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An Intelligent Supply Chain Information Collaboration Model Based on Internet of Things and Big Data

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ABSTRACT Supply chain information collaboration refers to a relationship in which supply chain partners organically integrate, coordinate, and develop resources, business processes, and organizations in order to achieve common goals. The goal is to create and coordinate efforts in all aspects of the supply chain. The overall value of the supply chain is greater than the simple sum of the value of each link, thereby improving the competitiveness of the entire supply chain. However, information sharing in supply chain information collaboration has always had problems such as information distortion, information loss, and information delay. The effective coordination of information has become a difficult point in supply chain management. This paper mainly uses the Internet of Things and big data technology to build a simulation model of the supply chain bullwhip effect based on the mathematical model of the bullwhip effect and uses the simulation method to simulate and study the key factors in the model. The image of the simulation results objectively clarifies the value of information collaboration in the supply chain.

INDEX TERMS Supply chain, information collaboration model, Internet of Things, big data.

I. INTRODUCTION

With the advent of economic globalization, integration, and the era of knowledge economy, competition among enterprises has intensified. The traditional business management and operation management model can no longer be used in the new market environment. More and more enterprises are beginning to understand the use of supply chain management ideas to achieve synergy and internal management of the internal and external environment [1], [2]. This will increase the customer's satisfaction with the company, which will enable the company to enhance its core competitiveness in such an environment. In the highly competitive dynamic market environment of the century, sufficient information coordination should be carried out between the supply chain nodes, so that the unknown within the supply chain is eliminated. Supply chain information collaboration allows companies to fully understand upstream product supply information as well as downstream raw material demand information. Only by fully grasping this part of the information, each supply chain node can plan production, transportation and sales. Information collaboration can solve the bullwhip effect, reduce the overall cost of the supply chain, and create overall value [3], [4].

Domestic and foreign scholars have also done a lot of research work on the impact of the Internet of Things in supply chain management. Literature [5] studied the problem of using the Internet of Things to solve the bullwhip effect through case and experimental methods. It is believed that the advantages of RFID technology and network technology can enable real-time information transmission, ensuring that supply chain members can understand information in a timely and accurate manner; it also can eliminate the bullwhip effect. The literature [6] establishes a mathematical model to study how to help enterprises to develop the optimal ordering strategy of supply chain through the Internet of Things technology; the literature [7] points out that through the Internet of Things technology can reduce inventory, the cost of loading

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and unloading is reduced, lacking the number of goods is reduced, which increases the efficiency of the supply chain; according to the business application and business classification of the Internet of Things, the literature analyzes the key technologies and bottlenecks of the current development of the Internet of Things, and tries to use a new business development model to better integrating IoT information management; the literature [9] analyzes the impact of the Internet of Things on all aspects of supply chain management, and uses the enterprise logistics module as the research object to explore the practical application of enterprises in the Internet of Things environment; IoT technology can better help companies solve three major dilemmas, namely tracking, monitoring and coordinated control.

The research on supply chain information coordination mainly focuses on the content, method and value of information collaboration. Literature [11] will be divided into three categories: management coordination, technology collaboration and human-machine collaboration. The differences in value sharing between information sharing under different conditions are analyzed, and the internal relationship between supply chain coordination and information sharing is discussed. The literature [12] believes the supply chain system has a wide range of synergistic effects, and deeply analyzes the key role of information synergy in supply chain system decision-making, and studies the information risk control strategy in information collaboration. Through the objective evaluation of the degree of synergy, finding the weak links of information coordination in the supply chain can provide quantitative criteria and basis for the further improvement of supply chain information coordination. Therefore, how to evaluate the degree of information collaboration between node enterprises has become a very valuable research issue. Some studies have adopted a quantitative evaluation method for information collaboration, and analyzed the cooperation effect of supply chain information according to different evaluation indicators, which is used to judge the information sharing and collaboration status of enterprises in each link of the supply chain [13]. The most representative and authoritative study is the supply chain coupling method proposed by Mehmet, which can quantify the degree of synergy in supply chain information [14]. In [15], Jianli mathematical model, a performance evaluation index system was established for the information system under the supply chain management mode, and the fuzzy comprehensive evaluation method was used to evaluate the information system collaboration. The literature [16] proposed supply chain information collaboration. The evaluation method evaluates the breadth and depth of sharing and application information such as demand, production capacity, inventory, and production plan in the supply chain based on a two-dimensional index.

Judging from the traditional implementation of supply chain management, most enterprises in the supply chain first consider the interests of their own enterprises. The lack of communication between enterprises is difficult to achieve shared collaboration. Moreover, the lack of information management in the operation of the enterprise, the products cannot be effectively monitored, the actual demand information of the products of each node cannot be transmitted and shared in time, and the enterprises often make mistakes in the processing of information. Based on the theory of Internet of Things and big data, this paper comprehensively considers the information characteristics of supply chain based on the perspective of supply chain vulnerability, and analyzes the existing bullwhip effect problem and information collaboration model in the supply chain based on the existing theory. The simulation model verifies the effectiveness of the information collaboration model for weakening the bullwhip effect. The contribution of the algorithm is to improve the efficiency of information sharing, reduce the risk of supply chain interruption, and enrich the research results of information coordination mechanism construction, so as to propose a supply chain coordination model to improve the bullwhip effect, and effectively solve the bottleneck problem in the bullwhip effect to provide a new way to solve the bullwhip effect.

II. SYSTEM MODEL

A. INTERNET OF THINGS

From the development history of the Internet of Things, from the initial simple identification of objects to the application of sensors to the integration of radio frequency identification [17], nanotechnology [18], intelligent embedded technology [19], the technology and connotation of the Internet of Things is constantly expanded. The essence is to allow the items on the earth to transmit information spontaneously. Through the network, people receive information about the items and send instructions to the items, and the items can intelligently receive control information, intelligently act to reach the purpose of intelligent dialogue of material world and people.

Long before the Internet of Things was popular, applications such as smart home, smart transportation, smart grid, and intelligent logistics have developed in their respective industries and fields. The term IoT, which is gradually widely recognized, unifies the ''intelligence'' of various industries and can produce a good cluster effect. The research on the Internet of Things is not limited to a certain industry, but covers human production and life all activities.

The technical architecture of the Internet of Things is basically determined to be divided into three levels: the perception layer, the network layer, and the application layer. The sensing layer is equivalent to the nerve endings of human beings, recognizing objects in different environments, and collecting information; the network layer is equivalent to the human nerve center, and the collected external information is processed and transmitted; the application layer is equivalent to the external behavior of the human being, the analyzed and processed information is intelligently applied, and its structure is shown in Figure 1.

