Construction of Supply Chain Financial Risk Management Mode Based on Internet of Things

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ABSTRACT The objective of this paper is to analyze the problems of information asymmetry, mode lag, and high operational risk between banks and enterprises in the practice of supply chain finance business. In this paper, first, the concept and function of supply chain finance were elaborated, and the theoretical basis of supply chain financial risk control was studied. The implement of principal agent, information asymmetry theory, and self-compensated trade finance theory on realizing the risk avoidance in the actual development process was analyzed. Then, the business processes of the three basic financing models of supply chain finance and the shortcomings in the operation of each model were proposed. On this basis, risk sources and influencing factors of supply chain finance were analyzed, and operational risks were emphasized. Finally, a new financing mode of inventory pledge was designed based on the special function of Internet of Things (IoT) technology and the business process of inventory financing mode. The results showed that there was a big gap in the value of risk loss caused by various types of loss events in the operation risk of supply chain finance inventory pledge financing mode; among them, the biggest losses were from external fraud. By comparing the expected loss (ES) value of inventory pledge financing mode based on the IoT with the operation risk of traditional mode, it could be found that the supply chain finance mode based on the IoT technology effectively reduced the operation risk. Therefore, the system designed in this paper has certain reference and practical significance for financial risk management.

INDEX TERMS Supply chain finance, IoT, management mode.

I. INTRODUCTION

By means of Internet + and electronic information technology, supply chain finance has formed a sound solution to the financing difficulties of Small and medium enterprise (SEMs). According to statistics, the compound growth rate of the supply chain financial market in the next five years will remain at about 15%, and the market share will further reach about 15 trillion by 2020 [1]. Although great breakthroughs have been made in the development of supply chain finance business, other risk loopholes have gradually emerged in the actual development process due to the large number of supply chain participants, complicated structure and operation [2]. For example, in the mode of warehouse receipt pledge financing, because the transaction information between banks is

relatively confidential, the information of pledge business is only shared to a limited extent, which leaves room for financiers to operate. Financing demanders can conduct joint fraud with third-party logistics enterprises to obtain financing from different financial institutions [3]. Therefore, how to make full use of supply chain finance to develop banking business and solve the financing problems of SEMs, at the same time, how to optimize and improve its mode so as to achieve effective risk management has become a problem to be studied.

The development of supply chain finance by banks and other financial institutions effectively alleviates the financing pressure of SEMs, but with the development of business and the increasing complexity of its structure, the forms of risk are gradually diversified [4], [5]. This shows that the existing supply chain financing mode can't meet the needs of the times and needs to be improved and optimized.

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Therefore, in this research, from the perspective of optimizing financing mode, based on the characteristics of inventory pledge financing mode of supply chain finance and combined with the functions of IoT, a new inventory pledge financing mode was designed. This model not only further effectively reduced credit risk and market risk, but also reduced operational risk such as external fraud. Then, according to the classification of operational risk in Basel accord and the actual situation of inventory pledge financing mode [6], the loss events of operational risk were divided into five categories, and the extreme value theory Peak Over Threshold (POT) model was constructed to measure operational risk. The empirical results show that the operational risk loss of the inventory pledge financing model based on the IoT was effectively reduced compared with the traditional inventory pledge financing model. It is hoped that this research can further enrich the financing mode of supply chain finance and provide some references for supply chain participants.

This paper was divided into five chapters. The first chapter introduces the background and research significance of the topic. The second chapter introduces the previous research and the innovation of this paper. The third chapter introduces the design of inventory pledge financing model based on Internet of Things technology. The fourth chapter conducts risk analysis and risk measurement on the inventory pledge financing model based on the Internet of Things technology and the traditional inventory pledge financing model. The fifth chapter summarizes the main research results of this paper.

In terms of risk management, most researchers summarize the risks of supply chain finance into credit risks, market risks and regulatory risks from the perspective of banks. In addition, most measures to control risks are to give early warning of risks by controlling the pledge rate and constructing the risk evaluation index system, and few are to reduce the risks caused by some defects in the actual development of the financing mode from the perspective of optimizing the financing mode. And few of them take the operational risk of supply chain finance as a special risk control object and conduct quantitative analysis. Moreover, this study used IoT to design the inventory pledge financing model, so this research has significant innovation.

