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Research Article

Research of Vulnerability for Fresh Agricultural-Food Supply Chain Based on Bayesian Network

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Unbalanced supply and demand, bottleneck of transport capacity, seasonal cycle, and other factors lead to fragile supply chain of fresh agricultural products led by the platform, impeding smooth operation of the supply chain and even causing disruption risk. This paper studies the short-term and long-term vulnerability of the platform leading fresh agricultural product supply chain under the influence of logistics capital flow and information flow, defines its structure and the meaning of its vulnerability, analyzes the vulnerability of each link, and finds out the existing weak links in the supply chain through empirical research. The probability of accident is quantitatively analyzed by using the Bayesian Network. Firstly, the bow-tie model is used to identify the cause and consequence of the accident, and then it is transformed into the Bayesian Network model; then, the "Precursor Incident" information and prior probability are introduced to derive the posterior accident occurrence probability, and the probability of accident occurrence changing with time is quantitatively analyzed; finally, the dynamic risk calculation of fresh agricultural product trading center dominated by a certain platform was carried out. The results show that, with the increase of supply chain operation time and Precursor Incident, the probability of short-term supply chain vulnerability and accident risk present a significant increase trend, while the probability of long-term supply chain vulnerability and accident risk present a significant decrease trend. Therefore, it is suggested that enterprises should establish a dynamic risk evaluation system to monitor and predict the probability of event vulnerability, pay attention to "Precursor Incident," and take measures to reduce it, such as effective integration of supply chain principal information, timely improvement of information integrated technologies, and comprehensive training on food safety and moral credibility.

1. Introduction

The perishability, nonstandard, seasonal, regional, and periodicity of fresh agricultural-food (FAF) is different from the particularity of industrial products, and the degree of organization of agricultural production and logistics operation is too low, the degree of information integration is not high, the cold chain infrastructure is weak, and the quality traceability system is lacking, resulting in the shortage of supply chain system of fresh agricultural products in China [1].

The circulation of fresh agricultural products not only involves the survival of hundreds of millions of farmers, but also relates to the quality of life of the masses, and has become a social hot issue concerning the national economy and the people's livelihood. At present, the development of the supply chain model of fresh agricultural products based on market platform in China is rooted in the macro background of Chinese agriculture. Summary of literature on supply chain vulnerability is listed in Table 1.

1.1. Characteristics of China's Platform Dominated Fresh Agricultural Products Supply Chain. China's fresh agricultural product circulation system is different from the European and American countries' agricultural product supply chain. The former needs to undertake the function of horizontal cross-regional material allocation and faces a larger consumer market, while the latter has obvious blockization characteristics, and there is a lack of tight connectivity between

Table 1: Summary of literature on supply chain vulnerability [3–7].

Keyword		Research contents	Author
Vulnerability of supply chains		The concept was first put forward as a kind of "random disturbance"	Svessen, 2006
		The concept of distinguishing between supply chain vulnerability and risk	Juttner, 2003
		Identify supply chain risk and create flexible supply chain	Waters, 2007
		Review the meaning of supply chain vulnerability	Briano, 2009
Factors affecting vulnerability		Unpredictability and uncertainty of supply and demand	Christopher
		Including war, strike, and other external motivations	Colema, 2006
		External vulnerability drivers such as complexity and uncertainty of demand forecasting	Edmund, 2001
		Selection and supply risk management among different suppliers	Micheli, 2008
		Response mechanism of external supply chain risk	Suresh
		7 factors including globalization of supply chain and fluctuation of demand, and propose 3P management principles	Ning Zhong
		The prevalence of OEMs, the decrease in the number of suppliers, etc.	Liu Xilong
		The increasing trend of supply chain management and the effect of uncertainty risk on supply chain	Liu Yanping
		Methods to reduce supply chain risk such as multi-purchasing and robust supply chain construction	Chen Changbin
		Impact of complex environments	Du Zhiping
Industry supply chain	productability	Node importance, supplier quality and production synergy efficiency	Yu Kunpeng
	Agricultural products	Analyzing the causes of supply chain maladjustment of agricultural products, establishing strategic partnership, information sharing and perfecting benefit distribution mechanism.	Du Zhao Wei, Liu Shunyi, 2007
	coal	Using Fault Tree Analysis Method and Bayesian Network Model to calculate the network parameters of supply chain vulnerability	Liu Jia, Shi Liwei, 2016