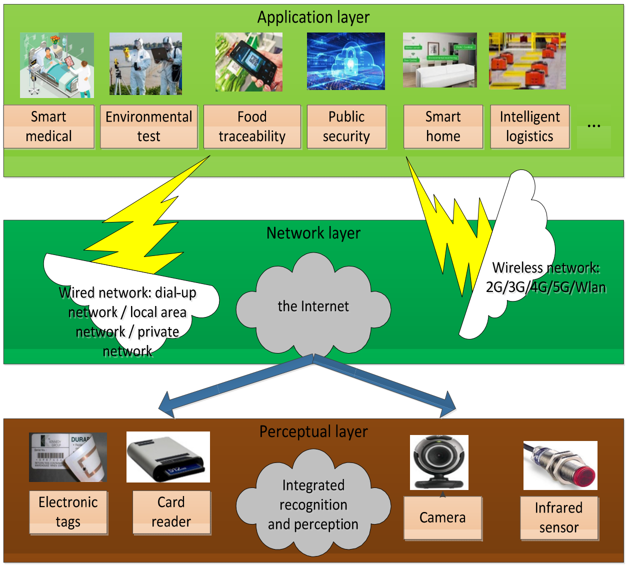

FIGURE 1. Structure of the internet of things.

The development of the Internet of Things relies on electronic product coding technology and Internet technology. It is a new product of the organic combination of these two technologies, and it is also one of the research results across disciplines. The Internet of Things is a network that uses the Internet platform as a carrier to establish all interconnected and independently addressable things through wireless communication technology and radio frequency technology. Simply put, the Internet of Things contains the following two points: (1) all foods that can be independently addressed can serve as clients of the Internet of Things, and the Internet of Things realizes timely contact between these users; (2) the Internet of Things is relying on in the essence of the internet, the Internet of Things is a special form of the Internet. It is within the scope of Internet technology development. It can be seen that the internet is not only the basic condition for the existence of the Internet of Things, but also its future development of core [20].

B. INTERNET OF THINGS TECHNOLOGY AND ITS APPLICATION IN SUPPLY CHAIN MANAGEMENT

Because all links in the supply chain are changing in real time, it affects the availability and real-time of supply chain information. The supply chain information collaboration based on the Internet of Things has overcome the above problems well, and its application feasibility, efficiency and other advantages have been demonstrated by many scholars. This section will briefly introduce the Internet of Things technology and its application in the supply chain.

1) EPC/RFID TECHNOLOGY AND ITS APPLICATION

RFID radio frequency identification is a non-contact automatic identification technology that automatically identifies target objects and acquires relevant data through radio frequency signals. The electronic product code EPC is a unique identifier unique to each entity object. EPC uses RFID as a carrier to establish a global open labeling standard for each item, enabling tracking and tracing worldwide.

TABLE 1. Basic composition of EPC/RFID system.

System Components	Name	Comment
Global product electronic code coding system	EPC coding standard	Identify the specific code of the target
Radio frequency identification system	EPC label	Stick to an item or embedded in an item
	Reader	Read EPC tags
Information network system	Savant	EPC system software support system
	ONS	
	PML	

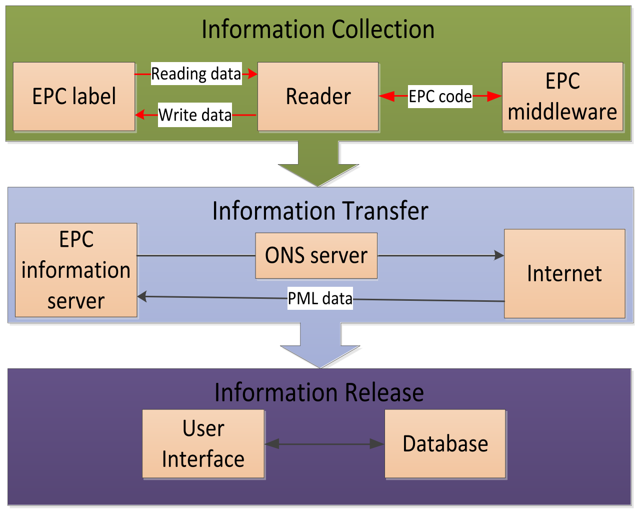

FIGURE 2. EPC / RFID system workflow.

The Internet of Things based on EPC/RFID technology is mainly composed of electronic product coding (EPC), radio frequency identification (RFID) system and information network system. The basic composition of each part is shown in Table 1. The EPC middleware is the nervous system of the RFID system. It is responsible for processing and processing the information flow read by the reader. It is the link between the reader and the enterprise application. The ONS object name resolution service is used as the EPC middleware and EPC information service. A hub connects to the middleware to indicate information about the product. EPCIS provides a modular, scalable interface to data and services that allows EPC-related data to be shared across the enterprise or across enterprises. The workflow is shown in Figure 2.

In the supply chain, EPC labels are affixed to individual products, containers, pallets, carriers, and the label codes of these physical objects are related in the supply chain process, according to which the circulation process of the products is completely recorded, come down. Each part installs a scanner with a built-in RFID reader or a variety of information read by the handheld device, and is equipped with corresponding EPC middleware and computer internet system to transmit the acquired information to the internal information system in real time. And the internet system to achieve information collection, transmission and sharing in the intersection. The application of EPC/RFID technology improves the transparency of the supply chain. Consumers can read the EPC label to understand the details of the product's circulation and purchase the product with confidence; the logistics enterprise can realize the advantages of dynamic product entry and exit, automatic inventory, and real-time recording of product status; other members of the supply chain can also grasp the dynamic information of the products and achieve high information sharing and information coordination in the supply chain.

2) WIRELESS SENSOR NETWORK TECHNOLOGY AND ITS APPLICATION

The sensor is the sensory organ of the machine sensing the world of the material. A large number of sensors are distributed in the monitoring area to sense the most original information such as temperature, humidity, concentration, pressure, vibration and pollution.

The wireless sensor network combines sensors with wireless network technology, assigns each sensor an address, integrates sensor nodes, aggregation nodes, and task management nodes to collaboratively sense, collect, transmit, and process monitoring information within the network coverage area, also have the function of real-time data collection, supervision and control, information sharing and storage management. The wireless sensor network nodes form a network in a self-organizing manner. Each node collects data autonomously and transmits the monitoring data to other sensor nodes. The data is sent to the aggregation node through single-hop or multi-hop relay. The aggregation node sends the collected data to the remote task management node via the Internet or satellite, or sends the data to the machine for data processing and storage through the interface. The user manages the sensor network through the task management node and configures it reasonably, publishes real-time tasks, and collects monitoring data, as shown in Figure 3.

