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# Research on Inventory Simulation of Pulse Supply Chain Based on Controllable Lead Time

**Boxi Zuo, Chengqi Peng & Wenying Liu**


## Abstract

In the e-commerce environment, how supply chain enterprises respond to surge demands has become an urgent issue to address. This article takes into consideration the overall interests of the supply chain system, aiming to maximize the supply chain profit. By applying system dynamics theory, an in-depth analysis is conducted on a two-tier supply chain consisting of a single manufacturer and a single retailer with controllable lead times. A system dynamics model is constructed using Vensim simulation software as the modeling platform, and simulation analyses are performed for both single and multiple surge demands. The findings reveal that in both single and multiple surge demand scenarios, implementing a controllable retailer lead time strategy leads to higher profits compared to normal lead time and random lead time strategies. Moreover, as the lead time is compressed, the profit exhibits an increasing-to-decreasing trend. Additionally, when both the manufacturer and retailer lead times are controllable, the profit of the entire supply chain surpasses that of the normal lead time and random lead time strategies.


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## 1 Introduction

Due to the influence of factors such as extreme weather, pandemics, shopping festivals, and more, the supply chain system frequently faces uncertainties in various aspects such as demand and production ,according to Wu, Peng, et al. (2023). For instance, during the pandemic, there was a surge in demand for face masks, leading to overcapacity and severe stockpiling as evidenced by the addition of 480,000 face mask production companies nationwide by August 2021. However, by the end of 2022, over 60% of these companies had gone bankrupt due to excessive inventory. Additionally,Wang, Liu,et al. (2023) argued that the pandemic has fostered consumers' habit of online shopping, resulting in China's online retail sales reaching 13.79 trillion yuan in 2022. In the e-commerce model, demand can experience sudden and drastic changes due to marketing methods, referred to as the pulse effect. This phenomenon of rapid demand growth within a short period of time can trigger a series of inventory problems. For example, during the Singles' Day event in 2022 alone, online retail sales reached 557.1 billion yuan, accounting for 4% of the annual total. After the event, clothing brands were left with an accumulated inventory worth over 2.3 trillion yuan, increasing at a rate of 5% annually. Effectively addressing pulse market demand has become a pressing challenge for many e-commerce companies. Therefore, studying inventory management in supply chains with pulse demand can provide valuable insights for decision-making in e-commerce enterprises, holding significant practical significance. Research on inventory control issues can be classified into two major categories based on demand: fixed demand and stochastic demand. Papachristo et al.(2006) explored the case of constant demand. Setiawan et al. (2018) developed a returnable perishable inventory model under the assumption of deterministic demand with returns. Zanoni et al. (2018) found that even with price reductions, product demand decreases steadily over time at a constant rate. To make the models more realistic, an increasing number of scholars have focused on inventory models considering stochastic demand. Jain et al.(2017) studied an inventory model with inflation and changing environmental conditions, where both production rates and market demand vary over time, and imperfect-quality items can be repaired, obtaining the optimal EOQ solution. Chen et al.(2023) researched a multiple-period risk-averse inventory model where both the supply and demand sides depend on the quality level . Ben-Ammar et al.(2019) investigated the problem of multi-period inventory control strategy under the assumption of a discrete lead time as an independent random variable, concluding that optimizing the reorder period is more effective than implementing a safety stock strategy. Liu et al.(2020) developed a decision model for multi-period production-inventory considering demand uncertainty and the fixed proportion processing of two types of raw materials. None of the aforementioned literature considered the impact of the pulse effect on supply chain-related decisions. Currently, there is limited literature on considering the pulse effect in supply chain research. Peng et al.(2022) developed a supply chain model considering the pulse phenomenon, analyzed its impact on the supply chain system, and proposed strategies to stabilize the system. Wu et al.(2023) investigated the pulse discrete synchronization strategy of a chaotic supply chain system under uncertainty. However, none of these studies considered the lead time. Effective control of the lead time can enhance the supply chain's ability to meet end-consumer demands and capture a larger market share. Both manufacturers and retailers have motivations to reduce the lead time. Therefore, it is necessary to incorporate the lead time in the research scope. In this study, we focus on the characteristics of random jump demands and investigate a two-tier supply chain driven by a stochastic demand process with pulse characteristics. We analyze the impact of pulse demand on supply chain enterprises by considering the controllable lead time. This analysis aims to provide solutions for a range of related issues such as stockouts and inventory backlog caused by pulse demand in the context of e-commerce. The dynamic, complex, and stochastic nature of the inventory management in supply chain systems makes it challenging to solve mathematical models or renders them unsolvable. Hence, we employ the system dynamics approach to build a simulation model for the pulse supply chain and study the variation of supply chain factors under different lead time control strategies. These findings will serve as a basis for inventory management in companies operating in the e-commerce environment.