II. LITERATURE REVIEW

The idea of supply chain finance was first proposed by foreign scholars and evolved into the development of trade finance. Hofmann and Zumsteg put forward the idea of carrying out supply chain finance business, and described its role and specific implementation framework in financing of SMEs through case studies [7]. Juan et al. defined supply chain finance specifically. They believed that it was a way for two or more organizations, including supply chain enterprises and third-party service providers, to achieve common benefits by reasonably controlling and planning the effective flow of funds between organizations [8]. Hui and Yun-Lin further refined the definition of supply chain finance and expressed

it as the process of capital reallocation and cost optimization in the industry chain dominated by core enterprises [9]. Zhao et al. believed that supply chain finance is a special means of payment [10]. In terms of the research on the development of supply chain financing mode, Huff and Rogers put forward the design idea of supply chain financing based on their own understanding and carried out the design of prepayment financing mode [11]. Gelsomino et al. summarized the financing mode of inventory pledge, designed the financing mode of chattel pledge based on this, and pointed out that this mode not only effectively reduced the operating cost of supply chain enterprises, but also greatly alleviated the financing pressure of small and medium-sized enterprises [12]. Lekkakos and Serrano believed that the use of three financing modes (inventory pledge, receivable accounts and advance payment) effectively improved the operation and management efficiency of enterprises in the supply chain, ensured the return of funds, and effectively reduced credit risks [13]. Based on previous studies, Zhang proposed that supply chain finance should start from the perspectives of financial driver and supply chain driver [14]. Zhu et al. discussed the advantages and disadvantages of prepayment financing model and conducted a feasibility study on it through the construction of planning model [15].

The risk management of supply chain finance is closely following the development of supply chain finance. In 2016, Wuttke et al. analyzed the role of warehouse receipt pledge in accelerating the production and operation of agricultural products, discussed and studied the specific implementation process of the financing mode, and proposed the measures of risk prevention [16]. In 2016, Yan et al. tried to analyze the risk of inventory management in the inventory pledge financing mode, and obtained the optimal goal of inventory with the expected utility to reduce the risk [17]. In 2017, Bustos et al. demonstrated the degree to which the determination of interest rate and loan amount during the development of supply chain finance business influenced the risk through quantitative research, and proposed a conceptual model of supply chain finance risk analysis [18]. In 2017, Mantovani and Galvao believed that the acquisition of historical credit records of financing enterprises directly affected the feasibility of financing receivables [19]. In 2017, Chicaiza-Becerra and Garcia-Molina regarded various risks of supply chain finance as a whole, and built a model by value at risk (VaR) method to measure the comprehensive risks of credit risks, market risks and operational risks [20]. In 2017, in the context of economic globalization, Seaman et al. proposed that the premise of effective implementation of supply chain financial risk management was to identify risks, and then to take positive measures to deal with risks, so as to truly reduce risks and realize profits [21]. In 2017, Offringa et al. classified the risks in the supply chain financial business carried out by banks and other financial institutions into four categories, namely, credit risk, market risk, operational risk and systemic risk, and proposed that credit risk was the main research object
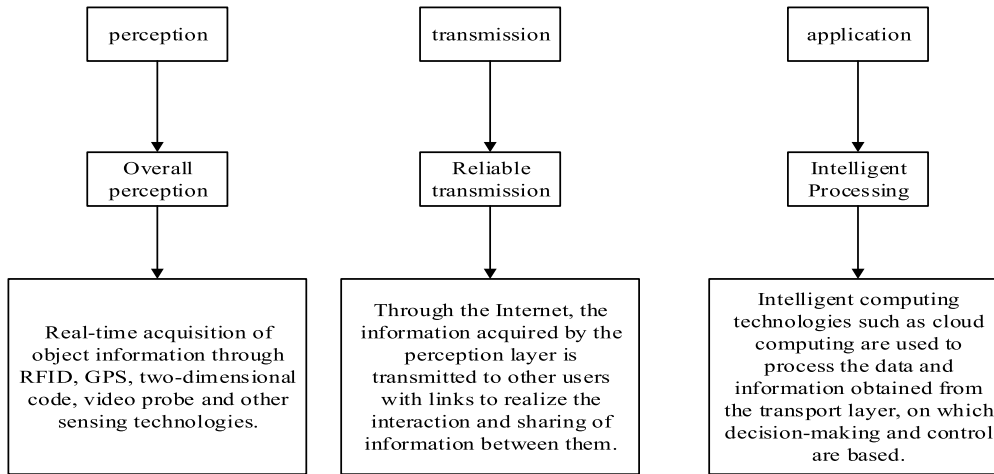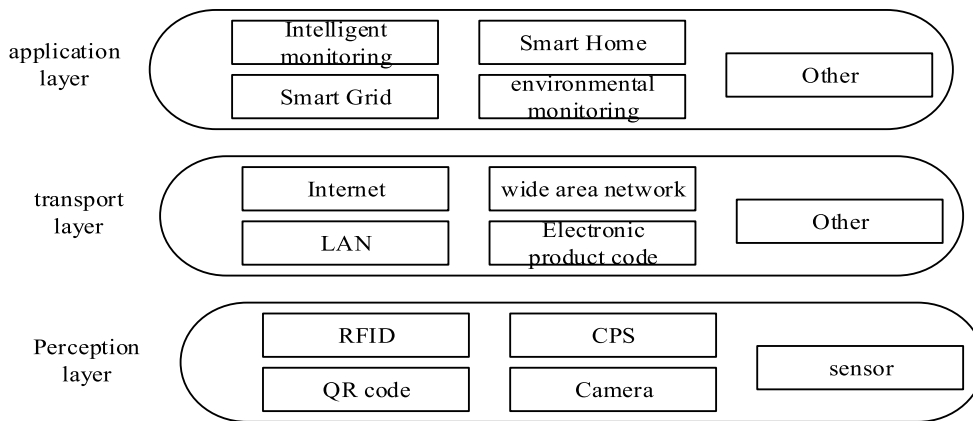
FIGURE 1. The working principle of IoT.

