the downstream enterprises. The mental models of downstream enterprises often regard the acceptance period of upstream enterprises as exogenous, that is, open-loop thinking. Downstream enterprises believe that their demand is only a small part of the total demand of upstream enterprises, and downstream enterprises are often confident that they must give priority to meet our needs. When all downstream enterprises adopt the same behavior, upstream enterprises can only adopt the quota consignor. Once downstream enterprises learn that they have been shipped by quota, they will further increase the number of orders, which further increases the instability of the supply chain. In the actual system, the supply of upstream enterprises is greatly affected by the orders of downstream enterprises, which is a closed-loop process.

4. Supply Chain Management Strategy

The formation of the bullwhip effect can be divided into two types: man-made causes and systematic causes (Bendoly, Donohue, and Schultz 2006 [3]; Gino and Pisano 2008 [7]; Arianna Alfieri & Giulio Zotteri 2017 [8]). Man-made causes refer to how to collect information, use information, make decisions, create incentive mechanisms, and competitive games. System causes refer to delays in manufacturing and transportation, fluctuations in supply and demand, etc. Therefore, supply chain management strategies can also be divided into mental model change strategies and system change strategies.

In order to test the effectiveness of various system change strategies in supply chain management, each strategy is tested individually, and the various strategies are combined and optimized.

4.1. Consider Supply Lines

The oscillation reaction was further exacerbated by managers’ too much attention to the current inventory and ignoring supply lines (materials that have already been placed orders but have not yet been received). When the manager considers the supply line, the stock flow chart of a single link in the supply chain is shown in figure 6.

Set the expected inventory to 9 boxes. Define the Weight on the Supply Line= stock adjustment time/supply line adjustment time. When the supply line is not considered, it is assumed that the supply line adjustment time is 10000 weeks. When the supply line is fully considered, the supply line adjustment time = inventory adjustment time =3.85 weeks, which means WSL=1. The remaining parameters remain unchanged.

Assuming that the ordering rate = expected ordering rate, the difference between the supply line and
the supply line is not considered, and the simulation results are shown in figure 7.

![Figure 7](image-url)

**Figure 7.** The reaction of ordering rate and inventory caused by the supply line and supply line are not considered in the first stage of the beer game.

When the supply line is fully considered, excessive adjustment can be avoided, oscillation can be effectively eliminated, and the amplification effect of one ring of the supply chain can be reduced (the amplification ratio is reduced from 2.12 to 1.64).

Considering the supply line means that it is not sensitive to changes in the stock, so the supply line weight can be approximated by increasing the stock adjustment time. Assuming that the stock adjustment time is increased to 20 weeks, the remaining parameters remain unchanged. The simulation results are shown in figure 8.

![Figure 8](image-url)

**Figure 8.** Inventory changes of retailers, wholesalers, distributors, and manufacturers in the beer game when considering supply lines.

Among them, the inventory shortage at the beginning of the period was followed by retailers, wholesalers, distributors, and manufacturers. Note the comparison between these figures.

Consider the supply line greatly reduces the supply chain inventory. The inventory of the supply chain (the inventory of retailers, wholesalers, distributors, and manufacturers within 100 weeks) was reduced from 13411 boxes to 7904 boxes (ignoring the shortage of inventory), with a reduced rate of 41%. The magnification ratio of the manufacturer was reduced from 15.56 to 2.31.

Although ignoring the supply line caused serious oscillation, most people still ignored the supply line, and the average weight of the supply line was only 0.34 (Sterman 1989[9]). Actively responding to current inventory while completely ignoring supply lines will lead to serious instability and high costs. Moreover, even if players are informed of the distribution of demand, i.e. the customer demand changes from exogenous variable to endogenous variable, the game results are almost consistent with standard games with unknown demand (Croson and Donohue 2002[1]; 2003[10]). The progress of learning is slow. The result of the second game is still significantly lower than the best result. This shows that our mental model determines how we understand information and how we make decisions, and it is difficult for people to quickly understand the supply lines.

Economists refer to the phenomenon of ignoring supply lines as "delayed discount", that is, when people cannot get something immediately, the longer the delay, the lower the value of the thing. "The first rule of survival" makes the incentive mechanism based on short-term behavior, and it is human nature to discount "future rewards". "Future rewards" cannot effectively stimulate people's actions and make the incentive mechanism fall into short-term behavior. “Things always get worse before they get..."
better”, which has exacerbated people's neglect of long-term interests.