## 2 System Dynamics Analysis of Impulse Supply Chain Inventory System

Supply chain is a large complex system composed of multiple nodal enterprises, such as raw material suppliers, product manufacturers, distributors at all levels, and terminal retailers. It has the characteristics of causal feedback, nonlinear, complexity, dynamic, etc. It is difficult to use analytical modeling and solve, so system dynamics can be used to build its inventory management model. The system behavior is simulated dynamically by computer simulation, the behavior characteristics and key factors of the system are analyzed, and constructive suggestions are put forward to improve the overall benefit of the supply chain. The pulse supply chain studied in this paper is composed of a single retailer and a single manufacturer, producing and selling a single product, and its structure is shown in Figure 1. In normal times, the market demand is maintained in a relatively stable state, manufacturers and retailers are replenished in accordance with the regular replenishment method (T,Q), that is, every other time T, order Q units; Before the arrival of the pulse demand, the retailer determines the order quantity and issues the order to the manufacturer according to the forecast of the market pulse demand and the inventory strategy, and the manufacturer organizes the raw material procurement and product production by the way of production to order.

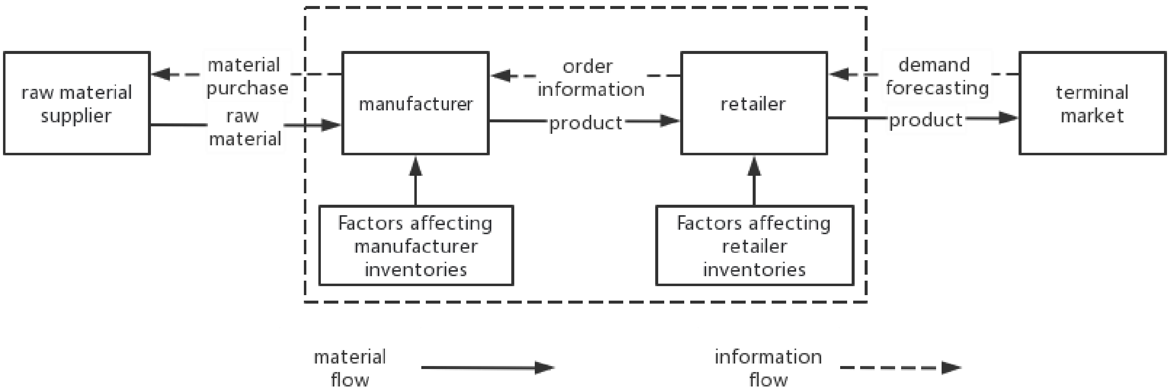


**Figure 1.** Inventory system structure of two-stage pulse supply chain

The flow of goods from the manufacturer to the retailer for sale is essential (i.e., logistics), and logistics is driven by the retailer's ordering decisions, which are based on available inventory and demand information (Sun & Zuo, 2023). Therefore, this paper intends to add the upstream and downstream activities related to commodity ordering, such as information flow and logistics, into the system for modeling. In addition, the model established in this paper is the inventory model of the supply chain, so only costs and profits related to inventory control are considered in terms of capital flow.

## 3 SD Model Construction of Pulse Supply Chain

### 3.1 fundamental assumption

(1) The pulse supply chain consists of a retailer and a manufacturer, and it focuses on the production and sale of a single product.