FIGURE 2. IoT architecture.

of supply chain financial risk management [22]. In 2017, Coates and Gurnell conducted risk management research by constructing a systems-oriented model, classified relevant factors that stimulated supply chain financial risks into system factors and divided them into three sub-factors, namely financing enterprises, supply chain and environment, and then used different methods to describe sub-factors in depth [23]. In 2018, Postolovska et al. proposed the use of forward and derivative hedging to avoid risks in supply chain finance based on the characteristics of various financing modes of supply chain finance [24]. In 2018, Rodriguezaguilar put forward supply chain financial risk mainly came from the money flows in the cooperation process of supply chain enterprises and the stability of the supply chain as a whole, they believed that the management of cash flow in supply chain was an effective way to control risk [25].

Through the research and analysis of the relevant results of domestic and foreign scholars, it is not difficult to find that some achievements have been made in the research on the ideas, concepts, financing modes, risks and management problems in the business process of supply chain finance. In terms of risk management, most researchers summarize the risks of supply chain finance into credit risks, market risks and regulatory risks from the perspective of banks. In addition, most measures to control risks are to give early warning of risks by controlling the pledge rate and constructing the risk evaluation index system, and few are to reduce the risks caused by some defects in the actual development of the financing mode from the perspective of optimizing the financing mode. And few of them take the operational risk of supply chain finance as a special risk control object and conduct quantitative analysis, which provides a starting point for this research.

III. METHODOLOGY

IoT is a network technology that realizes intelligent identification, tracking and supervision by comprehensively adopting various sensing technologies to connect objects to the Internet for information exchange and communication under the agreed protocol. The working principle of IoT is shown in Figure 1:

IoT consists of three layers, as shown in Figure 2. The first layer is the perception layer, which mainly realizes the identification and tracking of objects through RFID, GPS, camera
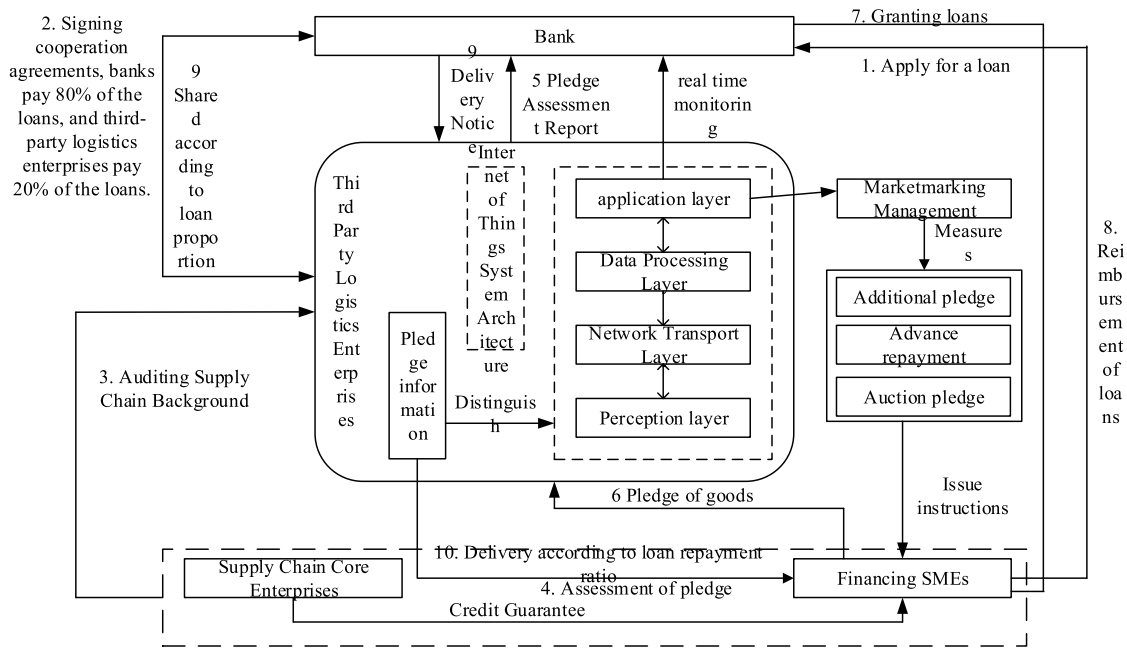
FIGURE 3. Inventory pledge financing model based on IoT.

and other sensing technologies, and reads the relevant information of objects in real time. The second layer is the network transmission layer, through the use of electronic product code (EPC), WAN, Internet and communication network, the information and data acquired by the sensing layer will be transferred to the users who have link relations, so as to realize the information interaction and sharing between each other. The third layer is the application layer, which realizes the intelligent processing and application of the acquired data and related information on the basis of the first two levels. IoT can be applied to a wide range of areas in practice, such as environmental monitoring, smart grid, intelligent monitoring and so on.

