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Research on simulation of school uniform supply chain optimal model based on internet of things

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Abstract

In this paper, the information sharing platform based on the Internet of things is constructed to improve the efficiency of supply chain, and the flow chart based on the Internet of things of the school uniform is analyzed, integrated application of Internet of things technology in supply chain to analyze the detail of the system. By calculating Lyapunov Index, power spectrum, and correlation dimension, the bifurcation and chaos characteristics of supply chain under different production strategies are analyzed. At the same time, the periodicity and initial value sensitivity of chaos are used to explain the feasibility of manufacturer organizing flexible production and the causes of bullwhip effect in supply chain and corresponding prevention measures. And the experiment results show that bullwhip effect will occur in the chaotic supply chain system, which can be suppressed by short-term forecasting and accelerating the speed of demand information transmission. Chaos also has a favorable side for enterprises, such as making low-cost flexible production possible.

Keywords: Internet of things, Supply chain, Modelling, Dynamic characteristics, Chaos, Wireless network

1 Introduction

The purpose of supply chain management is to link up the planning and production, distribution and storage, and sales and service activities of enterprises to form an integrated network system, so as to achieve the goal of saving cost and improving efficiency [1]. This complex network of multi-node, the complex supply-demand relationship between node members and the exchange of supply chain system and external environment, determines that the supply chain system is a complex system; supply chain management has the characteristics of complexity [2]. Therefore, from the perspective of complexity, we further reveal and grasp the inherent law of supply chain system optimization [3]. Over the past two decades, with the further development of modern information technology, the Internet of things (IOT) technology has been widely used in the field of supply chain [4]. The application of RFID and EPC technology in the field of supply chain has attracted more and more attention. The traceability design of agricultural products based on Internet of things technology is studied with emphasis, and the

information sharing model of agricultural products supply chain based on RFID technology is proposed. Literature establishes a supply chain inventory management system based on the Internet of things and studies the application mechanism of information and data sharing in the inventory management of the Internet of things [5]. Literature studies the application of RFID and EPC technology in aquatic products supply chain traceability and develops an aquatic products supply chain traceability platform based on RFID technology. Literature [6] applies the Internet of things technology to the cold chain logistics of agricultural products and establishes a traceable and monitorable information management system. In the existing research of scholars, there are more researches on the application of Internet of things in inventory management and product traceability but less on the application of information sharing in the supply chain. Under the requirement of industrial information, the Internet of things provides a technical basis for the realization of information sharing in the supply chain. Therefore, it is of great significance to further study the information sharing mechanism of the supply chain under the IOT environment to improve the overall competitiveness of the supply chain [7].

The bullwhip effect in supply chain is studied by system dynamics modeling. They believe that the bullwhip effect will be caused by any product forecasting method as long as the order demand of members at all levels in the supply chain is up-to-demand strategy. On this basis, combining with spreadsheet simulation and control engineering methods, two new control mechanisms are proposed, which are adjusting the feedback sequence of supply chain and smoothing forecast data. Through the study of the machinery tool processing industry, it is shown that the appropriate order strategy can effectively avoid the bullwhip effect to the upstream members of the demand amplification. The supply chain model of system dynamics is constructed by Inovai, who finds and explains the phenomenon of supply chain demand enlargement [8]. Literature chose the automotive steel industry as a relatively closed industry and proved that the relative independence of members at all levels of the supply chain is an important reason for the bullwhip effect. To achieve greater efficiency and economic benefits, it is necessary for each member of the supply chain to pay more attention to and cooperate extensively [9].

In this paper, the information sharing platform based on the Internet of things is constructed to improve the efficiency of supply chain, and the flow chart based on the Internet of things of the school uniform is analyzed, integrated application of Internet of things technology in supply chain to analyze the detail of the system. By calculating Lyapunov Index, power spectrum, and correlation dimension, the bifurcation and chaos characteristics of supply chain under different production strategies are analyzed. At the same time, the periodicity and initial value sensitivity of chaos are used to explain the feasibility of manufacturer organizing flexible production and the causes of bullwhip effect in supply chain and corresponding prevention measures. And the experiment results show that bullwhip effect will occur in the chaotic supply chain system, which can be suppressed by short-term forecasting and accelerating the speed of demand information transmission [10].