(2) The study period is denoted as a fixed duration, T (which differs for single and multiple

pulses). It starts from the moment the retailer places an order and ends when the pulse demand ceases. In relation to the entire cycle, the duration of pulse demand is relatively brief.
(3) Within the time interval T, demand, excluding pulse demand, follows a uniform distribution. Within T, there may be one or multiple instances of pulse demand, which do not affect the uniform demand. Hence, market demand can be considered as a superposition of uniform and pulse demands, with known occurrence times for pulse demand.
(4) The manufacturer adopts a make-to-order production approach, i.e., a pull-based production method.
(5) After the manufacturer places an order for raw materials, they do not arrive immediately due to a procurement lead time.
(6) The raw materials required for one finished product are treated as a single entity, meaning that one unit of raw material produces one unit of finished product.
(7) Inventory at the manufacturer's facility is negligible; hence, inventory costs mainly refer to the holding costs of raw materials. Purchasing costs for both the retailer and manufacturer are fixed and are not included in the cost analysis in this study.
(8) The inventory capacity of both the manufacturer and retailer is unlimited. The manufacturer's transportation capacity is not infinite, but production capacity can be increased indefinitely at an increasing cost.
(9) There is full information sharing and centralized decision-making between the retailer and supplier.

**3.2 Analysis of basic causality of inventory system in pulse supply chain**

Causality is the basis of constructing system dynamics model, and correct causality diagram is the premise of establishing model. The inventory model of two-stage pulse supply chain studied in this paper aims to maximize the profit of supply chain, and the model mainly involves inventory causality and cost causality. As shown in Figure 2 and 3.