blocks. The agricultural products wholesale trading platform with extensive participation has a high flexibility to adjust the supply and demand of agricultural products, and the platform-driven (PD) mode has more value-added services and development potential. Therefore, the smooth operation of the platform-led fresh agricultural product supply chain (referred to as "PD-FAF-SC") has far-reaching significance for ensuring the sustainable development of China's fresh agricultural products circulation and related industries.

The vulnerability of FAF-SC is mainly reflected in the following aspects: first is the fragility of cooperative relationship. As a supplier, the farmers usually adopt a random way to establish cooperative relations with the platform enterprises, the cooperative relationship is unstable, and the quantity and quality of agricultural products supply are always confronted with interference and fluctuation. The second is the vulnerability of natural factors. Agricultural products are greatly affected by the production environment; natural disasters easily break the FAF-SC. Third is the fragility of the transportation system. At present, there exist certain contradictions between the diversity and uncertainty of demand for fresh agricultural products and regional characteristics of production, the imperfection of modern logistics system, and the biological properties of fresh agricultural products (high water content, short shelf life, perishable, etc.), and circulation transactions between different regions put forward higher requirements for transportation efficiency and preservation conditions. Fourth, restricted by the natural production time and seasonal characteristics of agricultural products, there is a delay between decision-making information and production cycle, which increases the production risk and affects the stability of FAF-SC and agricultural product market.

With the rapid development of China's fresh agricultural products industry, FAF-SC is not only a product material chain connecting suppliers, producers, and consumers, but also a process of processing, packaging, and transportation of fresh agricultural products in the supply chain. The value-added chain increases its value; the continuous extension of the chain increases the probability of risk occurrence and increases the vulnerability.

At present, researches on dynamic evaluation of supply chain vulnerability are concentrated, but in the selection of vulnerability index and the comprehensive dynamic resilience analysis, in the process of evaluation, the selection of vulnerability status monitoring index is easily influenced by subjectivity, and the quantification of index also depends on the knowledge and experience of valuator, resulting in poor objectivity of evaluation results. In addition, in the mathematical method applied by comprehensive elastic dynamic evaluation, the dynamic impact of potential vulnerability in supply chain management on the resilience of supply chain is not taken into account. In the process of supply chain management, vulnerability event and security event are collectively referred to as "Precursor Incident," which is an effective indicator to predict the possibility of risk occurrence [2]. As evidence information in Bayesian networks, "Precursor Incident" is used to calculate dynamic vulnerability.

Therefore, this paper takes into full consideration the dynamic impact of Precursor Incident on vulnerability, introduces bow-tie model and Bayesian Network (hereinafter referred to as BN) model, and establishes a dynamic vulnerability evaluation model. Taking the accident scenario of the platform-dominated fresh agricultural product supply chain as an example, the dynamic change trend of vulnerability with time is analyzed, and the reduction of the vulnerability is sought to improve the effective measures of the supply chain resilience.

1.2. Theoretical Model of PD-FAF-SC Vulnerability Assessment. On the basis of the research mentioned in Table 1, this study uses Bayesian network for quantitative analysis and builds the model as shown in Figure 1.

Figure 1 shows that the vulnerability assessment of the traditional fresh agricultural products trading platform is mainly based on the transaction data of the trading platform, such as supply and demand status, the number of registered trading members, the history of transaction accidents, the loss rate, and the transaction amount. Because of the restriction of less dimension and small coverage group, it is difficult to evaluate the vulnerability of FAF-SC accurately by trading platform data. The PD-FAF-SC vulnerability assessment under big data uses other relevant data on the supply chain platform to innovate the defects of traditional evaluation system. In addition to supply and demand data, PD-FAF-SC vulnerability indicators under big data also make use of natural disasters on supply chain platform, climate change, agricultural production factors, market platform infrastructure and management, cold chain logistics, supply and marketing models, relevant industry policy information, and the bullwhip effect of the supply chain to cross-reproduce the vulnerability of PD-FAF-SC.