The Internet of Things based on sensing technology can be applied to medical and health, remote theft, infrastructure management, environmental monitoring and other fields. The distribution of various sensor nodes in the production hall enables real-time monitoring of the production environment and intelligent control of the infrastructure. During the transportation process, the information is collected periodically or irregularly through micro-sensors such as temperature, humidity, air pressure and vibration distributed around the article, and sent to the remote monitoring center through the communication network to realize the whole process monitoring.

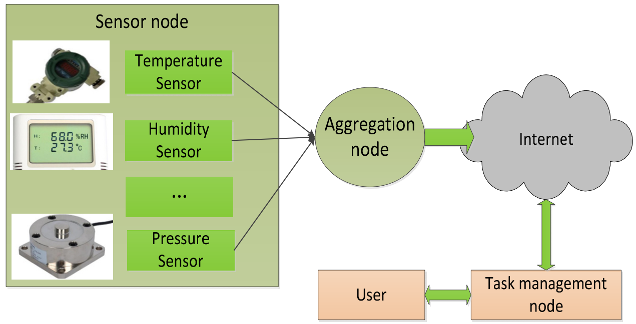

FIGURE 3. Wireless sensor workflow.

In the event of a dangerous or excessive signal, perform appropriate emergency measures based on the results to avoid causing huge losses. Sensing technology can effectively realize remote control in supply chain information sharing, collect detailed information in management, master all factors affecting the supply chain, comprehensively monitor and control and optimize supply chain processes.

C. CLOUD COMPUTING

In order to solve the resource problem of complex data in the Internet of Things environment, cloud computing technology in big data is adopted. Cloud computing is a supercomputing model that combines server resources with a large amount of information stored on mobile terminals, individuals, and other terminal devices. The information collaboration based on the cloud computing platform can solve the shortcomings of the traditional information collaboration platform.

Cloud computing is equivalent to a shared pool of configurable computing resources. This shared pool includes resources such as computing servers, storage servers, and application servers. Users can access shared pools through network access, enjoy resources and services, and spend the least cost. A computing model enjoys better service with time. Figure 4 shows a conceptual diagram of cloud computing.

D. SUPPLY CHAIN INFORMATION COLLABORATION

This paper mainly studies the information collaboration model of intelligent supply chain, and the management collaboration has first appeared in the research on diversified investment of enterprises. In 1965, Igor Ansoff first mentioned the concept of synergy in the book "Company Strategy" and described it as: the business performance of the business group formed by a simple summary of the individual components, i.e. the relationship between the two companies is symbiotic, which is based on resource sharing. In 1996, Jim Hepplemann, the father of collaborative business, proposed that people-oriented collaborative work will become the core to measure whether a company is truly competitive in the future. The most basic meaning of synergy is that multiple people and multiple departments work together to achieve the same goal. Collaboration is based on users and businesses,

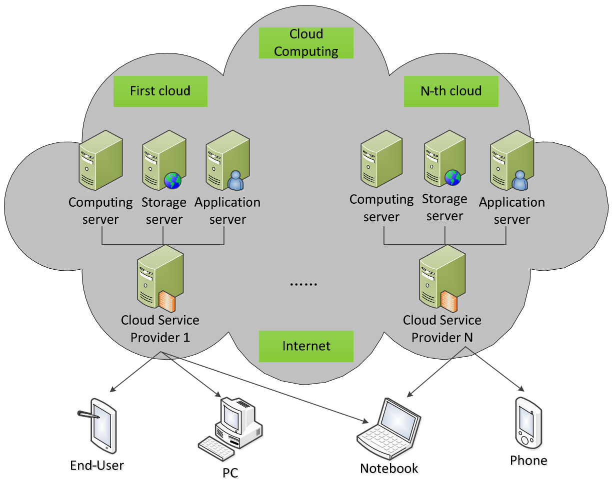

FIGURE 4. Cloud computing concept map.

effectively organizing and harmoniously utilizing various resources to eliminate the ideological system of information islands.

Supply chain collaboration [21] refers to a relationship in which supply chain partners organically integrate, coordinate, and develop resources, business processes, and organizations in order to achieve common goals. The goal of supply chain coordination is to start from the supply of raw materials, in the whole process of moving products or services to the final customers, through the coordination and joint efforts of all links in the supply chain, to create a supply chain that is larger than the simple sum of the value of each link value, thereby increasing the competitiveness of the entire supply chain.

Supply chain collaboration describes a state of synchronized operation between members of the supply chain. In the development of members with synergy, the company not only develops into a strategic partnership, but also has long-term agreements to achieve common goals. There must be strict distinction and definition of collaborative supply in planning, role differentiation and communication channels. The decision-making power of each member of the chain remains within their respective companies, but all decision-making processes need to be coordinated and coordinated on the basis of highly shared information [22].

To achieve coordinated supply chain management, enterprises must meet the following conditions: first, to stabilize and strengthen the synergy between enterprises, the second is to fully play the synergy effect, and finally avoid the problems that may arise from the expansion of enterprise organization scale. To form a large competitive advantage, an enterprise must have a certain scale. Enterprises participating in supply chain coordination can guarantee the basic independence of member companies, thus avoiding the disadvantages of the expansion of the organization scale and at the same time obtaining synergy through cooperation and mutual assistance among member companies.

III. CONSTRUCTION OF INTELLIGENT SUPPLY CHAIN INFORMATION COLLABORATIVE MODEL BASED ON INTERNET OF THINGS

Based on the theory of Internet of Things and big data, this paper analyzes the relationship between the bullwhip effect problem and the information collaboration model in the supply chain based on the existing theory, and constructs the information collaboration model of the supply chain bullwhip effect in order to improve the efficiency of information collaboration, reduce the risk of supply chain disruption, and enrich the research results in the construction of information coordination mechanisms.

A. MATHEMATICAL MODEL OF BULLWHIP EFFECT

Based on the Internet of Things technology and cloud computing environment, this paper builds an information collaboration model of supply chain bullwhip effect through bullwhip effect, in order to improve the efficiency of information collaboration, reduce the risk of supply chain interruption, and enrich the research results of information coordination mechanism construction.