Radio frequency identification (RFID) technology is a non-contact automatic identification system which can automatically identify target objects and acquire relevant data through radio frequency radio signals. The system mainly includes electronic tag, reader and computer network. An electronic tag is embedded in the pledges in the inventory pledge financing mode to store the relevant information of the pledges. The reader reads the information in the electronic tag through the radio frequency wireless signal, and it first needs to send a specific query signal. When the electronic tag reaches this signal range, it senses the signal and gives a response signal, which contains the information stored in the electronic tag. After receiving the reply signal, the reader will transfer it to the host in the computer network after corresponding processing. The host completes the functions of data processing, transmission and communication.

The global positioning system is a technology application combining satellite and communications. GPS can quickly and accurately obtain three-dimensional position, speed and time information of target objects without limitation of weather and time. It has the characteristics of high accuracy,

high efficiency and automation. GPS is an indispensable existence in IoT system. In the inventory pledge financing mode, the effective control of collateral liquidity is one of the problems that need to be solved urgently. RFID can effectively solve the real-time tracking of pledges within a small range, but once the pledges are transported over a long distance, RFID alone can't solve the problem. However, the combination of RFID and GPS can solve the problem very well. A vehicle equipped with a GPS receiver can be located precisely by satellite.

In the architecture hierarchy of IoT, the types and quantities of information transmitted from the perception layer to the application layer were increasing step by step, and the amount of data to be processed and analyzed was multiplied. How to effectively mine, sort out and apply such massive information was a difficult problem for IoT to solve. Data analysis and processing was a key to the effective application of IoT, and the emergence of cloud computing made this possible.

In this study, IoT and related technologies were elaborated. Through the comprehensive application of RFID technology, video monitoring, GPS positioning system and other technologies, IoT could realize the visual tracking of pledges and track the quantity, position and status of pledges. Cloud computing platform could analyze and process the mass collected information, such as monitoring the market price of pledges and making trend prediction. The comprehensive application of LAN, WAN and Internet could realize the real-time sharing of all kinds of information in the process of business operation. Combining the above functions and the business characteristics of the inventory pledge financing mode of supply chain finance, the inventory pledge financing mode based on IoT was designed in this research, as shown in Figure 3.

In the inventory pledge financing mode designed in this research based on IoT, financing SEMs also need to rely on the credit guarantee of supply chain core enterprises to apply to the bank for inventory pledge loan business. After receiving the application and completing the relevant assessment work, the bank selected to cooperate with the third-party logistics enterprise and entrusted the storage, supervision and transportation of pledges to the third-party logistics enterprise as an agent, which was different from the original inventory pledge financing mode. For the loan applied for by financing SEMs' inventory pledge, the bank shall pay 80% of the total loan amount, and the third-party logistics enterprise shall pay 20%, and then both parties shall share the benefits according to their respective investment ratios. This design not only reduced the risk of full capital contribution of the bank, but also further strengthened its cooperative relationship with third-party logistics enterprises. Based on the application of IoT, third-party logistics enterprises conducted comprehensive evaluation on the supply chain background, core enterprises, financing SEMs and pledges, determined the pledge rate on this basis, and then submitted the evaluation report to the bank. If the opinions of both parties were agreed, the application for financing the SME's inventory pledge loan business would be approved.

In the inventory pledge financing mode based on IoT, the visual real-time tracking of pledges improved the supervision and operation ability of logistics enterprises. Real-time and accurate warehouse information was effectively transmitted among participants, which increased the transparency of financing business, and real-time data sharing improved the regulatory capacity of banks, thus reducing capital risks.

IV. RESULTS AND DISCUSSION

A. OPERATIONAL RISK ANALYSIS OF INVENTORY PLEDGE FINANCING MODE BASED ON IoT

The supply chain finance business carried out by banks no longer independently evaluated the financial status of financing SEMs, but focused on the real trade background of the supply chain, emphasized the trade self-compensation of credit and repayment, and conducted closed management of funds. In addition, the credit strength of supply chain core enterprises was introduced as the guarantee, which effectively reduced the credit risk of developing loan business with SEMs. In the development process of supply chain finance business, because there were many participants involved, operational links of the business were added, and operational risks increased step by step due to the complexity of the structure. In this study, the inventory pledge financing mode designed based on IoT reduced the credit risk and market risk of the loan business between banks and financing SEMs, and meanwhile reduced the operational risk. However, the introduction of new things also brought new operational risks. In this study, operational risks of the inventory pledge financing mode based on IoT were analyzed and studied.