Based on previous research experience, this paper adds platform management information that can affect the PD-FAF-SC vulnerability assessment status, such as transaction cycle, test data, food mileage, information security traceability of information, and expected loss to evaluate the vulnerability status of the platform's FAF-SC. Multidimensional data can intersect the vulnerability of PD-FAF-SC, but it also complicates the operation. The improper evaluation model can easily lead to the distortion of evaluation results due to the interference of "data noise." The existence of "black box" requires the selection of appropriate PD-FAF-SC vulnerability assessment method.

A quantitative model is analyzed for calculating the vulnerability of PD-FAF-SC under the influence of logistics, capital flow, and information flow. This paper first proposes the structure of the upper, middle, and lower reaches of PD-FAF-SC. The combination of fault tree and Bayesian network is used to analyze the short-term and long-term vulnerability of the supply chain to obtain the risk transfer process and its influencing factors and quantitatively calculate the results and through the empirical research to find out the weak link of PD-FAF-SC [8].

The Bayesian network can completely describe the substitution of conditional probability to logic gate. The application of conditional probability method can make full use of the historical data and the prior probability of PD-FAF-SC to improve the accuracy of vulnerability. Using Bayesian network quantitative methods to analyze the vulnerability of PD-FAF-SC is more helpful to analyze the weak links in the actual operation while conducting in-depth research on the influencing factors and risk transmission links of its operation mechanism and vulnerability. Some reasonable suggestions are put forward to solve the problems such as unbalanced supply and demand of fresh agricultural products, and difficulties in continuous supply under seasonal consumption peaks or emergency management conditions caused by information asymmetry, natural disasters, food safety, etc.

2. Description of PD-FAP-SC Supply Chain Vulnerability Model

Part of fragile factors such as extreme weather and natural disasters in PD-FAF-SC has the characteristics of short-term and rapid risk transmission, which has a deep impact on the upstream, middle, and lower reaches of the supply chain and factors such as economic crisis have a significant and substantive impact on the long-term vulnerability of supply chain. According to the characteristics of PD-FAF-SC, this paper analyzes the short-term and long-term vulnerability to reflect the objectivity and scientific of the research.

2.1. Description of Short-Term Vulnerability Model. The short-term vulnerability description of PD-FAF-SC affected by risk factors in a short period of time will occur in the calculation of the probability of operating imbalance or even local fracture. The process of vulnerability transmission is as follows: the upstream link mainly includes farmers and fresh agricultural products circulation processing enterprises and fresh agricultural products suppliers/primary purchasers; since more than 70% of the downstream demand structure of fresh agricultural products is retail, the retail demand for fresh agricultural products has a great impact on supply chain [9]; the middle and lower reaches of the supply chain are simplified as follows: trading market, logistics enterprises, downstream distributors, and retailers of fresh agricultural products; the platform is the main bottleneck of FAF-SC, in which the transfer function connects all the upstream and downstream links.