Suppose you build a simple supply chain with only one producer and retailer (the supply chain can also be a four-tier supply chain with suppliers, producers, wholesalers, and retailers). In the t period, the manufacturer predicts the order quantity of the retailer t+1 period based on the retailer's order quantity historical data. In this supply chain, manufacturers only sell to retailers, and assuming that only one product is sold. Since the retailer is closest to the market, he directly controls the demand information of the end customer, and he can predict the demand information. Suppose the variable D_t represents the end customer's needs, and this demand is random [23], [24]:

$$D_t = \mu + \lambda D_{t-1} + \theta_t \tag{1}$$

In equation (1), μ is constant and greater than zero; λ is the correlation coefficient between demand variables in two adjacent periods, referred to as autocorrelation coefficient, and satisfies $-1 < \lambda < 1$; θ_t refers to demand the variation error of the variable, which is independent in each period, $\theta_t \sim N(0, \sigma^2)$; assuming that σ is much smaller than μ, thus ensuring that the demand variable $D_t > 0$. Obviously, when $\lambda = 0$ in the equation (1), the demand variable $D_t \sim N(\mu, \sigma^2)$ is required.

It can be known from the above formula (1) that this demand variable changes with time. When $t \to \infty$,

$$E(D_t) = \frac{\mu}{1-\lambda} \tag{2}$$

$$Var(D_t) = \frac{\sigma^2}{1-\lambda^2} \tag{3}$$

It can be seen from equations (2) and (3) that $E(D_t)$ floats up and down $\mu/(1\text{-}\lambda)$, but $E(D_t)$ and $E(D_{t-1})$ do not necessarily be the same. Many scholars who study supply chain management information sharing have adopted the above method for demand variables.

Assume that there is an order lead time L when the retailer orders from the upstream supplier in the supply chain, and the retailer receives the goods ordered from the supplier at the end of the t period each time during the t+L period. Also assume that the retailer adopts a (s, S) inventory strategy to ensure that the product is maintained at a certain level. Set the order point y_t at any time t, the following function:

$$y_t = L\bar{D}_t + \varphi\sqrt{L}S_t \tag{4}$$

In equation (4), L represents the order lead time and is constant; S_t represents the standard deviation estimate; φ refers to the supply service level factor.

According to the normal distribution function, when $\varphi = 1, 3$, there is a supply rate of 84.1% and 99.8% in the L time.

The retailer's market demand and standard deviation are predicted by the moving average method. D_i is used to represent the customer demand during the i period, and there is the following formula:

$$\bar{D}_t = \frac{\sum_{i=t-n}^{t-1} D_i}{n} \tag{5}$$

$$S_t^2 = \frac{\sum_{i=t-n}^{t-1} (D_i - \bar{D}_t)^2}{n-1} \tag{6}$$

Then in the formula (5)(6) represents the number of observation periods selected in the moving average method, and the larger the n value, the more the observed historical data is, and the smoother the processing result is.

Assume that the variable Q_t is the quantity of goods ordered by the retailer to the upstream enterprise manufacturer, which satisfies the following formula:

$$Q_t = y_t - y_{t-1} + D_{t-1} \tag{7}$$

In equation (7), if the order quantity Q_t has a negative number, then the supplier is allowed to allow the retailer to return the excess order quantity without cost. Then, the formula (4) and the formula (5) (6) are substituted into the formula (7), and the results are as follows:

$$Q_t = (1 + \frac{L}{n})D_{t-1} - (\frac{L}{n})D_{t-n-1} + \varphi\sqrt{L}(S_t - S_{t-1}) \tag{8}$$

For the order quantity Q_t in the formula (8), take the variance and sort it out:

$$Var(Q_t) = [1 + (\frac{2L}{n} + \frac{2L^2}{n^2})(1 - \lambda^n)]Var(D_t) + \varphi^2 LVar(S_t - S_{t-1}) \tag{9}$$

$$Var(D_t) = \frac{\sigma^2}{1-\lambda^2} \tag{10}$$

$$Cov(D_{t-1}, D_{t-n-1}) = \frac{\lambda^n \sigma^2}{1-\lambda^2} \tag{11}$$

In this calculation, the following theorem is borrowed: if the retailer predicts the customer's demand in the form of formula (1), and the estimated value of the standard deviation in the order lead time L is $\hat{\sigma}_t^L$, then $Cov(D_{t-i}, \hat{\sigma}_t^L) = 0, i = 1, 2, \ldots, n$.

As can be seen from equation (9), the second term at the right end is a non-negative number, which is divided by $Var(D_t)$ in equation (2)(3) to obtain a value, resulting in equation (12). This value represents the ratio of the variance of the order quantity received by the manufacturer to the variance of the customer's demand received by the retailer. Therefore, this formula can be used as the quantization formula BE of the bullwhip effect.

$$BE = \frac{Var(Q_t)}{Var(D_t)} \geq 1 + 2(1 - \lambda^n)\frac{L(L+n)}{n^2} \tag{12}$$

From the above analysis of the application of moving average prediction, the same applies to other prediction methods. The following is an exponential smoothing method for predictive analysis, and the demand variable $D_t = \alpha D_{t-1} + (1-\alpha)D_{t-1}$ is set, where α represents a smoothing coefficient and $0 < \alpha < 10$.

In equation (12), we can clearly see that the demand information becomes larger after being transferred from the retailer to the producer in the supply chain, that is, the information synergy model of the bullwhip effect.

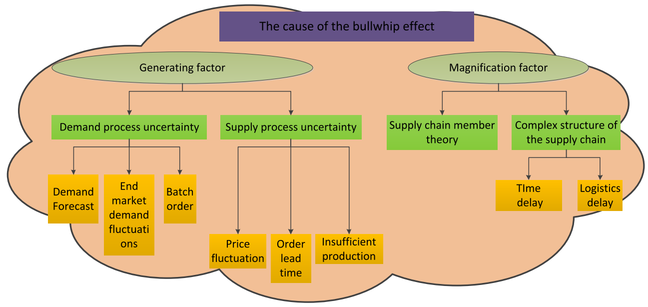

FIGURE 5. Analysis of the cause of the bullwhip effect.

B. ATTENUATING THE BULLWHIP EFFECT BASED ON THE IOT TECHNOLOGY INFORMATION COLLABORATION MODEL

As one of the important issues in the supply chain information coordination, the bullwhip effect has an extremely important impact on supply chain management and affects the implementation of supply chain collaborative management. Its impact mainly includes poor response service capability and chaotic production planning. The illusion of increased demand and the cause analysis diagram is shown in Figure 5.

1) REDUCE DEMAND RESPONSE AND SERVICE LEVELS

Because the demand information changes too much, the supplier cannot truly judge the terminal market demand situation, and it cannot correctly respond to the downstream distribution order demand. Especially in the case of multiple products, suppliers usually cannot adjust production capacity in time, but instead produce products that are not urgently needed, thus making the entire supply chain less responsive to customer needs and lower service levels.