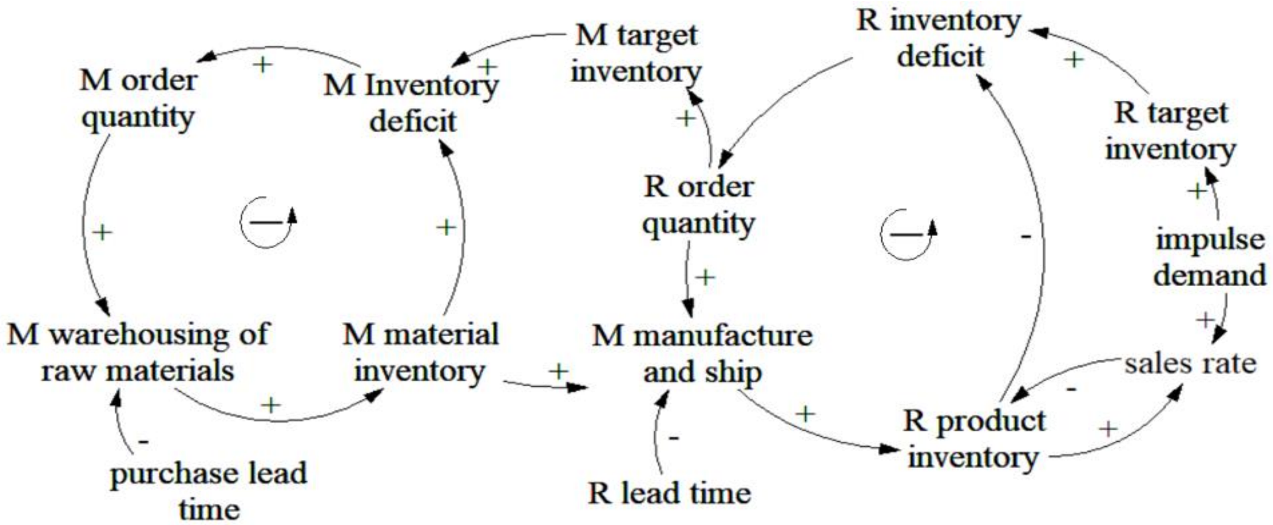


**Figure 2.** Inventory causality diagram of pulse supply chain

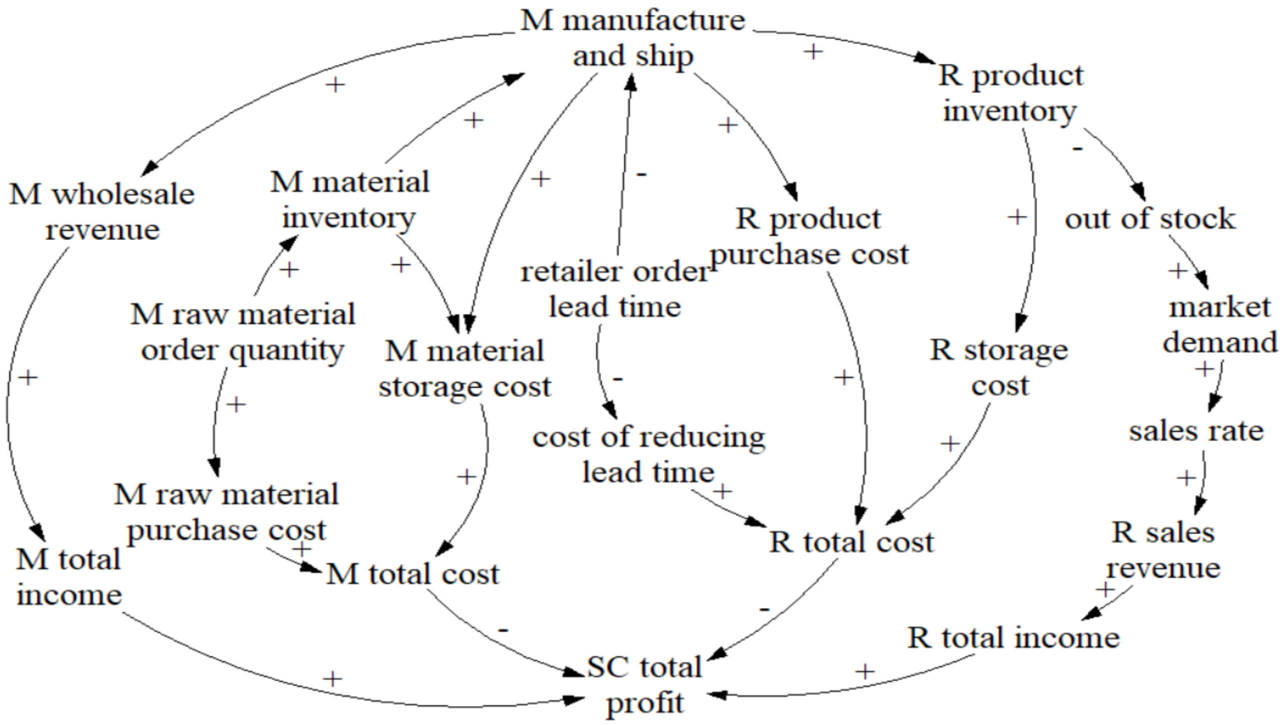


**Figure 3.** Cost causality diagram of pulse supply chain

### 3.3 SD model of pulse supply chain inventory system

Based on Figures 2 and 3, M raw material inventory, R product inventory, M profit and R profit are selected as state variables to draw the SD flow diagram of the system, as shown in Figure 4. In this SD model, all variables are as follows:

State variables: M raw material inventory, R product inventory, M profit, R profit;

Rate variable: M raw material inventory rate, production and delivery rate, sales rate, M daily profit increase rate, M daily cost increase rate, R daily profit increase rate, R daily cost increase rate;

Auxiliary variables: Raw material purchase lead time, retailer order lead time, M order quantity, M inventory gap, M target inventory, R order quantity, R inventory gap, R pulse demand forecast, forecast error, pulse demand, market demand, raw material unit price, M daily raw material purchase cost, M daily raw material storage cost, M daily production cost, unit production cost, M daily wholesale revenue, wholesale price, R Daily product purchase cost, R-day lead time compression cost, R-day lead time compression amount, R-day storage cost, R-day stock loss, R-day sales revenue;

Constants: M storage cost factor, R storage cost factor, M profit margin, unit out of stock loss, market price.