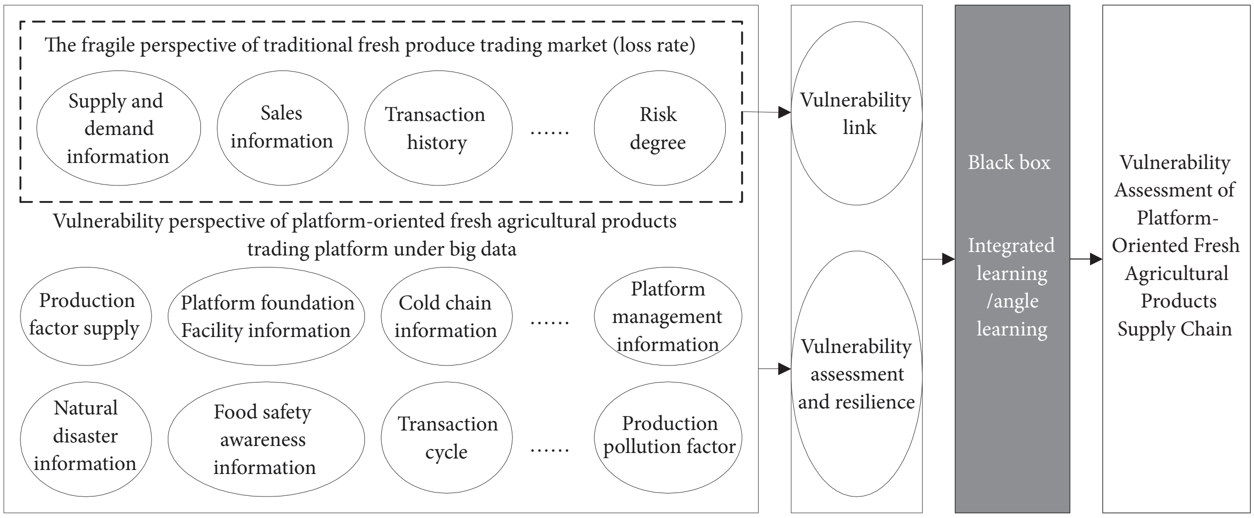

Figure 1: Theoretical model of PD-FAF-SC vulnerability assessment.

2.1.1. Upstream Planting Links. In the upstream planting process, farmers or enterprises of different forms of fresh agricultural products are included. The strong seasonal fluctuations in the prices of raw materials have been the prominent factors restricting the healthy operation of the fresh agricultural products industry in China in recent years. The failure of farmers' production decision and the difficulty of raising agricultural resources will also cause a great negative impact on the short-term supply chain and even lead to the sudden interruption of the chain.

Agricultural production has a strong dependence on natural conditions. The external environmental risk factors of short-term supply chain include insect disasters, animal and plant epidemics, drought, and other natural disasters [10]. The abuse of production materials such as pesticides, chemical fertilizers, and hormones in the production process of farmers, the risk of production pollution caused by the destruction of cultivated land, and water resources seriously affect the resilience of the supply chain. Events such as lean meat powder, melamine milk powder avian influenza, blue ear disease (PRRS), and banana black poisoning have all exposed the huge risks in the production of fresh agricultural products in China.

2.1.2. Midstream Circulation Links. Cold-chain transportation and platform-oriented and cold-chain distribution are all sublinks of PD-FAF-SC midstream circulation. Meteorological disasters have the greatest restriction on land cold chain transportation, while the cold chain technology and equipment are not mature, the logistics infrastructure is relatively backward, and the transportation organization is not good that causes the fresh agricultural products to not be delivered in time and quality, resulting in a certain degree of harm to the supply chain. In the platform-oriented aspect, the deviation of goods source or scheduling error caused by organization and management errors occurred frequently, and the mismatch between food mileage and cold chain logistics facilities, due to poor communication of information, which leads to platform-led transaction disputes and increases the internal management cost of the platform transaction, hinders the operation of the midstream supply chain, resulting in the phenomenon that agricultural products are stranded and stored, rot is difficult to resell, and the loss rate is high. Short-term supply chain risks include logistics risks and lack of integrity of operators.

2.1.3. Downstream Consumption Links. The consumption of fresh agricultural products is greatly affected by natural and environmental conditions. The short-term supply chain demand risk comes from sudden changes in customer demand. The main influencing factors are price fluctuations, scientific and technological progress, quality and safety rumors, etc., resulting in the disruption of the entire supply chain.

2.2. Description of Long-Term Vulnerability Model. Different from the short-term supply chain, some influencing factors may lead to the probability of partial interruption of FAF-SC in a foreseeable and long period of time. According to the scale of the enterprise, the corresponding risk degree, and the environment, the long-term PD-FAF-SC divides the upstream planting link into the large-scale fresh agricultural product planting leading enterprises and the small- and medium-sized fresh agricultural product planting farmers. For the downstream link of the supply chain, in addition to terminal retail, high-value-added food processing enterprises also have a significant demand for fresh agricultural products.