In the supply chain inventory pledge financing model, the core enterprises of the supply chain attached their own credit strength to the financing of SEMs, and the latter used their own inventory as pledge to finance loans from banks and other financial institutions. Pledges became the most core guarantee for banks and other financial institutions to maintain their capital security. Naturally, the safety and quality of pledges were the top priority of risk management, which created a high quality requirement for operational specifications during business development. In this research, combined with the classification of operational risk in Basel accord and the actual situation of the new inventory pledge financing mode, the operational risk was studied and analyzed.

First, internal fraud: in supply chain finance business, internal fraud mainly refers to the fact that banks and other financial institutions and related employees of core enterprises accept bribes or kickbacks because they can't resist the temptation of interests, and give the green light to businesses that fail to meet the loan requirements or deliberately conceal hidden risks, so that banks may suffer losses. Second, external fraud: the external fraud of supply chain finance business refers to the collusion and fraud between the third party institutions compared with financial institutions. It refers to the collusion between the third party logistics enterprises and financing SEMs in the process of business development and the use of unconventional means to defraud banks of loans. Third, the loss and damage of pledges: there are operational risks when pledges are pledged, such as the destruction and loss of pledges caused by human or non-human factors. Fourth, system risks of IoT: the new inventory pledge financing model brings new operational risks because of the introduction of Internet of Things technology. That is, in the process of business development, accidents such as interruption or interference in the IoT system would affect the accuracy of information obtained, resulting in wrong decisions and losses. According to the hierarchical division of the IoT architecture, the operational risk in the new inventory pledge financing mode is classified into the perceived risk, the network transmission risk and the application risk. Fifth, operational errors of practitioners: in the development of supply chain finance business, there are operational errors of practitioners due to the complex and changeable supply chain relationship and business process, which bring corresponding operational risks.

B. OPERATIONAL RISK MEASUREMENT OF INVENTORY PLEDGE FINANCING MODE BASED ON IoT

In the existing application, the extreme value theory (EVT) is mainly used to deal with the deviation of the mean distribution limit of statistical data. It can infer the probability of the event has not occurred from the random characteristics of historical data [26]. The extreme value theory POT model determines a reasonable threshold from the operational risk loss sample data and models the sample data that exceeds the threshold [27]. By estimating the relevant parameters in the model, it is possible to derive the value at risk (VaR) and expected loss (ES) of operational risk at a certain level of confidence. The difference between the extreme value theory

and the traditional VaR method is that it only considers the tail portion of the loss data, because the measurement of the tail can be used to determine the possibility and loss of extreme events.

As the historical sample data of operational risks were rarely collected during the development of supply chain finance business, the historical simulation method was used to calculate VaR, which was difficult to move forward in practice. In addition, loss event types of operational risks generally had the characteristics of low frequency and high loss, so the distribution of loss sample data didn't have the characteristics of normal distribution, but showed the characteristics of sharp peak and thick tail distribution. Based on the researches of relevant scholars, it can be found that extreme value theory was a new method to calculate VaR value without obeying normal distribution.

It was assumed that $X_1, X_2...X_n$ represented sample data of various types of loss events based on the operational risk of inventory pledge financing mode of IoT, and each random variable was independently and equally distributed.

The distribution function was defined as F(x). A sufficiently large and reasonable variable x was selected from the sample data of the loss event as the threshold u, and the conditional distribution function exceeding the threshold u was defined as F(y), then,

$$F(x) = p(X - \mu \le x | X > \mu) \, x \ge 0 \tag{1}$$

Formula 2 could be derived from conditional probability formula.

$$F_\mu(y) = \frac{F(y+\mu)}{1 - F(\mu)} = \frac{F(x) - F(\mu)}{1 - F(\mu)} \tag{2}$$

By deducing and converting equation 2, equation 3 could be obtained:

$$F(x) = F_\mu(y)[1 - F(\mu)] + F(\mu) \, x > \mu \tag{3}$$

According to the theorem of Balkema et al., the sample data of operational risk loss in the new inventory pledge financing mode was set as $y(y_1, y_2...y_t)$. When the threshold u was large enough, the tail extremum of y obeyed the generalized Pareto distribution (GPD), and the expression was as follows:

$$F_\mu(y) \approx G_{\delta,\theta,\mu}(y) = \begin{cases} 1 + \left[1 + \delta\dfrac{x-\mu}{\theta}\right]^{\frac{1}{\delta}} & \delta \ne 0 \\ 1 - \exp\left(-\dfrac{x-\mu}{\theta}\right) & \delta = 0 \end{cases} \tag{4}$$

Since y = x-u, it was substituted into equation 4 to get equation 5.

$$G_{\delta,\theta}(y) = \begin{cases} 1 + \left[1 + \delta\dfrac{y}{\theta}\right]^{\frac{1}{\delta}} & \delta \ne 0 \\ 1 - \exp\left(-\dfrac{y}{\theta}\right) & \delta = 0 \end{cases} \tag{5}$$

$G_{\delta,\ominus}$ was the GPD, among them, δ was the shape parameter, and Θ was the scale parameter. When $\delta > 0$, the GPD

distribution was a thick tail distribution. It needed to obtain the estimated values of Θ and δ by the application of the maximum likelihood estimation method to further judge the distribution of GPD.