2 The information sharing platform based on the internet of things
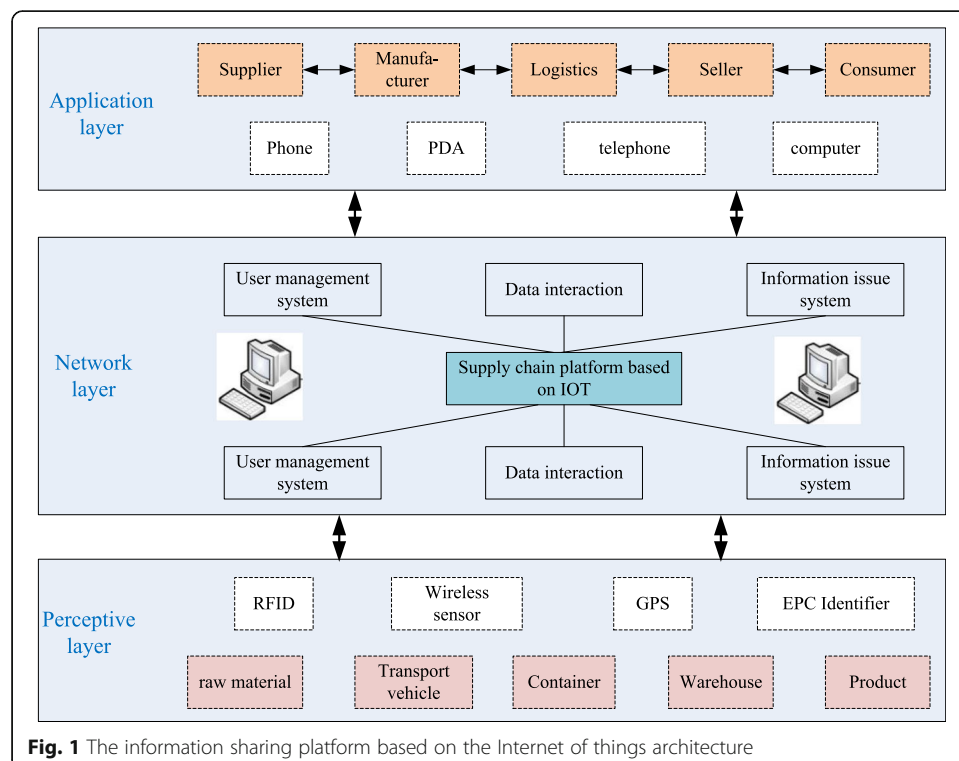### 2.1 Platform framework based on IOT
Because the model introduces the technology of Internet of things (IOT) to identify and track the product information of supply chain in an all-round way, the author

named the model the Inventory Management Model of Internet of things (IOT). The main idea of the model is to construct enterprise-level supply chain node enterprises by using RFID technology, wireless sensor technology, middle-ware technology, and so on. In the Internet of things (IOT) environment, the product information of each link of the supply chain operation is acquired immediately and then sent to the data center server through the Internet middle-ware [11]. Then, the product information is processed by the inventory management information platform, and the optimal inventory decision is made to ensure the lowest total inventory cost of the supply chain. The essence of the model is to transform supply chain inventory management into centralized inventory management with core enterprises as the core. Its basic connotation includes two aspects: one is to obtain product information by building enterprise-level Internet of things environment; the other is to develop inventory management information platform, using the obtained product information, to control and make decisions on supply chain inventory. At this point, the information sharing platform based on the Internet of things architecture has been formed, as shown in Fig. 1.

The information sharing mode based on the Internet of things architecture can be divided into three levels: the perception layer, the network layer, and the application layer.

The perception layer is located at the bottom of the information sharing mode. Through the use of sensors, RFID, electronic tags, and GPS technology, staff collect and record the information of production, transportation, warehousing, and sales of the supply chain and transmit the information to the network layer information platform through the hardware interface. Perception layer is the basis of information sharing model. The data collected by perception layer is processed and processed through

Fig. 1 The information sharing platform based on the Internet of things architecture

network layer to form effective information which is helpful for managers to make decisions [12].

The network layer is the core of the information sharing model. Its goal is to construct a visual information sharing platform for school uniform supply chain, providing users with the functions of permission query, information feedback, and security supervision. Information platform is based on the information obtained from the perception layer, through the information processing system; the original information is processed into the information needed by the chain enterprises. Information platform consists of information query, information release, data interaction, supervision and management, auxiliary decision-making, user management, and other modules [13].

The application layer is at the top of the information sharing mode and faces all the nodes in the school supply chain. The staff and consumers of each node in the chain can obtain the information they need by using simple receiving devices (such as mobile phones, personal computers, etc.). After processing by the information platform of the network layer, they can better meet the information needs of each node and consumers. Enterprises and consumers on the chain can obtain information through the application layer. And it also can make effective decisions for enterprises.

2.2 Integrated application of internet of things technology in supply chain

According to the problems in each link of the school uniform supply chain summarized above, we can use the Internet of things technology to integrate and improve the work of each link to improve the efficiency of each link of the supply chain.

2.2.1 Production link

In the manufacturing process, RFID technology is mainly used in the automatic operation of school uniform production line to realize the identification and monitoring of raw materials, parts, semi-finished products, and finished products and to reduce the cost of manual identification and error rate. According to the product information and production schedule of information sharing platform, managers can make timely decisions, carry out product scheduling, issue replenishment information, realize pipeline balance, and strengthen the control and tracking of product quality. The application of Internet of things in production is shown in Fig. 3.

2.2.2 Storage link

In logistics warehousing, RFID technology is mainly used to realize the automatic warehousing of uniforms and other operations. When the goods enter the distribution center, read all the electronic tags on the containers, determine the number of inbound and outbound, detect possible arrival errors, real-time monitoring of chemical products inventory status, and accurate inventory control. At the same time, EPC tagging system can effectively avoid the interaction among school uniform products, ensure the storage safety, and make rational use of storage space.