Behavioral economists also refer to people's behavior of increasing the order quantity when they are out of stock as “limited rationality” (Simon 1982 [11]) or “limited willpower”, that is, most people know that the materials ordered will be satisfied within the delivery period, but they still cannot resist the desire to obtain the materials immediately. One of the reasons is that our brains have not evolved to respond immediately to future values. "Bounded Rationality” further aggravates the Bullwhip Effect (Croson and Donohue 2003[10]; Oliva and Goncales 2006 [12]; Nienhaus, Ziegenbein, and Schoensleben 2006 [13]).

The phenomenon of ignoring supply lines shows people's insufficient understanding of complex systems (Senge, P. M., and J. D. Sterman. 1992 [14]). Our mental model also affects the system structure, information system, and incentive mechanism. This in turn will give feedback to our mental models. Faced with the complexity, variability, and unpredictability of the system, we have further focused our attention on short-term behavior. Or people may know that they should consider supply lines, but due to cognitive constraints, such as limited attention, working memory, and psychological calculation ability, it is difficult for them to do so (Simon 1997 [15]).

Fortunately, supply line weights (“delayed discount rates”) are not fixed. By changing people's mental models, supply lines can be better considered. For example, when you feel the pressure of shortage, imagine that if you don't restrain the impulse of increasing the order quantity, the supply will be less, the delivery period will be longer, and the supply chain will be more unstable. Or imagine how to place an order when you have already got the goods supplied by the supply line——forcing yourself to do what it needs to do now.

4.2. Sharing POS Data

When sharing POS data, the prediction of all links in the supply chain no longer depends on the orders of downstream enterprises, but more on the actual changes in market demand. Therefore, we modify the demand forecast formula as follows:

Forecast value of each link in the supply chain =SMOOTH (market demand rate, forecast smoothing time)

Other parameters remain unchanged, and we get the stock flow chart as shown in figure 9.

![Figure 9](image)

**Figure 9.** A flow chart of beer game stock when sharing POS data.

Note: This figure ignores the backlog of orders and supply lines.

The inventory simulation results of each supply chain link are shown in figure 10.
Figure 10. Inventory changes of retailers, wholesalers, distributors, and manufacturers in beer games when sharing POS data.

Note: Among them, the fluctuation ranges from small to large is retailers, wholesalers, distributors, and manufacturers. Note the comparison between this figure 10 and figure 4.

Sharing POS data effectively reduces the fluctuation range of inventory. Among them, the maximum inventory value of retailers, wholesalers, distributors, and manufacturers decreased by 0%, 20%, 66%, and 105% respectively. The inventory in the supply chain was reduced from 13,411 to 8,642 (ignoring the shortage), a reduction of 35.56%. When all parties in the supply chain realize information sharing, upstream enterprises tend to realize a larger inventory reduction and a larger benefit improvement than downstream enterprises (Cachon and Fisher 2000[16]; Lee et al. 2000[17]; Croson and Donohue 2006 [18]).

Although sharing POS data has greatly improved the supply chain and reduced the bullwhip effect (Wang, Jia, and Takahashi 2005[19]; Weimin and Wenwen 2011 [20]; Trapero, Kourentzes, and Fildes 2012[21]; Wei-Hsi, Chieh-Pin, and Chin-Fu 2014 [22]), but there are still many difficulties in application. Due to the existence of "competitive games" and "trade secrets" in various supply chain links, downstream enterprises are often reluctant to share real sales data with upstream enterprises. Moreover, to show the profitability of the downstream enterprises, the sales data are often distorted and enlarged. Thirdly, sharing POS data did not reduce the retailer's inventory, nor did it reduce the retailer's magnification ratio. "Harmful without profit" weakened the retailer's motivation to share POS data. Finally, information can be divided into clear information and fuzzy information. Data such as sales volume are clear information. How to interpret the present situation is fuzzy information. Clear information is shared more, but vague information lacks sharing because vague information contains opportunities, and people are not willing to share opportunities, although people claim to be willing to share all information.