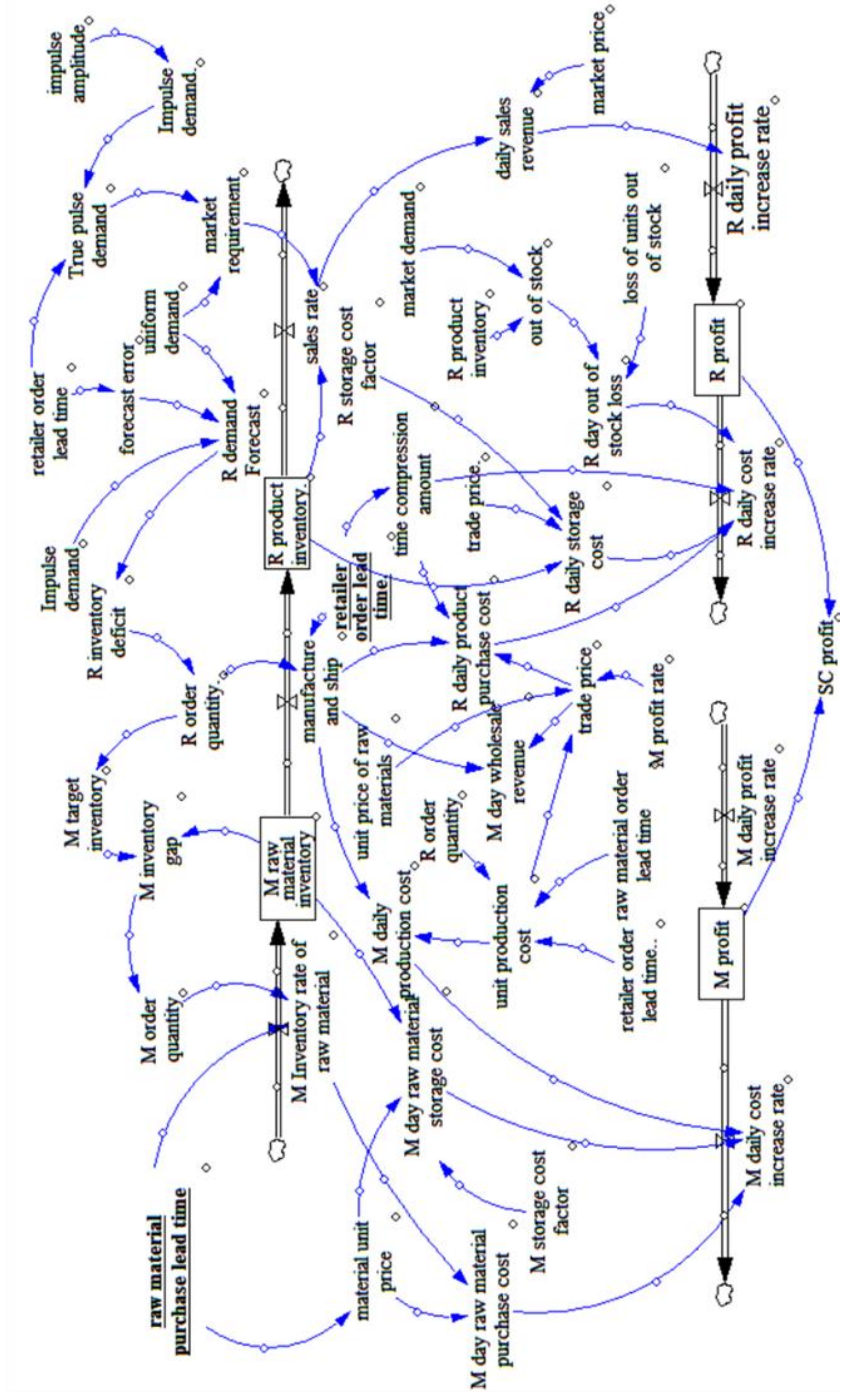


**Figure 4.** SD model of pulse supply chain inventory system

### 3.4 Structural equation design

The key structural equations in the SD flow diagram are as follows:

(1) Inventory module key structure equation

① M raw material inventory, R product inventory

M raw material inventory is accumulated by M raw material inventory rate and production and delivery, and its value can be expressed as follows:

M Raw material inventory K=M raw material inventoryJ+DT*(M Inventory rate of raw materials.JK-manufacture and ship.JK)

here, M raw material inventory. K is the amount of inventory available; M raw material inventory.J is the inventory before DT; DT is the time interval of calculation; M Inventory rate of raw materials. JK is the inflow within the JK interval; Production and delivery.JK is the outflow volume within the JK interval.