2.2.3 Distribution link

In the distribution link, RFID technology is mainly used for real-time tracking and control of school uniform products in transit and in the logistics center or transfer station to

improve the efficiency and accuracy of clothing sorting and distribution, reducing unnecessary manual operation. The RFID receiving equipment installed at the checkpoint of the transportation line can automatically collect the data of the goods and vehicles with EPC tag and better accomplish the task of tracking the position of the vehicles and confirming the arrival of the goods, thus reducing the transportation time cost and realizing the effective tracking management of the whole course of the uniform.

2.2.4 Sales link

In the sales process, EPC tagging system can improve the inventory management of school uniform retailers; retailers can use EPC system for real-time monitoring and management of merchandise, timely discovery of out-of-stock information for replenishment. At the same time, it can monitor the classification of some timeliness strong school uniforms. According to the instant information provided by the electronic tag, we can understand the relevant information and the circulation process of commodities and control the circulation of commodities. Customers can conveniently query product information and purchase products through the Internet.

3 Methods

The object of system dynamics is a dynamic system, which can be used to study the changes of variables with time in the problem, and to study whether the variables in the model have causal feedback relationship. In the supply chain system, there are a large number of states which change with time series, such as inventory, delivery rate, and order rate. These variables will change with time due to the changes of various factors.

In this paper, we hope to use system dynamics to study the dynamic mechanism of closed-loop supply chain, describe the closed-loop supply chain with causality diagram and flow diagram of system dynamics, transform the supply chain system into the corresponding information system for simulation, and do a numerical simulation analysis through the proposed closed-loop supply chain model.

The theoretical framework of supply chain management is the basis of establishing system model and its optimization and control. The characteristics of supply chain include the following aspects: complexity, which is the characteristic of its own structure compared with that of a single enterprise; dynamics, which is the dynamic characteristics of supply chain system in supply, manufacturing, sales, logistics, capital flow, and information flow; facing user demand, user demand pull is supply the driving force of logistics, capital flow, and information flow in the chain. For convenience, a three-tier supply chain consisting of a consumer, a distributor, and a manufacturer is investigated, and the following assumptions are proposed based on the above characteristics:

3.1 Hypothesis 1

The sales volume of a product at the $t + 1$ period depends on the quantity of the product that the consumer owns or consumes at the t period, that is, the purchasing behavior of the potential consumer is driven by the psychology of the herd consumption. And with the increase of sales volume of this product, the product market saturation also increases, which restricts the further sales of this product. The following is a mathematical formula.

$$x_{t+1} = ky_t, \quad k = k_1 - k_2 y_t \tag{1}$$

where x_{t+1} is the demand quantity of consumers at the $t+1$ period ($x_{t+1} < 0$ can describe consumers' rejection or disgust of products), y_t is the number of consumers at the t period (it is also the number of manufacturers at the t period). k indicates the degree of impact of product ownership on potential consumption at the t period; $k(k > 0)$ represents the market capacity of the product; k_2 ($0 < k_2 < 1$) indicates the saturation of the product market.

3.2 Hypothesis 2

There is a unit time delay in the transmission of consumer demand information from distributor to manufacturer, that is, the manufacturer processes consumer demand information at the $t+1$ period, and the delay will cause information distortion. Because the decision-makers of each node in the supply chain often reprocess the demand information based on their interests, which leads to a certain degree of delay and distortion of demand information, this assumption is reasonable. The following is a mathematical formula:

$$y_{t+1} = x_t - k_3 x_t \tag{2}$$

where y_{t+1} represents the manufacturer's production at the $t+1$ period ($y_{t+1} < 0$ reflects the manufacturer's virtual production due to consumer's aversion to the product). Because of the unit delay of information, it can only arrange production according to the consumption demand at the t period. k_3 is the distorted degree of delay to demand information. $k_3 \leq 0$ indicates that the entire consumer demand for the manufacturer has been amplified; $k_3 \geq 0$ indicates that the consumer demand has been reduced.

Manufacturers' production strategies mainly include make to stock (MTS) and build to order (BTO). MTS refers to the formulation of production plans and material procurement plans according to consumer demand and the needs of enterprise safety inventory and organizing production; BTO refers to the production of enterprises directly according to consumer demand orders, without considering the safety inventory situation. Combined with the above assumptions, two systems dynamics models of supply chain can be established as follows:

1. The supply chain model under MTS strategy:

$$\begin{cases} x_{t+1} = k_1 y_t + k_2 y_t^2 \\ y_{t+1} = (1-k_3)x_t + k_4 y_t \end{cases} \tag{3}$$

where $k_4(0 < k_4 < 1)$ is the product safety stock coefficient.