When the threshold u was well determined, the first derivative of the tail distribution function in equation 4 was taken to obtain the probability density function of the distribution:

$$g_{\delta,\theta}(x) = \begin{cases} \dfrac{1}{\theta}\left[1 + \dfrac{\delta}{\theta}\right]^{-\left(1+\frac{1}{\delta}\right)} & \delta \ne 0 \\ \dfrac{1}{\theta}e^{\frac{x}{\theta}} & \delta = 0 \end{cases} \tag{6}$$

Then, the part y $(y_1, y_2..., y_t)$ of the super-threshold value in the lost sample data was substituted into the above equation, and the log likelihood function expression was obtained as follows:

$$L(\delta, \theta|y) = \begin{cases} -n\ln\theta - \left(1 + \dfrac{1}{\delta}\right)\sum_{i=1}^{n}\ln\left(1 + \dfrac{\delta}{\theta}\right)y_i & \delta \ne 0 \\ -n\ln\theta - \dfrac{1}{\theta}\sum_{i=1}^{n} y_i & \delta = 0 \end{cases} \tag{7}$$

Finally, the estimated values of the parameters Θ and δ were obtained by maximizing the likelihood function in the above expression. After obtaining the estimated value of parameters, it was also necessary to carry out tail estimation of the over-threshold part of sample loss data. Only when a reasonable threshold value was selected, an accurate estimation result could be obtained. It was assumed that N_u represented the number of operational risk loss sample data in the new inventory pledge financing mode that was larger than the threshold u. N represented the capacity of operational risk loss sample, and $\frac{n-N_u}{n}$ represented the estimation of F(u). By substituting Fu(y) and F(u) into equation 3, the function expression of F(x) could be obtained as follows:

$$F(x) = \begin{cases} 1 - \dfrac{N_\mu}{n}\left[1 + \dfrac{\delta}{\theta}(x-\mu)\right]^{\frac{1}{\delta}} & \delta \ne 0 \\ 1 - \dfrac{N_\mu}{n}e^{\frac{(x-\mu)}{\theta}} & \delta = 0 \end{cases} \tag{8}$$

F(x) was the tail estimate of the over-threshold part of the operational risk loss data. In this case, in order to Figure out the operational risk capital of banks and other financial institutions to carry out the new inventory pledge financing mode with different confidence levels, it was also necessary to estimate the VaR.

According to the definition of VaR, it could be concluded that:

$$VaRa = F^{-1}(\alpha) \tag{9}$$

Therefore, when confidence level α was given, the expression of the estimated value of VaRα could be derived from the

TABLE 1. Preliminary analysis of operational risk loss events of inventory pledge financing model 2010-2016 (unit: 10,000 yuan).

Categories of Operational Risk Losses	Number of lost samples	average value	Intermediate value	Maximum	minimum value	skewness	kurtosis	J-B value
Internal fraud	97.02	2342.56	2332.93	6474.6	24.75	1.95	6.10	103.35
External fraud	74.25	3036.30	3023.46	7311.15	29.7	1.72	6.98	66.46
Loss or damage of pledge	44.55	1537.47	1517.67	3415.5	24.75	0.68	5.92	20.04
Operational errors of practitioners	19.8	842.49	715.77	2440.35	9.9	1.74	9.91	50.88

inverse function of formula 8:

$$
V\alpha R\alpha = \begin{cases} \mu + \dfrac{\theta}{\delta} \left\{ \left[\dfrac{n}{N_\mu} (1 - \alpha) \right]^{-\delta} - 1 \right\} & \delta \neq 0 \\ \mu - \theta \text{In} \left[\dfrac{n}{N_\mu} (1 - \alpha) \right] & \delta = 0 \end{cases} \quad (10)
$$

Since VaR had defects that didn't take into account the tail risk, ES considered the occurrence of extreme divergence on the basis of VaR. Therefore, the ES index could be used to quantify the extreme value of operational risk tail of the new inventory pledge financing mode.

Under the condition of given confidence coefficient α, ES could be expressed as:

$$
\begin{aligned} ES_\alpha (X) &= E[X|X \geq V\alpha R\alpha (x)] \\ &= V\alpha R\alpha + E[X - V\alpha R\alpha|X > V\alpha R\alpha] \end{aligned} \quad (11)
$$

$$
(\mu) = E[X - \mu|X > \mu] = \frac{\theta + \mu\delta}{1 - \delta} \delta + \mu\delta > 0 \quad (12)
$$

Based on the above equation, the expression of ES estimated value could be obtained as follows:

$$
ES_\alpha = \frac{V\alpha R\alpha}{1 - \delta} + \frac{\theta - \mu\delta}{1 - \delta} \quad (13)
$$

Through the application of the $\chi2$ goodness-of-fit test method, the optimal threshold was judged from the three thresholds obtained by the three methods, that is, excess mean function graph method, Hill graph method and kurtosis method. After determining the optimal threshold value, it was put into the logarithmic likelihood function of formula 7, and then maximized to obtain the estimated value of two parameters in GPD. Finally, the VaR value and ES value of the operation risk can be calculated by substituting the estimated value into equations 10 and 13. And the operational risk loss quantity could also be obtained.