2.2.1. Upstream Planting Links. At present, the scale of fresh agricultural products planting enterprises or farmers in China is on the low side due to the asymmetry of information, and the low degree of organization and industrialization, the production arrangement of farmers has great blindness and the increased market risks. For the small- and medium-sized farmers, affected by the circulation and processing equipment of fresh agricultural products, it is difficult for them to switch their production. Once the risk occurs, it is difficult to enter and exit quickly, which to a certain extent increases the management risk of small- and medium-sized fresh farm produce farmers. China's fresh agricultural products have a bumper harvest, and the slow sales have become a common phenomenon, which appears almost every year, but only in the reincarnation of varieties, which exposes the huge problem of circulation of fresh agricultural products in China.

2.2.2. The Midstream Circulation Links. The long-distance transportation of Chinese fresh agricultural products and the imperfect characteristics of cold chain transportation facilities hinder the transportation of fresh agricultural products and restrict the development of fresh agricultural products industry for a long time. The low level of informatization of China's fresh agricultural product market platform affects the sustainable development of long-term PD-FAF-SC. The high investment cost of the platform, the long construction cycle, the high technical requirements of data and information integration, and the inaccurate prediction of cold-chain logistics enterprises are the prominent features of PD-FAF-SC and face certain operational risks.

2.2.3. Downstream Demand and Terminal Consumption Links. From the downstream perspective, affected by the domestic macroscopic control, supply-side reform, and the development of e-commerce, the downstream demand and end-consumption structure of fresh agricultural products have undergone major changes, and the bullwhip effect has increased. Although the terminal direct retailing is still the main consumption mode of fresh agricultural products in China, the green deep processing industry of agricultural products has developed rapidly under the influence of national favourable policies.

3. Dynamic Bayesian Network Model Based on Bow-Tie Model

Bow-tie model is an accident causality analysis method integrating fault tree and event tree analysis method, which can comprehensively analyze the causes and consequences of an event and clearly and intuitively describe the occurrence sequence of the accident and the logical relationship between each event [11, 12].

BN has the advantages of describing common cause failure, polymorphism, and uncertainty logical relations and has developed mature auxiliary calculation software, which is applied to probability calculation and quantitative risk evaluation, and the theoretical basis is Bayesian conditional probability computational formula [13],

$$P(A \mid B) = \frac{P(B \mid A) P(A)}{P(B)} \tag{1}$$

where $P(A)$ is the prior probability, $P(A \mid B)$ is the posterior probability, $P(B)$ is the evidence factor, and $P(B \mid A)$ is the likelihood function.

3.1. Dynamic Vulnerability Assessment Based on "Precursor Incident". On the basis of the above theory, a dynamic vulnerability analysis model based on bow-Bayesian network is established, as shown in Figure 2.

In bow-tie model, the left side of the critical event is the fault tree, whose elastic barrier is used to prevent accidents. On the right is the event tree, whose resilience barrier is used to reduce the severity of accident consequences. Firstly, we screen the event scenarios that need to be analyzed, analyze the causes, consequences, and top events according to the supply chain structure and nodes, and describe them with the bow-tie model. Secondly, the bow-tie model is transformed into a Bayesian network model in accordance with certain rules, and the prior probability is input. According to the practical supply chain platform record, the Precursor Incident information is input into the Bayesian network model, and the results of dynamic vulnerability assessment can be calculated. The model can be dynamically updated continuously on the basis of the change of time and the increase of evidence information. The key point of model analysis is that the bowtie model is transformed into BN, and the dynamic vulnerability is calculated according to the Precursor Incident.

3.2. The Transformation of Bowtie Model to Bayesian Network Model. As the root node and intermediate node of the BN model, the basic and intermediate events of the fault tree have a directed edge from the base event to the intermediate event. Each resilience barrier of the event tree is represented as a node in the BN model, and all resilience barrier nodes that affect the severity of consequences should point to consequence nodes. The risk probabilities for the basic events in the model come from the CFSA database [14] and Table 2.