2. Supply chain model based on BTO strategy

$$\begin{cases} x_{t+1} = k_1 y_t + k_2 y_t^2 \\ y_{t+1} = (1-k_3)x_t \end{cases} \tag{4}$$

4 Experience

The Lyapunov exponent, power spectrum, and correlation dimension of the system are studied to reveal its dynamic properties.

4.1 Lyapunov index

Lyapunov exponent is an index to quantitatively describe the exponential divergence of adjacent orbits in phase space. If Lyapunov exponent is negative, it indicates that phase volume shrinks, motion is stable, and is insensitive to initial value; if Lyapunov exponent is zero, it corresponds to the critical state, that is, the stable boundary; if Lyapunov exponent is positive, it indicates adjacent orbits. Long-time behavior is very sensitive to initial values, and the motion is chaotic. There are many ways to calculate the Lyapunov exponent. In this paper, Gram-Schmidt orthogonalization algorithm is used in the paper, and the specific steps are as follows:

An autonomous system passes through the flow space of x_0 to form a track $x(t)$. If the initial condition is x_0, and there is a deviation of $\triangle x_0$, from $x_0 + \triangle x_0$ point to another orbit. And it forms another tangent space vector $\triangle x(x_0, t)$, defining the deviation $\omega(x_0, t) = \triangle x(x_0, t)$, and fixed small time interval τ is selected. The $\omega_{k-1}(\tau)$ is calculated according to the $\omega_{k-1}(0)$; the trajectory is from the $x((k-1)\tau)$ to $x(k\tau)$. And the variable can be calculated as follows:

$$d_k^{(j)} = \left| \omega_{k-1}^{(j)}(\tau) \right| \tag{5}$$

$$\omega_k^{(j)}(0) = \frac{\omega_{k-1}^{(j)}(\tau)}{d_k^{(j)}} \tag{6}$$

In which, $j = 0, 1, 2 \cdots n$, and orthogonalization is processing.

$$\omega_{k-1}^{(j)}(\tau) = \omega_{k-1}^{(j)}(\tau) - \sum_{i=1}^{j-1} \left\langle \omega_k^{(i)}(0), \omega_{k-1}^{(j)}(\tau) \right\rangle \omega_k^{(i)}(0) \tag{7}$$

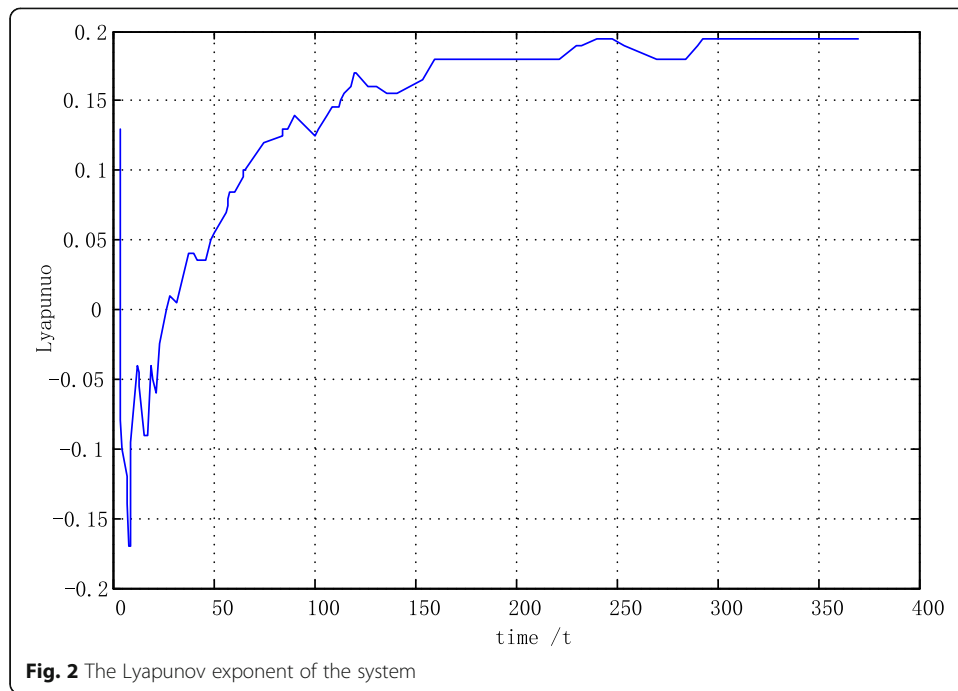$$d_k^{(j)} = \left| u_{k-1}^{(j)}(\tau) \right| \tag{8}$$

$$\omega_k^{(j)}(0) = \frac{u_{k-1}^{(j)}(\tau)}{d_k^{(j)}} \tag{9}$$

According to the relationship between higher order and first order, the Pth Lyapunov exponents can be obtained as follows:

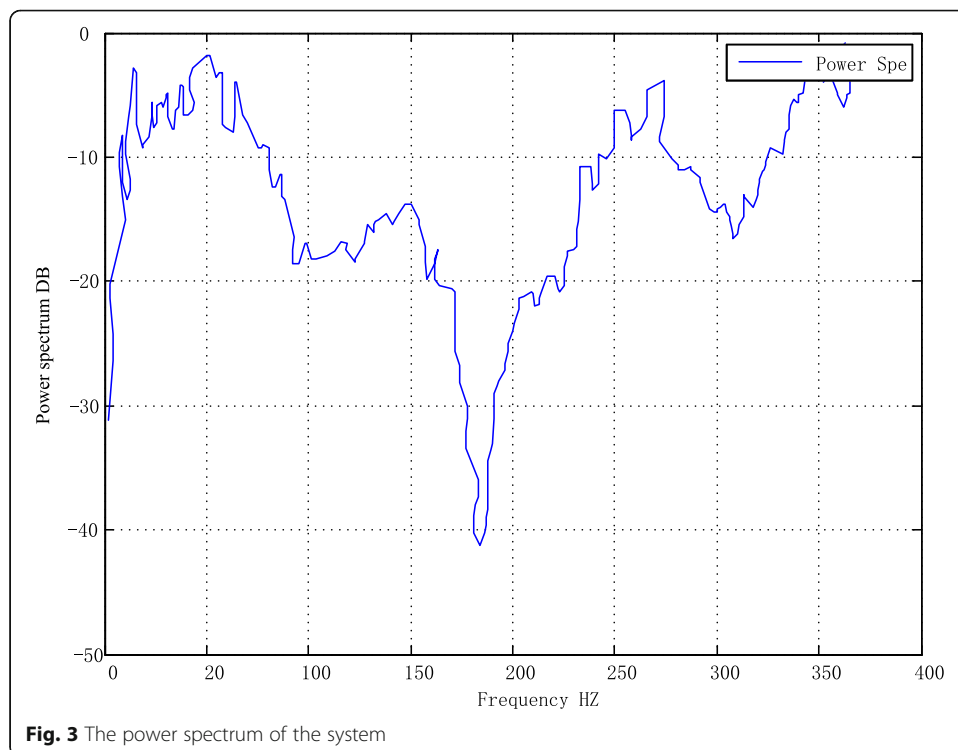$$\sigma_p = \lim_{m \to \infty} \frac{1}{m\tau} \sum_{i=1}^{m} \ln d_i^{(p)} \tag{10}$$

Formula (10) is the actual algorithm for calculating the Lyapunov exponent.

Under the above parameters, the Lyapunov exponent spectrum of the chaotic time series of the system (3) can be calculated by using the above algorithm. The Lyapunov exponent spectrum of the chaotic time series is 0.158115 and 0.078138, that is, the exponential spectrum of the perturbed coefficient is (+, +) type. Obviously, the Lyapunov exponent of the time series is always greater than zero over time, indicating that the system is chaotic. And the Lyapunov exponent of the system is shown in Figs. 2 and 3.

Fig. 2 The Lyapunov exponent of the system

4.2 Power spectrum

Chaotic motion is characterized by non-periodicity and complexity, which is different from the discrete characteristics of periodic motion or quasi-periodic motion. It is a continuous spectrum. The calculation method is the mean value of the square of the Fourier transformation square of the sample function as follows:

Fig. 3 The power spectrum of the system

$$S(jw) = \lim_{T \to \infty} \left| \int_0^T x(t)e^{-jwt}dt \right|^2 = \lim_{T \to \infty} |x_\tau(jw)|^2 \tag{11}$$

For the time series x_0, $x_1 \cdots x_n$ (time increment is t), its Fourier transformation is in the form of as follows:

$$X(jw_m) = \vartriangle t \sum_{k=0}^{N} p_k x_k e^{-jkw_m} \tag{12}$$

$$w_m = 2\pi \vartriangle tm/N, \quad m = 0, 1 \cdots (N/2)-1 \tag{13}$$

p_k is a time window, and $X(jw_m)$ can be obtained by using the fast Fourier transformation (FFT) algorithm.

Figure 4 is the power spectrum of the system (3) under the above parameters. It can be seen that the peak value of the power spectrum is continuous, so the system is a typical chaotic state.

4.3 Fractal

Fractal is a very vivid illustration of the geometric characteristics of chaotic time series, that is, there are structural, morphological, and functional similarities between the local and the whole; the similarity does not change when the scale of the Ministry of Administration changes. The complexity and irregularity of fractal can be described quantitatively by correlation dimension, which can represent the characteristics of essential factors, the number of state variables, and the degree of influence on the system. It can

Fig. 4 The correlation dimension of the system

be used to judge the chaos of supply chain and predict the future changes of production decisions.