2) CAUSING CONFUSION IN PRODUCTION PLANNING AND INCREASING PRODUCTION COSTS

Under normal circumstances, the manufacturer only predicts the product demand based on the order of the next-level customer, designs the production capacity of the product, controls the inventory quantity and arranges the production time. However, due to the bullwhip effect, the demand for orders faced by manufacturers is very volatile, far exceeding the actual needs of end customers, which brings many problems to the production scheduling of enterprises, such as poor production stability and sometimes even this leads to production being at a standstill, and sometimes in order to suddenly meet the increased demand, it is necessary to work overtime, rush to produce, and thus cause quality problems. At the same time, the poor smoothness of production will lead to an increase in the workload of production planners, and the production preparation costs will also increase, resulting in an increase in the total cost of production of suppliers.

3) THE ILLUSION OF INCREASING DEMAND, AMPLIFYING SUPPLY CHAIN RISKS

Due to the continuous enlargement of information, upstream enterprises in the supply chain do not understand the actual situation, resulting in the illusion that actual demand has increased demand. This problem was clearly demonstrated in the ''Beer Game''. In the early stage, due to changes in supply chain demand, distributors kept ordering a large number of manufacturers, which led manufacturers to produce the illusion of increased demand.

Through research and analysis of supply chain management, we can know that to achieve efficient supply chain management, an effective way is to establish strategic partnerships among members of the supply chain and strengthen the members of the supply chain. Information coordination ensures smooth information transmission, effective use of resources, improves overall communication and coordination, reduces time delays in the supply chain, reduces the bullwhip effect caused by information distortion, and reduces the overall operating cost of the supply chain.

The emergence of the Internet of Things technology has greatly improved the efficiency of the supply chain operation. Products can be tracked and monitored in real time when they are distributed in any part of the supply chain. Any member can also know the relevant information of the product in time. Through the Internet of Things technology, all members and products in the supply chain will be connected together, and the information from the upstream members of the supply chain to the end customers will be synergized to the greatest extent. Using advanced IoT information technology, a supply chain information collaboration model system based on IoT technology is established in the supply chain (Figure 6) to ensure efficient coordination of information among members

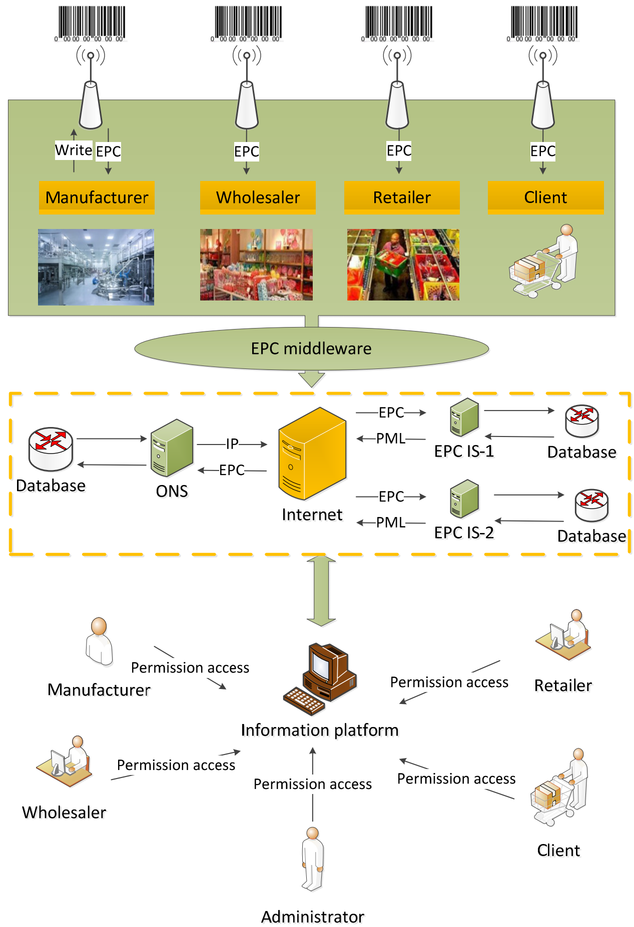

FIGURE 6. Supply Chain Information Collaborative Model System Based on Internet of Things Technology.

of the supply chain, thereby effectively reducing cattle the bullwhip effect.

Based on the Internet of Things technology and the cloud computing environment, this paper combines the advantages of the Internet of Things technology with the advantages of cloud computing. By constructing the information collaboration model of the supply chain bullwhip effect through the bullwhip effect, it can not only improve the efficiency of information collaboration, but also reduce the efficiency. The risk of supply chain disruption increases the efficiency of the system. Next, the efficiency of the system is verified by simulation experiments.

IV. PERFORMANCE ANALYSIS

With the advent of the new century, simulation technology has been greatly developed along with the advancement of computer technology. In the current market, there are various simulation softwares. They face various industries such as manufacturing companies, service companies, and logistics companies. They not only provide an effective tool for all walks of life, but the most important thing is to give each Enterprise bring huge economic benefits. These simulation softwares include Auto Mod, Any Logic, Witness, e M-Plant and Extend-Sim. Simulation software has its own unique features, which can be selected according to different needs of customers. In this paper, when using simulation, Extend-Sim was chosen.

Extend-Sim is widely used simulation software developed by Imagine-That in 1987. It is a comprehensive simulation platform. It provides a variety of efficient and fast modeling methods for researchers at different levels. It allows any professional user to simulate and develop functional libraries according to their respective needs and use Extend-Sim embedded language to create individual functional modules. All of this does not have to be done with another compiler or code generator, as long as it is done in its own integrated environment. Extend-Sim has designed an engine that delivers messages, which gives users the flexibility to model and quickly run the built models, where the various modules can be built together efficiently and quickly. Extend-Sim has been successfully applied in the fields of logistics, manufacturing, service, and technology.

According to the quantitative model of the bullwhip effect, some parameters are set as follows in the establishment of the simulation model. The service level standard of supply is $\varphi = 3$, and the simulation period is t=400.

Set customer demand $D_t$to:

$$D_t = \mu + \lambda D_{t-1} + \theta_t \tag{13}$$

In the above formula, take $\mu = 50$, $\lambda = 0$, $\theta_t \sim$ N(0,1).