C. ANALYSIS OF OPERATIONAL RISK MEASUREMENT OF TRADITIONAL INVENTORY PLEDGE FINANCING MODE

Data were collected from the public disclosure information of authoritative media magazines, portal websites, financial regulatory institutions, audit office, people's bank of China, China banking regulatory commission and other institutions, and sample of operational risk loss cases of financing business of supply chain inventory pledge by banks and other financial institutions from 2010 to 2016 were obtained. According to the identification and analysis of operational risks, the collected data were classified and preliminary analysis was made on the data. The results are shown in table 1:

The $\ominus$ and δ estimates of the loss distribution of each loss event of operational risk were estimated by the POT model, and the optimal value was obtained by the chi-square goodness-of-fit method. By putting the estimated value of the calculated parameters into equations 10 and 13, VaR value and ES value of each loss type event of operational risk in the traditional inventory pledge financing mode could be obtained. According to relevant requirements, measures of credit risk, market risk and operational risk should be at the same confidence level. Therefore, VAR and ES estimated value of various types of operational risk loss events in the traditional inventory pledge financing mode with a confidence of 99.9% were calculated in this research, as shown in table 2.

As can be observed from the results in table 2, under the condition that the confidence was equal to 99.9%, VaR and ES values of various types of loss events of inventory pledge financing mode highlighted the shockingly high loss characteristics of operation risk. At the same time, the numerical difference between different types of loss events was also large. The loss value of external fraud was the largest, its VaR was 90.5368 million yuan, while ES was as high as 172.799 million yuan. The second was internal fraud. The VaR was 66.633 million yuan, and the ES value is as high as 116.955 million yuan. The third was the operational risk of loss and damage of pledges, and the smallest was the operational risk caused by operational errors of employees. The total ES of the operational risk in the inventory pledge financing mode was as high as 367.291 million yuan. It can be concluded that when banks and other financial institutions carried out supply chain finance inventory pledge financing business, external fraud and internal fraud risk brought the

TABLE 2. VaR and ES of each loss category event of operational risk under 99.9% confidence level.

| Categories of Operational Risk Losses	Internal fraud	External fraud	Loss or damage of pledge	Operational errors of practitioners
VaR (99.9%)	6663.30	9053.69	3065.34	1360.10
ES (99.9%)	11695.50	17279.99	5195.34	2558.26

greatest threat, and the loss caused by the risk might be fatal. Therefore, effective prevention of operational risks of internal and external fraud was the top priority of risk management.

D. MEASUREMENT AND ANALYSIS OF OPERATIONAL RISK OF INVENTORY PLEDGE FINANCING MODE BASED ON IoT

In this study, the inventory pledge financing mode designed based on IoT mainly realized systematic and intelligent management of pledges such as identification, positioning, tracking and monitoring through radio frequency identification, GPS positioning and other technologies. Then the data were summarized and analysed, so that all participants in the supply chain finance could effectively get the status and changes of pledges in real time. This kind of visual supervision of pledges and reliable transmission of information could effectively reduce the occurrence of operational risks such as external fraud. The new inventory pledge financing mode effectively reduced the frequency of external fraud, pledge loss or damage in the traditional inventory pledge financing mode. By controlling variables, the loss data of the traditional stock pledge financing mode were adjusted to reduce the occurrence frequency of external fraud, pledge loss or damage in the traditional stock pledge financing mode. At the same time, the new model increased the operational loss caused by the risk of the IoT system. By referring to relevant data of other literatures and conducting market survey, the data of losses caused by system risks when financial institutions such as Ping An Bank carried out IoT financial business were collected and adjusted accordingly. Finally, the preliminary analysis of various types of loss data in the inventory pledge financing mode based on IoT was obtained.

The threshold value u_i (i = 1, 2, 3) of each type of loss event of the operation risk of the inventory pledge financing mode was substituted into the logarithmic relief function equation 7, By using Matlab software, the maximum likelihood of the function was realized, on this basis, the Θ and δ estimates corresponding to the thresholds in the various types of loss events of the traditional inventory pledge financing mode were obtained. The optimal threshold was determined by using the x^2 goodness of fit test, and the threshold corresponding to the minimum x^2 of each type of loss event was taken as the optimal threshold of the loss type event. The calculation results are shown in Table 2.