Using the C-C method, the embedding dimension 15 and time delay $T = 3$ of the chaotic time series can be calculated. The correlation dimension of Grassberger-Procaccian design is calculated as follows:

Embedding the time series into the multi-dimensional phase space and connecting the phase points is the evolution trajectory of the system in the reconstructed phase space. The degree of correlation between the points can be measured by their Euclidean distance. The Euclidean distance formula between the two points is as follows:

$$d\left(r_i, r_j\right) = \sum_{k=0}^{m-1} \left(x_{i+kT} - x_{j+kT}\right)^{1/2} \tag{14}$$

Set a number r, and then check how many points have their distances $d(r_i, r_j) < r$, and use the correlation integral $C(r)$ to represent the ratio of the logarithm of points whose distances are less than r to the logarithm of the total point N_m. And the $C(r)$ can be expressed as follows:

$$C(r) = \frac{1}{N_m(N_m-1)} \sum_{i,j=1,i\neq j}^{N_m} \theta\left(r - d\left(r_i, r_j\right)\right) \tag{15}$$

In which, $\theta(x)$ is a step function.

$$\theta(x) = \begin{cases} 1 & x > 0 \\ 0 & x < 0 \end{cases} \tag{16}$$

Properly selecting of interval r, $C(r)$ and r have the following relations:
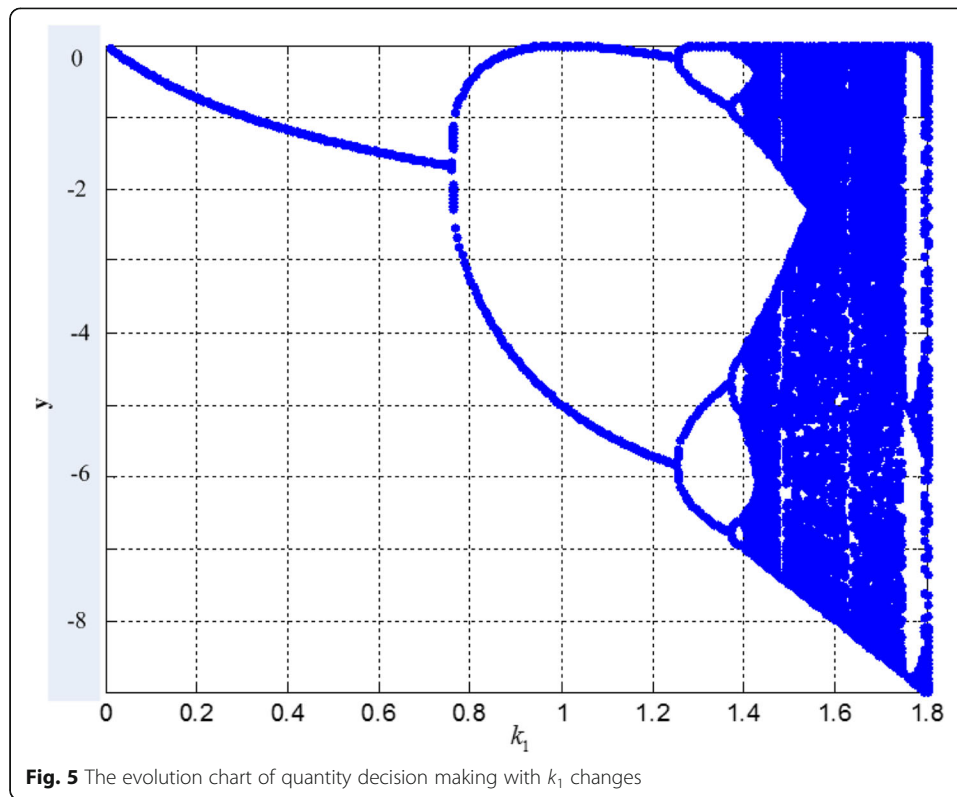
$$C(r) = r^D \tag{17}$$

D is the relative dimension of the time series; it is obtained as follows:

$$D = \lim_{r \to 0} \frac{\ln C(r)}{\ln r} \tag{18}$$

In practical calculation, if one interval of R is properly selected, multiple values of $C(r)$ can be obtained. The correlation dimension D can be obtained from the slope of the regression line of $\ln C(r)$ and $\ln r$, and then, the embedding dimension m can be increased. When D becomes stable gradually with the increase of m, the correlation dimension of the time series can be obtained.

By using the method of calculating the correlation dimension of chaotic time series, the relationship between the variables of system (3) and the $\ln C(r) - \ln r$ is shown in Fig. 4, when the embedding dimension is 5, 6, and 7 ($m = 1$), and the correlation dimension is 1. 79664; it shows that the system is a complicated chaotic system.

From the above analysis, it can be seen that the system (3) shows the fractal and chaotic characteristics of the very complex nonlinear system in a certain range of parameters. The evolution of the manufacturer's production strategy is shown in Fig. 5 when the parameter k_1 changes continuously in [0, 1.8], and the market demand capacity varies in a certain range, but other parameters remain unchanged; there are obvious single cycle, bifurcation, and chaos phenomena in the system.

Fig. 5 The evolution chart of quantity decision making with k_1 changes

This is because, with the increasing demand of consumers, manufacturers can initially satisfy demand through recruitment, purchase of raw materials and equipment, and the production of enterprises can maintain a balanced one-cycle state of demand and distribution; but after all, the capital of enterprises is limited, and when supply can not meet demand, the two bifurcate. The deviation is bigger and bigger, and finally leads to chaos. At this time, the production of enterprises is still not random; it changes in the scope of the "attractor" of consumer demand. If enterprises make their production capacity and market demand match again through restructuring, mergers and acquisitions, and other self-organizing methods, they can jump out of the chaos and recur periodic phenomena, and continuously evolution, but ultimately towards chaos.