The number of observation periods n and the stocking period L of retailers, wholesalers, and producers are set as follows:

(1) The number of observation periods in the retailer sub model is n=5, and the stocking period L=1;

(2) The number of observation periods in the wholesaler sub model is n=15, and the stocking period is L=3;

(3) The number of observation periods in the producer sub model is n=30, and the stocking period is L=6.

The unit is a uniform quantity.

The following is a comparative analysis of the demand for customers with or without information coordination in the supply chain and the inventory of retailers, wholesalers, producers, and the corresponding size of the bullwhip effect.

A. DISCUSSION ON PARAMETERS OF BULLWHIP EFFECT

1) NUMBER OF OBSERVATION PERIODS N

When the order lead time L and the autocorrelation coefficient λ are constant, changes the value of n to observe the bullwhip effect. The results are shown in Table 2. Assume that the order lead time L=4 and the autocorrelation coefficient $\lambda = 0.7$.

It can be seen from Table 2 that when the order lead time L and the autocorrelation coefficient λ are constant, the larger the value of the observation period n is, the smaller the bullwhip effect is.

TABLE 2. Effect of n values on the bullwhip effect.

The value of n	Bullwhip effect
2	7.1200
4	4.0396
6	2.9608
8	2.4135
10	2.0885

TABLE 3. Effect of L value on bullwhip effect.

The value of L	Bullwhip effect
1	1.1050
3	1.3450
5	1.6250
7	1.9450
9	2.3050

TABLE 4. Effect of λ value on bullwhip effect.

The value of λ	Bullwhip effect
0.1	6.2800
0.3	6.2799
0.5	6.2672
0.7	5.1150
0.9	3.1622

2) ORDER LEAD TIME L

When the observation period n and the autocorrelation coefficient λ are constant, the value of the order lead time L is changed to observe the bullwhip effect. The results are shown in Table 3. Assume that the observation period is n=20 and the autocorrelation coefficient $\lambda = 0.6$.

It can be seen from Table 3 that when the observation period n and the autocorrelation coefficient λ are constant, the larger the order lead time L is, the larger the bullwhip effect is, that is, the longer the order lead time is, the larger the bullwhip effect is.

3) AUTOCORRELATION COEFFICIENT λ

When the order lead time L and the observation period number n are constant, the value of λ is changed to observe the bullwhip effect.

a) When $\lambda = 0$, the demand function D_t conforms to the independent mean distribution with the mean μ and the variance is σ^2, and $D_t \sim N(\mu, \sigma^2)$, then equation (14) holds.

$$BE = \frac{Var(Q_t)}{Var(D_t)} \geq 1 + (\frac{2L}{n} + \frac{2L^2}{n^2}) \tag{14}$$

b) When $\lambda > 0$, that is, the consumption demand D_t is positively correlated. Assume that the order lead time is L=6 and the observation period is n=5. The results in both a and b are shown in Table 4.

It can be seen from Table 4 that under the premise of $\lambda > 0$, when the order lead time L and the observation period

TABLE 5. Effect of λ value on bullwhip effect.

The value of λ	Bullwhip effect
-0.1	3.6250
-0.3	3.6240
-0.5	3.6147
-0.7	3.4737
-0.9	2.3750

TABLE 6. Effect of λ value on bullwhip effect.

The value of λ	Bullwhip effect
-0.1	6.2801
-0.3	6.2928
-0.5	6.4450
-0.7	7.1367
-0.9	9.1245

n are constant, the larger the value of the autocorrelation coefficient, the smaller the bullwhip effect.

c) When $\lambda < 0$, that is, the consumer demand D_t has a negative autocorrelation relationship.

If n is an even number, then $(1 - \lambda^n) < 1$. Assume that the order lead time is L=6 and the observation period is n=8. The results are shown in Table 5. It can be seen that when the order lead time L and the observation period n are constant and n is an even number, the smaller the value of the autocorrelation coefficient is, the smaller the bullwhip effect is.

If n is an odd number, then $(1 - \lambda^n) > 1$. Assume that the order lead time is L=6 and the observation period is n=5. The results are shown in Table 6. It can be seen that when the order lead time L and the observation period n are constant and n is an odd number, the smaller the value of the autocorrelation coefficient, the larger the bullwhip effect.

It can be seen from the above two cases that when $\lambda < 0$, there is a special case where the bullwhip effect when the observation period n is even is smaller than the bullwhip effect when the observation period n is an odd number. However, after a lot of research, most products belong to the case of $\lambda > 0$.

B. DEMAND AND INVENTORY ANALYSIS UNDER NON-COLLABORATIVE AND COLLABORATIVE

1) ANALYSIS OF CUSTOMER DEMAND UNDER NON-COLLABORATIVE

In the non-cooperative bullwhip effect simulation model, the customer's demand is plotted as shown in Figure 7. According to the mathematical model of the bullwhip effect, the simulation result is obtained, which shows that the customer's demand is fluctuating around a value.

2) ANALYSIS OF CUSTOMER DEMAND UNDER SYNERGY

In the simulation model of the bullwhip effect, the customer's demand is drawn as shown in Figure 8. According to the mathematical model of the bullwhip effect, the simulation result is obtained, which shows that the customer's demand is also floating around a value.

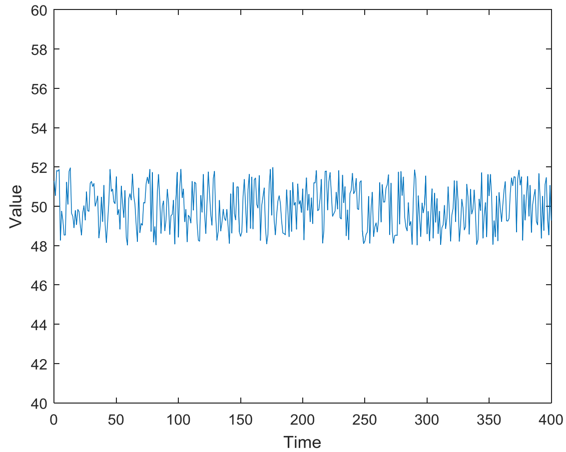

FIGURE 7. Customer demand under non-collaborative.

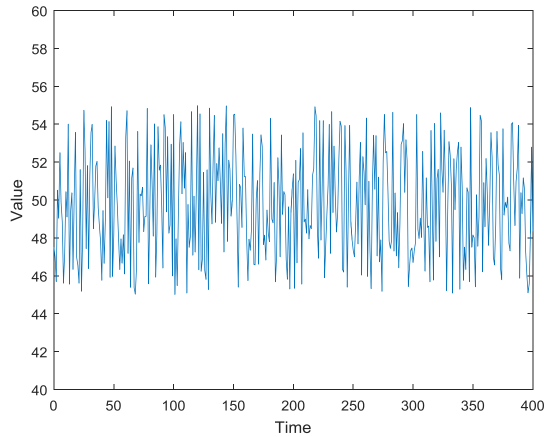

FIGURE 8. Collaborative customer demands.