The same can be obtained, R product inventory. K= R product inventory. J+DT*(Production and delivery. JK- sales rate.JK)

② Market requirement

In the pulse supply chain inventory model established in this paper, it is assumed that one or more pulse demand occurs in the cycle T, and in the absence of pulse demand, demand follows uniform distribution, so market demand can be regarded as the superposition of uniform demand and pulse demand.

Pulse demand: In the single pulse simulation, this paper intends to use the single pulse function of Vensim software to represent:

functional form—PULSE(start, width); in the formula:Start—pulse time; Width—pulse duration.

PULSE(6, 2)A pulse phenomenon that starts at the 6th time unit, lasts for 2 time units, and then quickly returns to 0.

③ Forecast error

According to WalMart's survey, 26 weeks in advance, the demand forecast deviation is 40%; 16 weeks in advance, demand forecast deviation is 20%; According to Papachristos, Konstantaras (2006), if purchased at the beginning of the selling season, the measurement deviation can be reduced to 10%. Based on this data, a table function of the prediction error regarding the retailer's order lead time is established:forecast error=WITH LOOKUP(Retailer order lead time,([(0,0)-(26,0.5)],(0,0.1),(16,0.2),(26,0.4)))

(2) Cost module key structure equation

① Reduce costs in advance

The retailer has a normal order lead time, under the normal lead time, the shrinkage is 0, and no compression costs are generated. However, in order to collect more information about the pulse demand and reduce the forecast error, retailers usually choose to order late, so manufacturers need to invest more manpower and material resources to organize production, resulting in additional costs, that is, compression cost in advance. In the model, it is assumed that all the compression costs are borne by the retailer, and with the increase of the compression volume, the unit compression costs are also increasing.

The cost of reducing lead time: $c(\Delta l) = \lambda e^{\lambda \Delta l},\ \lambda > 0$, Where $\Delta l$ is the retailer's lead time compression.

② Unit price of raw materials

The same as the retailer lead time, the manufacturer's raw material purchase lead time can also be compressed, the normal manufacturing lead time, the raw material unit price is fixed, with the increase of the lead time compression, the unit compression cost is higher and higher. This paper assumes that the manufacturer's purchase lead time compression cost is transferred to the unit price of raw materials.

Unit price of raw materials when the manufacturer's lead time is $l_M$

$c(l_M) = c_0 + \lambda_M e^{-\lambda_M (L_M - l_M)}$, $\lambda_M > 0$ . $c_0$ is the unit price of raw materials under normal lead time.

## 4 Pulse Supply Chain Simulation Research

### 4.1Single pulse supply chain simulation research

For enterprises in the e-commerce environment, the phenomenon of single pulse demand is widespread, such as the hot "Double eleven", "Double twelve" promotional activities in recent years, and some merchants' anniversary store celebrations, year-end promotional activities, etc., which makes the market demand fluctuate greatly compared with usual times.Under the condition that the market demand is a single pulse, the author focuses on the retailer's order lead time as the control variable, and analyzes the profit situation under the three strategies of fixed lead time, random lead time and controllable lead time.The specific parameters are set as follows:M Raw material inventory rate 0, production and delivery 0, M raw material inventory 100, R product inventory 100, normal raw material procurement lead time 6, normal retailer lead time 10, M profit 0, unit production cost 20, unit out of stock loss 50, raw material unit price 30, market price 100, R profit 0, R storage cost factor 10%, M profit margin 20 %, M Storage cost factor 5%. The simulation results are summarized in Table 1.

**Table 1. Profit of different retailers under lead time**

| Lead time(days) | 4 | 5 | 6 | 7 | 8 | 9 | Normal | Random |
|---|---|---|---|---|---|---|---|---|
| SC Profit (Yuan) | 9765 | 13662 | 14206 | 13250 | 11715 | 10079 | 8553 | 12506 |
| M Profit (Yuan) | 7598 | 6703 | 5826 | 4964 | 4124 | 3307 | 2502 | 4541 |
| R Profit (Yuan) | 2167 | 6959 | 8380 | 8286 | 7590 | 6772 | 6051 | 7965 |

When the lead time is 6 days, the profit of the supply chain is the largest, which is 14,206 yuan. In comparison, the profit under the normal lead time is 8553 yuan, and the profit under the random lead time is 12,506 yuan, both of which are smaller than the controllable lead time. It can be seen that reducing the procurement lead time by adding a certain amount of compression cost can increase the overall profit of the supply chain. With the shortening of the lead time, the profit of the supply chain shows a trend of first increasing and then decreasing, mainly because the compression cost exceeds the income brought by the compression.