Chaos is a pseudo-random process of seemingly irregular motion, which can be predicted in the short term and unpredictable in the long term. The process of chaos changes with the exchange of material, energy, and information between the system and the external environment. The behavior of the nonlinear system can be changed from simple to complex. This process is usually carried out in a certain way. For example, with the occurrence of period-doubling bifurcation, the self-similarity in the supply chain appears, and the system trend. Chaos can predict the future of the system from the nature of system changes.

Chaos will have adverse effects on the operation of the supply chain, such as bullwhip effect. Bullwhip effect refers to the enlargement of market demand in supply chain and the instability of the system resulting from it, which makes the inventory and inventory cost increase, the inventory redundancy of distributors, and the excessive production of manufacturers in supply chain, resulting in the confusion of product inventory and

Table 1 The difference of production decision-making caused by the change of consumption demand x_1

1	2	3	4	5	96	97	98	99	100
0.600	− 0.600	− 1.169	0.754	− 1.277	1.770	− 0.748	− 4.030	0.646	1.354
0.600	− 0.601	− 1.169	0.756	1.533	0.282	− 2.203	− 0.712	1.962	1.204

production strategy in supply chain. This is mainly due to the fact that the manufacturer's production decision-making is sensitive to the initial value of consumer demand under chaotic conditions, and any small change in consumer demand will make the forecast results vary greatly over time, as shown in Table 1. At the same time, demand information produces time delay and content twist in the process of progressive upload. The result of a slight change in the parameters is very different, as shown in Table 2. All these result in the inconsistency between the number of manufacturers and the actual market demand, that is, bullwhip effect.

5 Results

In practice, people not only need to use the chaotic characteristics of the supply chain to organize flexible production but also to prevent the harm of chaos. Because the supply chain system is not always chaotic, whether chaos occurs and whether it occurs sooner or later is conditional, so it is feasible to control chaos according to different needs. By adjusting the parameters or initial values of the system, on the one hand, bifurcation can be stimulated, and chaos can be induced to implement flexible production; on the other hand, bifurcation can be restrained, and chaos can be eliminated or delayed, and chaos control can be finally realized.