3) INVENTORY ANALYSIS OF RETAILERS, WHOLESALERS AND PRODUCERS UNDER NON-COLLABORATIVE

In the non-cooperative bullwhip effect simulation model, the simulation results are graphically displayed. From Figure 9, we can see that the customer's demand fluctuations cause information when the supply chain does not implement information coordination. Distortion distortion causes the level of demand at the other levels of the supply chain to be greater than the level, and the farther away from the end customer, the greater the fluctuation.

This phenomenon occurs because the retailer issues an order to the wholesaler of the first-level member according to the demand of the end customer, and the wholesaler only predicts based on the order information from the retailer. Since there is an order lead time, the wholesaler goes up. A first-order order will consider a safety stock, which will allow the wholesaler to maintain a high inventory.

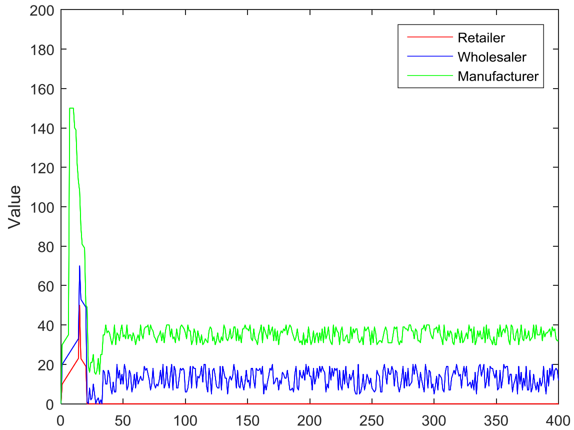

FIGURE 9. Customer demand under non-collaborative.

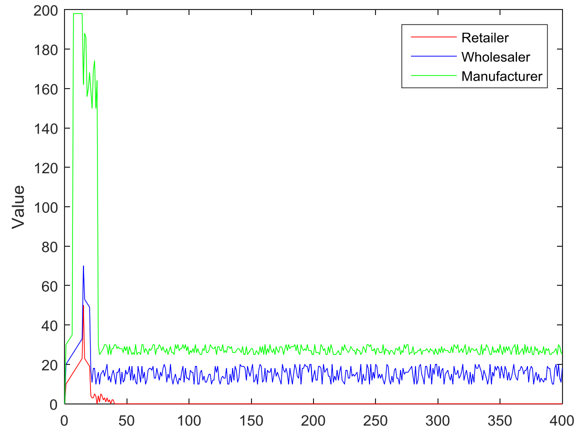

FIGURE 10. Collaborative inventory simulation.

By analogy, the producer's inventory will remain higher than the wholesaler.

Although the end-customer demand of the product is relatively stable, since the information in the supply chain is not coordinated, the wholesaler and the manufacturer only make predictions based on the order information issued by the next level, and through layer-level prediction and modification of the supply chain, finally resulting in the formulation. The order plan or production plan has a large deviation from the actual demand, resulting in high inventory levels in the supply chain, and the inventory cost of the entire supply chain has increased sharply, which is contrary to the goal of implementing supply chain management.

One thing to note here is that in this simulation model, the prediction method adopted by each level member is the moving average method. As the simulation time is extended, whether in the case of information coordination or non-coordination, due to the end customer's. The demand is slowly stabilizing, so the demand forecast of each level member will gradually become stable, that is, the inventory of each level member will remain at a relatively stable level.

4) INVENTORY ANALYSIS OF RETAILERS, WHOLESALERS, AND PRODUCERS UNDER SHARING

In the graphical results, we can know that after the supply chain implementation information coordination, the upstream members of the supply chain grasp the demand information of the downstream members in time, and can respond quickly to the needs of downstream members, and the demand of downstream enterprises appears in a short time. The probability of change is also low, and in this case the demand forecast is more accurate. Therefore, there is no need to maintain a high inventory level in the supply chain to prevent out-of-stocks and out-of-stocks. Although the information level is lower than that of the non-collaborative inventory level, we still see the existence of the bullwhip effect, which cannot be completely eliminated, but can only be weakened as shown in Figure 10.

C. COMPARATIVE ANALYSIS OF NON-COORDINATION AND SYNERGY

1) COMPARATIVE ANALYSIS OF CUSTOMER DEMAND IN THE CASE OF NON-SHARING AND SHARING

In the quantity model, we can see that the customer's demand variable D_t changes up and down a value; in the simulation results, it can also be seen that as the simulation time increases, the customer demand variable Dt is relatively stable, and the variation fluctuates little.

Since the parameter value setting related to the customer's demand variable D_t is the same in both the information synergy and the non-collaborative case, the simulation result of the established simulation model in the case of non-collaborative and collaborative situations should also be consistent, the graphs drawn by the simulation results shown in Figure 11 are overlapped.

2) COMPARATIVE ANALYSIS OF STOCKS OF RETAILERS, WHOLESALERS AND PRODUCERS IN THE ABSENCE OF SYNERGY AND SYNERGY

Since the first-tier member retailers in the supply chain always face the needs of end customers, and the end customer's needs are the same in the case of supply chain implementation and non-implementation of information collaboration, the retailer meets customer needs in a timely manner. The maintained inventory level should be consistent in the case of information synergy and non-synergy, as shown in Figure 12.

The retailer will coordinate the actual demand information of the terminal customers, so that the upstream enterprises in the supply chain can grasp the information of the downstream enterprises in time, and then formulate the corresponding order information or production plan, so the retailer's upstream enterprise wholesaler is based on the actual situation. The inventory plan is developed to meet the needs of downstream companies without having to maintain excessive inventory. Inventory is much lower than in the case of non-coordination of information, as shown in Figure 13.

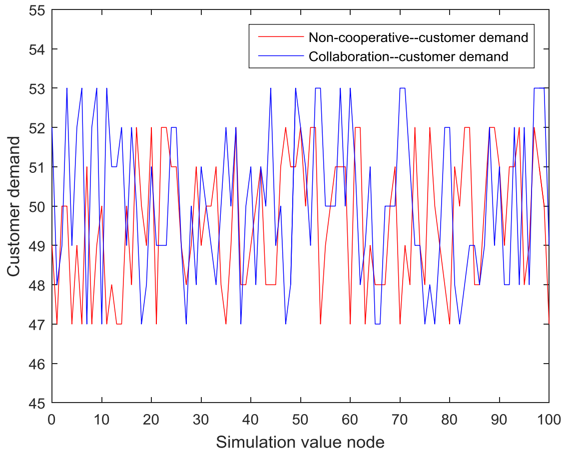

FIGURE 11. Comparison of customer demand under non-collaborative and collaborative.