It can be concluded that: in the single pulse supply chain, the profit of the controllable retailer lead time strategy is higher than the normal lead time and random lead time, and with the compression of lead time, the profit increases first and then decreases.

### 4.2 Multi-pulse supply chain simulation research

In real life, the phenomenon of multiple pulse demand is also very common, such as supermarkets, catering and other industries every weekend or holiday passenger flow than the week increased significantly, bringing greater demand fluctuations. Based on three strategies: fixed lead time, random lead time and controllable lead time, this section will conduct simulation research on the supply chain under fixed multiple pulse and random multiple pulse respectively.

Fixed multiple pulse simulation

Hypothetical pulse demand=10+300*PULSE TRAIN(0, 1 , 7 , 30)， That is, the pulse occurs once every 7 days or once a week, and the duration of each pulse is one day, so the normal lead time shall not exceed 6 days, which is initially set as 6, and the simulation time is set as one month. The simulation results are summarized in Table 2.

**Table 2. Profit under multiple fixed pulse demand and different lead times**

| Lead time(days) | 2 | 3 | 4 | 5 | Normal(6) | Random(3.5) |
|---|---|---|---|---|---|---|
| SC Profit (Yuan) | 21846.5 | 24774.5 | 21387.2 | 17235.7 | 12850.63 | 20654.3 |
| M Profit (Yuan) | 15198.1 | 13867.7 | 11622.2 | 8854.6 | 6841.13 | 11744.6 |
| R Profit (Yuan) | 6648.4 | 10906.8 | 9765 | 8381.1 | 6009.5 | 8909.7 |

It can be seen that reducing the procurement lead time by increasing a certain amount of cost can increase the overall profit of the supply chain, and as the lead time becomes shorter and shorter, the profit of the supply chain will increase first and then decrease. In addition, unlike a single pulse, the lead time compression has brought about a significantly smaller profit increase for retailers than a single pulse, but for manufacturers, profits have been increasing and rising. It can be concluded that the profit of controllable retailer lead time strategy is higher than normal lead time and random lead time in multiple fixed pulse supply chain.

Random multiple pulse simulation

The random number between 500 and 1000 generated by random function is used as the pulse amplitude to simulate the supply chain system driven by multiple random pulse demand.

**Table 3. Random pulse demand and profit under different lead times**

| Lead time (days) | 3 | 4 | 5 | Normal | Random |
|---|---|---|---|---|---|
| SC Profit (Yuan) | 60571 | 65226 | 63460 | 57602 | 62120 |
| M Profit (Yuan) | 24458 | 20378 | 16368 | 15427 | 18457 |
| R Profit (Yuan) | 36113 | 44848 | 47092 | 42175 | 43663 |

When the lead time is 4, the profit of the supply chain is the largest, which is 65,226 yuan. In comparison, the profit under the normal lead period is 57,602 yuan, and the profit under the random lead period is 62,120 yuan. It can be concluded that the profit of controllable lead time strategy is higher than normal lead time and random lead time in multiple random pulse supply chain.