According to X theory, if the leaders of an enterprise like to see good current situations or scold employees who provide bad news, all employees will only provide good news instead of the real current situation, and leaders will be more convinced that employees are unreliable, thus forming a vicious circle. Distortion amplification of sales data will further aggravate the bullwhip effect. Sadly, due to "wrong attribution", leaders often punish or even dismiss "dishonest" employees, ignoring their responsibilities.
Figure 11. Leaders Create Organizational Environment.

Note: This figure is adapted from Harvard's "Leadership Psychology" course

On the surface, the upstream enterprises bear more high inventory costs caused by the bullwhip effect, but these costs will eventually be transferred to the downstream enterprises, resulting in higher costs, poorer service levels and, less reliable delivery time. That is, the retailer's local optimization cannot achieve the overall optimization of the supply chain. If supply chain participants can establish a certain compensation mechanism, it will effectively promote the implementation of shared POS data.

Another problem with information sharing is that too much information is shared, making important information submerged. People's attention is limited. Sharing information blindly may make the information chaotic and unable to attract people's attention. Besides, simply sharing information cannot change people's way of thinking, and people may choose to ignore it.

4.3. Shorten Supply Chain Length

Now consider eliminating wholesalers and distributors in the supply chain and retaining only manufacturers and retailers. The stock flow chart of the beer game is shown in figure 12.

Figure 12. The stock flow chart when only manufacturers and retailers are retained in the beer game.

Note that this figure ignores the backlog of orders and supply lines.

The simulation results are shown in figure 13. Note the comparison between this figure 13 and figure 4.
Figure 13. The reaction of the stock of the manufacturer and retailer in the beer game. The fluctuation ranges from small to large is retailers and manufacturers respectively.

Shortening the length of the supply chain can effectively deal with the bullwhip effect. The manufacturer's magnification ratio decreased from 15.57 to 4.88. Besides, shortening the length of the supply chain greatly reduces the inventory of the supply chain. The inventory in the supply chain was reduced from 13411 cases to 4609 cases (ignoring shortage inventory), with a reduction of 65.63%.

With the improvement of the supply chain, the length of the supply chain for many commodities has been greatly shortened. With the rise of e-commerce, many manufacturers have taken into account retailers themselves, further weakening the bullwhip effect. However, due to the vast market, retailers cannot be wholly owned by manufacturers. Japan’s Kazuo Inamori proposed the ‘amoeba model’, which flexibly responds to changes in supply and demand through a team system including procurement, design, manufacturing, and sales, thus shortening the supply chain length to the greatest extent. China’s Handu Group (a fast fashion clothing enterprise) has implemented the amoeba model well and has achieved great success.

4.4. Rapid Response

With the enhancement of production capacity, the improvement of supply chain efficiency (e.g. electronic data interchange, effective customer response, itinerant mixed loading, multimodal transportation, etc.) and the improvement of transportation conditions, the delivery delay is continuously shortened. Assuming that the supplier reduces the order processing, loading, and delivery time, its expected acquisition delay is reduced from 3 weeks to 1.5 weeks, with the remaining parameters unchanged. The expected delay is obtained by sensing the delay in delivery. The simulation results are shown in figure 14.

Figure 14. Shows the inventory changes of retailers, wholesalers, distributors, and manufacturers in beer games after fast response.

Among them, the fluctuation ranges from small to large is retailers, wholesalers, distributors, and manufacturers. Note the comparison between this figure and figure 4.

Rapid response can deal with the bullwhip effect very effectively. The magnification ratio of the manufacturer was reduced from 15.56 to 9.68. Rapid response greatly reduced the inventory of the supply chain. The inventory of the supply chain was reduced from 13411 cases to 5808 cases (ignoring the shortage of inventory), with a reduced rate of 56.69%.
To improve the response quickly, Japanese Toyota Company has adopted lean production, also known as Toyota mode, including "Just in Time", One Piece Flow, Balance Production, etc. The core of lean production is to speed up the flow and reduce all unnecessary waiting time. While most manufacturing enterprises keep "three days" of inventory, Toyota has already achieved only "three minutes" of inventory. Of course, this also benefits from decades of efficient cooperation between Toyota and its supply chain partners. Toyota's model has effectively reduced Toyota's inventory holding cost, making it one of the most profitable car manufacturers.