According to Bayesian formula (1), the posterior distribution $P(A \mid B)$ is proportional to the product of the prior distribution $P(A)$ and the likelihood function $P(B \mid A)$, Beta distribution is selected as the prior distribution of the Bayesian network model for dynamic vulnerability assessment, and binomial distribution function is selected as the likelihood function, assuming that the vulnerability probability of each node obeys binomial distribution.

Suppose that a node x_i in the Bayesian network model obeys the $Beta(a, b)$ distribution, i.e.,

$$P(x) = \frac{\Gamma(a+b)}{\Gamma(a)\Gamma(b)} x^{a-1} (1-x)^{b-1} \propto x^{a-1} (1-x)^{b-1} \tag{2}$$

If the "Precursor Incident" information shows that the vulnerability data $Data = (d_1, d_2, \cdots, d_i)$ of a node, $d_i = 1$(resilience) or 0(inresilience) obeys Bernoulli distribution, $\delta = \sum_{i=1}^{n} d_i$, then the following equation is available.

$$\begin{aligned} P(x \mid D) = \frac{P(D \mid x) P(x)}{P(D)} \propto P(D \mid x) P(x) \propto \\ x^{\delta} (1-x)^{n-\delta} x^{a-1} (1-x)^{b-1} \propto x^{a+\delta-1} (1-x)^{b+n-\delta-1} \end{aligned} \tag{3}$$

According to (3), the posterior distribution satisfies $Beta(a+\delta, b+n-\delta)$; thus it can be seen that both the prior distribution

Table 2: CPT between resilience nodes.

Supply chain vulnerability	Supply chain disruption	Supply chain sustainability
Short-term vulnerability	0.99	0.01
Long-term vulnerability	0.02	0.98

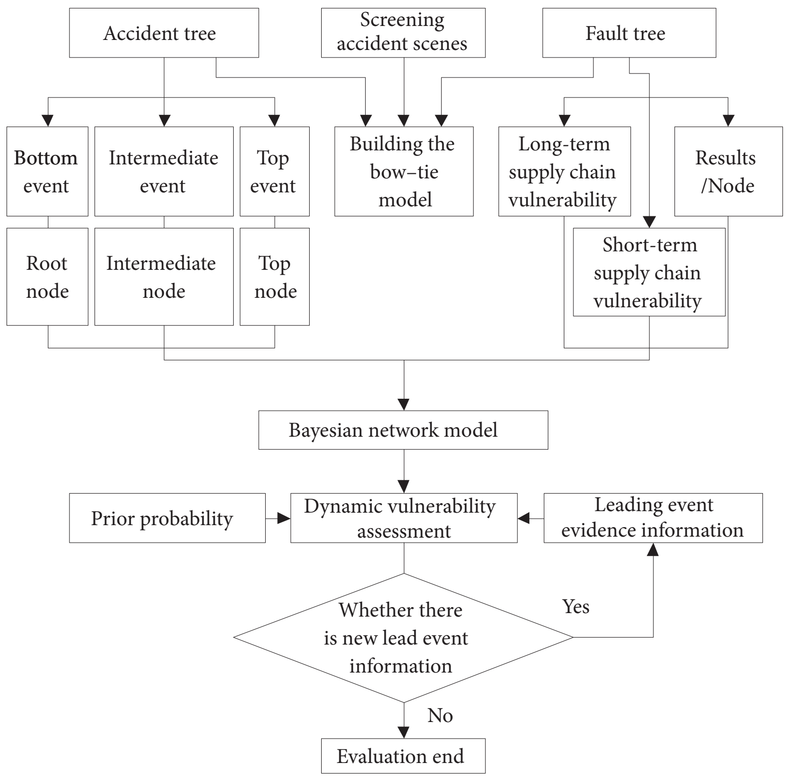

Figure 2: Flow chart of dynamic vulnerability assessment based on the bow-Bayesian network model.

and the posterior distribution satisfy Beta distribution, which shows that Beta distribution has good transitivity, and with the increase of sample number, the influence degree of prior probability gradually decreases. Parameters a and b can be obtained by fitting of historical data, or directly given on the basis of the expert experience. In summary, it can be seen from the analysis that the posterior distribution of node vulnerability can be calculated by using "Precursor Incident" information as evidence information, and then the dynamic vulnerability evaluation results can be obtained.