Similarly, SPSS software was used to obtain Q-Q graph of risk loss data of IoT system to determine whether it presented
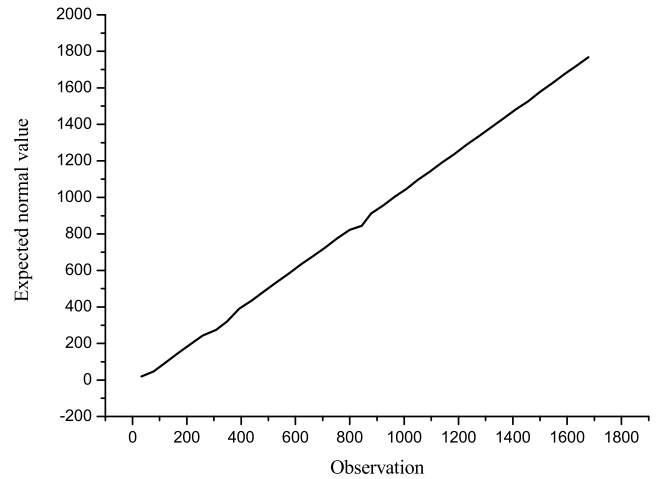
FIGURE 4. Data Q-Q diagram of risk samples for IoT systems.

thick-tailed distribution. It could be determined from Figure 5 that the sample data obeyed the thick-tailed distribution.

The Θ and Θ estimated value of the loss distribution of each loss event of operational risk were estimated by the POT model, and the optimal threshold was obtained by the chi-square goodness-of-fit method. The previously calculated Θ and δ parameters were substituted into Equations 10 and 13 to obtain VaR and ES for various types of operational risk loss events in the inventory pledge financing model based on IoT. According to relevant requirements, measurement of credit risk, market risk and operational risk should be at the same confidence level, so the VAR and ES estimated value of each type of operational risk loss events with 99.9% confidence could be calculated, as shown in table 4.

By calculating the VaR and ES values of the new inventory pledge financing model with 99.9% confidence, it could be found that the value of external fraud decreased by 43.607 million yuan compared with the traditional inventory pledge financing mode, and the value of pledge loss and damage decreased by 10.8281 million yuan. The VaR and ES values of the newly added IoT system risk were only slightly larger than the operational errors of practitioners, which were at an acceptable level. The total ES value of operating risk based on IoT was 301.3746 million yuan, which was 69.6265 million yuan less than the total ES value of the traditional mode. This indicated that the inventory pledge financing mode based on IoT designed in this research effectively reduced the operational risk of supply chain finance.

TABLE 3. Preliminary analysis of operating risk loss data of inventory pledge financing model based on IoT (unit: Ten thousand yuan).

Type of operational risk loss	Number of lost samples	average value	Middle Value	maximum	minimal value	Bias	Peaks	J-B value
Internal fraud	86	2366.23	2376.6	6556	26	1.97	10.62	227
External fraud	42	3104.04	3057	7345	37	1.5	3.84	9.96
Loss or damage of collateral	21	1652.95	1588	3451	27	1.63	3.96	8.47
IoT system risk	17	914.33	878	2445	20	1.78	7.96	9.48
Practitioners 'operating errors	23	869.74	756	2498	20	1.94	5.61	11.89

TABLE 4. VaR and ES for each loss category event with operational risk at 99.9% confidence level.

Type of operational risk loss	Internal fraud	External fraud	Loss or damage of collateral	IoT system risk	Practitioners 'operating errors
VaR (99.9%)	6750.61	4764.45	2016.4	1588.59	1393.84
ES (99.9%)	11823.64	8726.8	3836.87	3066.04	2584.11

V. CONCLUSION

In this research, from the perspective of optimizing the supply chain finance mode, a new financing mode of inventory pledge was designed by combining the functions of IoT and the characteristics of the financing mode of inventory pledge in supply chain finance. The new mode was based on IoT intelligent identification, visual tracking and cloud computing big data processing functions to make up for the shortcomings of the original mode. For example, the intelligent identification and visual positioning and tracking of pledges avoided the occurrence of the fraud risk of pledges being pledged by multiple or empty pledges, and at the same time, it realized the information sharing and avoided the relevant risks caused by information asymmetry of each participant in the supply chain finance. Based on the classification of operational risks in Basel accord and the characteristics of inventory pledge financing mode, the operational risks were divided into five types: internal fraud, external fraud, loss and damage of pledges, interruption of the IoT system and operational errors of employees. Then, the POT model based on the extremum theory was built to measure all kinds of loss events in operational risk. Through empirical analysis, when Banks and other financial institutions carried out supply chain finance business, the loss value difference caused by various loss types of operational risk events was quite large. Among them, the external fraud ES was the largest, and the smallest was the operational error of the practitioners. At the same time, the ES value of operational risk of inventory pledge financing mode of IoT technology was smaller than that of traditional inventory pledge financing mode. It showed that the model designed in this research was of certain utility, and it also illustrated the application advantages of IoT technology in supply chain finance, which provided certain reference value for supply chain finance participants.

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