When the total market demand increases to 200, the retailer's sales will increase to 200, and the retailer and distributor's replenishment demand will also increase to 200, so the manufacturer's expected and actual output will eventually increase to 200. Since the expected inventory levels of retailers, distributors, and manufacturers are all 400, the inventory levels of retailers, distributors, and manufacturers should eventually stabilize to 400.
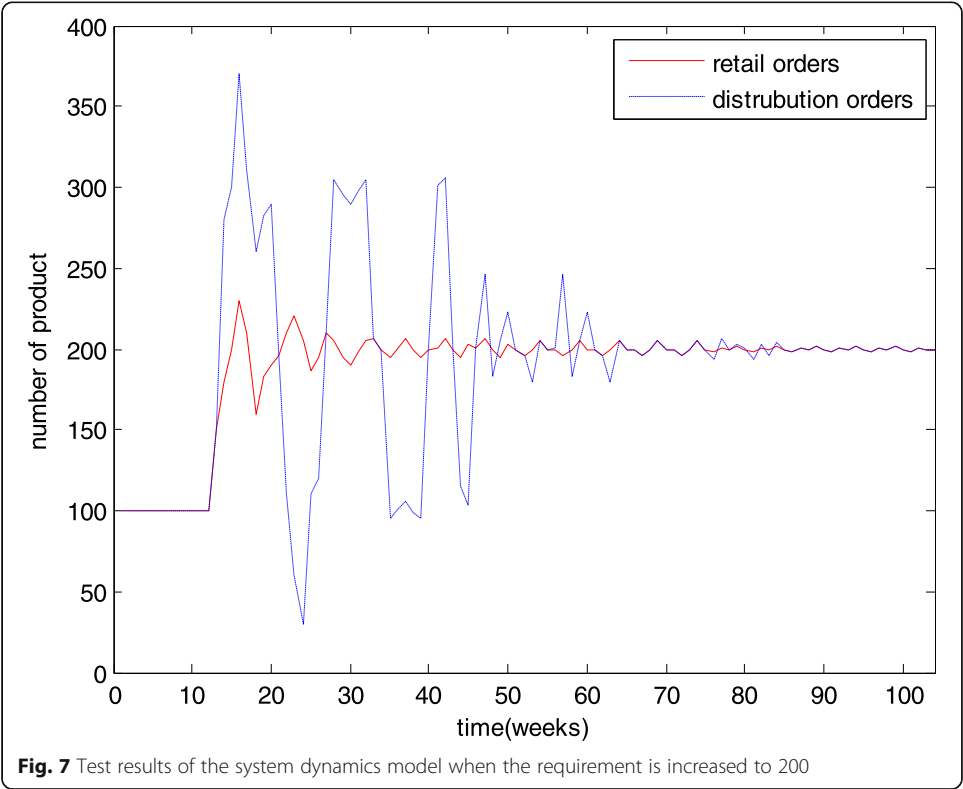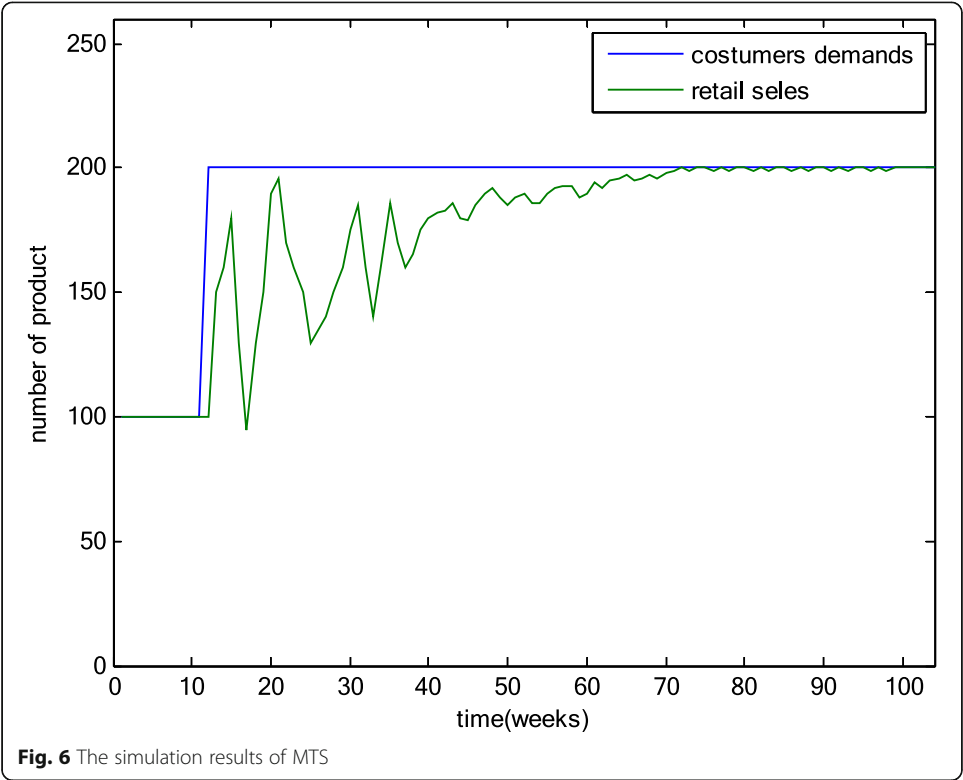
Figure 6 is the result of MTS simulation, and Fig. 7 shows the test result of the system dynamics model of the MTS production strategy when the demand increases to 100. It can be seen from Figs. 6 and 7 that the order quantity and inventory changes of retailers and distributors are completely in line with the actual situation.

6 Discussion

Facing the rapid development of modern information technology and the increasingly complex competition trend, information sharing in supply chain enterprises is the necessary guarantee for enterprises to provide high-quality, high-satisfaction products and services in time. By introducing the characteristics of school uniform products and the problems existing in the supply chain of school uniform products, and the emerging

Table 2 The difference of production decision-making caused by the change of k_3

1	2	3	4	5	96	97	98	99	100
0.600	− 0.600	− 1.169	0.754	1.533	1.770	− 0.748	− 4.030	0.646	1.354
0.600	− 0.601	− 1.170	0.756	1.556	− 0.524	− 3.227	− 0.452	1.935	− 0.620

Fig. 6 The simulation results of MTS

Fig. 7 Test results of the system dynamics model when the requirement is increased to 200

Internet of things technology framework, this paper applies the Internet of things technology to the supply chain of school uniform industry and establishes an efficient and visual school uniform product supply chain system based on the Internet of things technology. And based on the characteristics of complexity, dynamics, user-oriented, and node-member crossover of supply chain system, this paper establishes a supply chain model under MTS and BTO strategy. By calculating Lyapunov exponent, power spectrum, and correlation dimension, the bifurcation and chaos of the supply chain system under certain conditions are analyzed. The following conclusions can be drawn: (1) Bullwhip effect will occur in the chaotic supply chain system, which can be suppressed by short-term forecasting and accelerating the speed of demand information transmission; (2) Chaos is also beneficial to enterprises, such as making low-cost flexible production possible, so there is a high theory and practical research value.

Abbreviations
RFID: Radio frequency identification devices; IOT: Internet of things

Author's contributions
Chen Jun was responsible for full-text data collection, experimental simulation, and thesis writing. The author read and approved the final manuscript.

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate
This article does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication
All authors agree to submit this version and claim that no part of this manuscript has been published or submitted elsewhere.

Competing interests
The author declares that he has no conflict of interest.

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