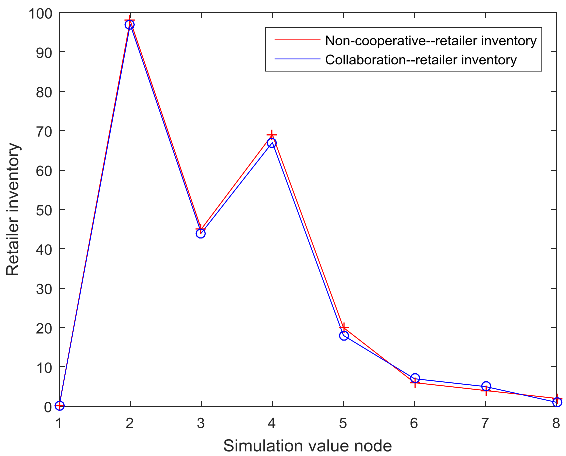

FIGURE 12. Comparison of retailer inventory under non-collaborative and collaborative.

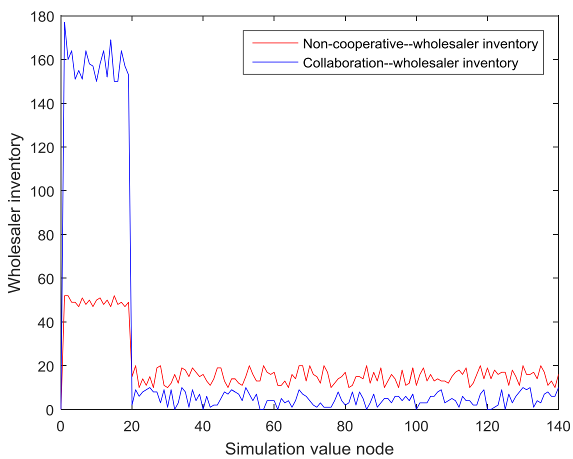

FIGURE 13. Comparison of wholesaler inventory under non-collaborative and collaborative.

The more the bullwhip effect is away from the customer, the greater the fluctuation in demand. In the case of non-synergy, the manufacturer produces according to the order information of the subordinate members, and the information

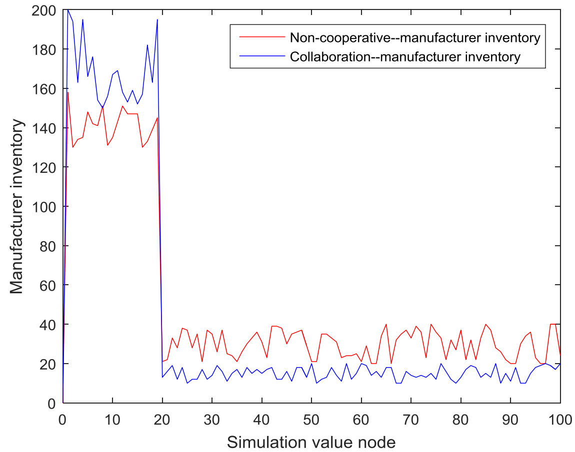

FIGURE 14. Comparison of producer inventory under non-cooperative and collaborative.

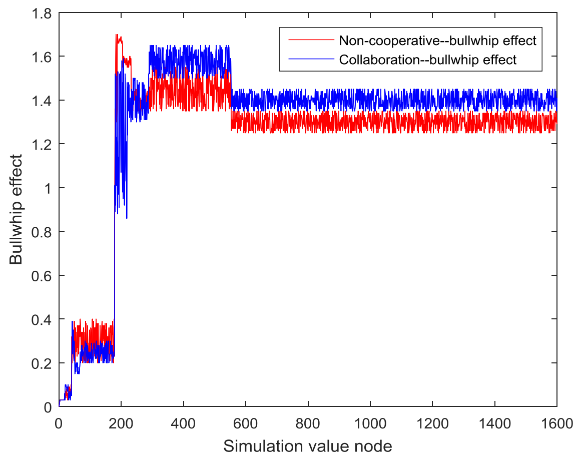

FIGURE 15. Comparison of the bullwhip effect between non-synergy and synergy.

is transmitted and modified at the first level of the supply chain, and finally the demand information is distorted and enlarged, causing the producer to produce too many products and a large backlog of inventory; in collaboration, the manufacturer obtains the collaborative information and directly grasps the end customer demand information, and then uses this as a basis to predict and formulate the production plan. As shown in Figure 14, the inventory levels of producers under non-coordination are significantly larger than in the case of synergies.

3) COMPARATIVE ANALYSIS OF BULLWHIP EFFECT UNDER NON-COORDINATION AND SYNERGY

From Figure 15, we can see that the bullwhip effect persists in the case of synergy or non-coordination, and cannot be completely eliminated. However, the bullwhip effect is significantly weakened under the condition of supply chain implementation information coordination. Therefore, implementing information coordination in the supply chain is an effective way to control the bullwhip effect and improve the efficiency of supply chain management.

In this paper, simulation software is used to build a simulation model based on the mathematical model of the bullwhip effect. The graphical results and data generated by the simulation software are compared and analyzed from the above five aspects. Here, we can analyze from the above results that the supply chain implementation information synergy, the operating costs and risks of each node in the supply chain can be reduced compared with the non-cooperative situation, and also shows the corresponding benefits of the supply chain. It has been improved and market competitiveness has been enhanced. The simulation results have good guidance and reference for the operation of enterprises in reality.

V. CONCLUSION

Based on the research of supply chain management based on Internet of Things technology and big data technology, this paper establishes the supply chain information collaboration model system under the Internet of Things environment through the impact and value of IoT technology on modern supply chain.

Starting from the problems in supply chain management, this paper proposes the phenomenon of bullwhip effect in the supply chain. In view of the bullwhip effect, its causes and suppression methods are discussed in detail. Based on the previous research, from the perspective of information coordination, the information writing platform is constructed by using Internet of Things technology and big data related technology, and information is implemented in the supply chain. Synergy to suppress the bullwhip effect, construct a simulation model of the supply chain bullwhip effect, and use the simulation method to simulate and study the key factors in the model, and use the graphical simulation results to objectively clarify the supply chain implementation information synergy value.

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