## 5 Summary and Prospect

This study focuses on the overall benefits of the supply chain system and develops a simulation optimization model for the inventory system of a two-tier pulse supply chain, with the retailer's order lead time as the decision variable. The model primarily simulates and compares the inventory fluctuation and supply chain profitability under different ordering strategies by controlling the lead times of the manufacturer and retailer. The following findings are observed: (1) In a single-pulse supply chain, implementing a controllable retailer's lead time strategy leads to higher profits compared to normal and random lead times. Additionally, as the lead time is compressed, the profit exhibits an initial increase followed by a decrease trend. (2) When both the manufacturer and retailer lead times are controllable, the overall supply chain profit surpasses the profit obtained with normal and random lead times. (3) Within the supply chain, the profit margin of the manufacturer affects the overall profitability. The higher the manufacturer's profit margin, the lower the supply chain profit, whereas a higher supply chain profit is achieved when the profit margin is 0. (4) In a multiple-fixed-pulse supply chain, implementing a controllable retailer's lead time strategy results in higher profits compared to normal and random lead times. (5) In a multiple-random-pulse supply chain, implementing a controllable retailer's lead time strategy leads to higher profits than normal and random lead times. The research object of this paper is one-to-one simple two-level supply chain, and the future research work can be extended to one-to-many, many-to-one or many-to-many two-level supply chain or multilevel supply chain. Because it is difficult to collect relevant data, there is no specific data for reference when determining the initial values of some parameters and the mathematical logic relationship between parameters, which is mainly based on previous studies or assumptions. Therefore, in the future research, we can collect first-hand data through field investigation of pulse supply chain enterprises, so as to make the model more convincing and closer to the reality. In this paper, it is assumed that the supply chain lead time decision is made when the time of pulse demand is known, but in practice, due to the influence of some external factors, the time of pulse occurrence is uncertain, and the uncertain pulse can be studied in the future.

## References


Ben-Ammar, O., Bettayeb, B., Dolgui, A. (2019). Optimization of Multi-period Supply Planning under Stochastic Lead Times and a Dynamic Demand. *International Journal of Production Economics, 218*, 106-117.

Chen, C.Y., Zhang, J.W., Wu, J., et al. (2022). Dynamic Simulation Analysis of Supply Chain Collaboration Operation System under Cloud Manufacturing. *Science and Technology Management Research, 42*(21), 211-225.

Chen, J., Xing, L., Li, W., et al. (2023). Multi-period Risk-averse Inventory Model with Quality Ripple Effect. *Journal of Industrial Engineering and Engineering Management*, 1-11. Retrieved from https://doi.org/10.13587/j.cnki.jieem.2023.06.012.

Jain, S., Tiwari, S., Cardenas-Barron, L.E., et al. (2017). A Fuzzy Imperfect Production and Repair Inventory Model with Time Dependent Demand, Production, and Repair Rates Under Inflationary Conditions. *RAIRO - Operations Research, 52*(1), 217-239.

Liu, H., Zhang, J., Cheng, T.C.E., et al. (2020). Optimal Production-Inventory Policy for the Multi-period Fixed Proportions Co-production System. *European Journal of Operational Research, 280*(2), 469-478.

Papachristos, S., Konstantaras, I. (2006). Economic Ordering Quantity Models for Items with Imperfect Quality. *International Journal of Production Economics, 98*(1), 148-154.

Peng, Y., Wu, J., Tan, T., et al. (2022). Complex Supply Chain Systems Considering Pulse Phenomenon and Its Stability Strategy. *Statistics and Decision, 38*(02), 159-163.

Setiawan, S.W., Lesmono, D., Limansyah, T. (2018). *A Perishable Inventory Model with Return. In Microelectronics Systems Education* (pp. 1-11). IOP Publishing.

Sun, P., & Zuo, X. (2022). Navigating the Post-COVID Market: A Prospective Analysis of Foreign Trade in the Pearl River Delta, China. *Journal of Scientific Reports, 5*(1), 8-14.

Wang, W., Liu, Q., Feng, G., et al. (2023). Decision-making and Contract Research on Dual-channel Supply Chain Recovery Efforts during Epidemic. *Systems Engineering Theory and Practice, 43*(03), 857-870.

Wang, Y., Fu, H., Fang, X., et al. (2019). Strategies for Supply Chain Coordination and Response Under Sudden Output. *China Management Science, 27*(07), 137-146.

Wang, Y.Q., Chen, J.L. (2023). Research on Digital Technology-Driven Innovation of Third-Party Supply Chain Financial Business Models: Based on the Ecological Rent Perspective. *Science Decision*, 1-19.

Wu, J., Peng, Y., Zou, L., et al. (2023). Research on Pulse Synchronization Strategy in Chaotic Supply Chain Systems under Uncertainty. *Chinese Journal of Management Science*, 1-11. Retrieved from https://doi.org/10.16381/j.cnki.issn1003-207x.2020.2270.

Zanoni, S., Zavanella, L. (2007). Single-vendor Single-buyer with Integrated Transport-Inventory System: Models and Heuristics in the Case of Perishable Goods. *Computers & Industrial Engineering*, 52.



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