4.5. Vendor Managed Inventory (VMI)
Vendor managed inventory is also a common measure to deal with bullwhip effect (Disney and Towill 2003 [23]; Towill, Zhou, and Disney 2007). Assuming that the upstream enterprise monitors the inventory of the downstream enterprise and delivers goods according to the delivery volume of the downstream enterprise, the delivery volume adopts the heuristic principle of anchor adjustment, i.e. anchor delivery volume is adjusted according to the deviation between expected inventory and inventory. The formula for constructing wholesalers is as follows (and so on for other supply chain participants):

Wholesaler delivery rate = \text{MAX} (\text{DELAY3} (\text{market demand rate} + \text{retailer inventory adjustment}, \text{wholesaler delivery delay}), 0)

Wholesaler Sales Forecast = \text{SMOOTH} (\text{Market Demand Rate}, \text{Wholesaler Forecast Smooth Time})

Build the stock flow chart as shown in figure 15. Note that this figure ignores the backlog of orders and supply lines.

![Figure 15](image)

**Figure 15.** Flow chart of beer game stock when the supplier manages stock.

The other parameters remain unchanged, and the simulation results are shown in figure 16.

![Figure 16](image)

**Figure 16.** Changes in inventory of retailers, wholesalers, distributors, and manufacturers in beer games when suppliers manage inventory.

Among them, the fluctuation ranges from small to large is retailers, wholesalers, distributors, and manufacturers. Note the comparison between this figure 16 and figure 4.

Vendor managed inventory also reduces the bullwhip effect to some extent. The magnification ratio
of the manufacturer was reduced from 15.56 to 13.88. The inventory in the supply chain was reduced from 13,411 cases to 12,108 cases (ignoring the shortage), a decrease of 9.7%. The effect of the supplier’s inventory management strategy is not obvious, which may be caused by only sharing the information on two levels of participants.

4.6. Other Strategies
The bullwhip effect can be effectively reduced by increasing the initial inventory value and equalizing procurement-reducing the fluctuation of procurement to reduce uncertainty (Croson, R., K. Donohue, E. Katok, and J. Sterman. 2014). Due to people’s selfishness, they are more sensitive to changes in their interests. Therefore, the establishment of a punishment mechanism is conducive to ensuring supply, and the downstream of the supply chain often formulates a punishment strategy for shortage in the upstream.

5. Supply Chain Reengineering
Considering the combination of various supply chain management strategies to build a beer game supply chain model. The supply chain is simplified to have only manufacturers and retailers. At the same time, the inventory flow chart is constructed by considering supply lines, sharing POS data, and quick response strategy, as shown in figure 17.

![Figure 17. Supply Chain Reengineering of Beer Game.](image)

The simulation results are shown in figure 18.

![Figure 18. Inventory Changes of Retailers and Manufacturers in Beer Game during Supply Chain Reengineering.](image)

Among them, retailers and manufacturers are in the order of inventory shortage. Note the comparison between this figure and figure 4.

Supply chain reengineering has greatly reduced the bullwhip effect and supply chain inventory. The magnification ratio of the manufacturer was reduced from 15.56 to 1.16. The inventory in the supply chain was reduced from 13411 cases to 1548 cases, a decrease of 88%. Shortening the supply chain
length and improving the response speed can continue to reduce the inventory of the supply chain. When the supply is fast enough, the inventory of the supply chain can even approach "zero inventory", thus achieving the ideal state of the supply chain, which means the supply is equal to the sales volume without inventory.

6. Conclusions
The beer game is a classic representation of the response of the supply chain in the fast-growing industry to the growth of market demand. Through simulation, supply chain management strategies such as considering supply lines, sharing POS data, shortening supply chain length, quick response, and supplier management inventory are gradually investigated. The direction of supply chain optimization is to reduce delay, that is, to reduce material delay and information delay. Among them, the strategy of shortening the supply chain length and the strategy of quick response-accelerated flow (including lean production, effective customer response, electronic data exchange, itinerant mixed load, "constraint theory" etc.) can effectively reduce the supply chain inventory, which is the direction of supply chain management optimization.

The model constructed in this paper simulates the beer game approximately, but there are still some deficiencies. For example, extended inventory adjustment time is used instead of considering supply lines, reduced expected delay is used instead of quick response, overstock orders are not considered, and other supply chain management strategies are not verified, which is the direction for further research.

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