3.3. Short-Term Vulnerability Model of PD-FAF-SC

3.3.1. Short-Term Vulnerability Model. According to the analysis of vulnerability characteristics, the design of fault tree event of PD-FAF-SC short-term vulnerability is described. The vulnerability is defined as the top event of the fault tree, and the intermediate event is used to describe the vulnerability of upstream, middle, and downstream supply chain operations, using logic OR gate and AND gate to construct the fault tree structure as shown in Figures 3–5 [15]. The English UP in upstream planting is Upper planters, the English PD in the platform leading UP is Platform-driven, and other similarities are no longer explained.

3.3.2. Short-Term Vulnerability Calculation Based on Bayesian Networks. The PD-FAF-SC vulnerability fault tree has 13 minimum cut sets, which are $\{X_1\}$,$\{X_2, X_3, X_4\}$, $\{X_5, X_6, X_7\}$, $\{X_8, X_9\}$, $\{X_{10}\}$, $\{X_{11}, X_{12}, X_{13}\}$, $\{X_{14}\}$, $\{X_{15}, X_{16}, X_{17}, X_{18}\}$, $\{X_{19}, X_{20}, X_{21}\}$, $\{X_{22}, X_{23}, X_{24}\}$, $\{X_{25}\}$, $\{X_{26}, X_{27}\}$, $\{X_{28}, X_{29}, X_{30}, X_{31}, X_{32}\}$.

Transform the above PD-FAF-SC fault tree into Bayesian Network structure; the conversion formulas of logic gates "OR" and "AND" are given, respectively, as well as the analysis formulas for calculating the short-term vulnerability of PD-FAF-SC which is constructed by various network parameters.

3.3.3. Transform PD-FAF-SC Fault Tree into Bayesian Network. Using Figures 3–5, the basic relationship among the top event, the intermediate event, and the bottom event can be given, corresponding nodes are established and linked in the Bayesian network, and the logic gates in the fault tree are converted to conditional probability in Bayesian network. The event occurs when the event is equal to 1, and when the event is equal to 0, the event does not occur [15]. The conversion formula is as shown in formulas (4)-(16):

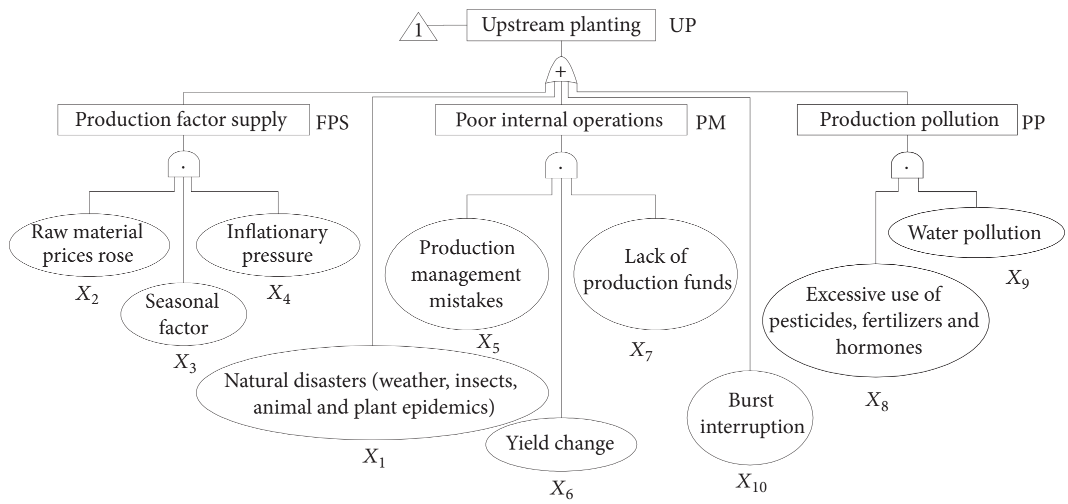

Figure 3: Fault tree of short-term vulnerability of PD-FAF-SC upstream planting links.

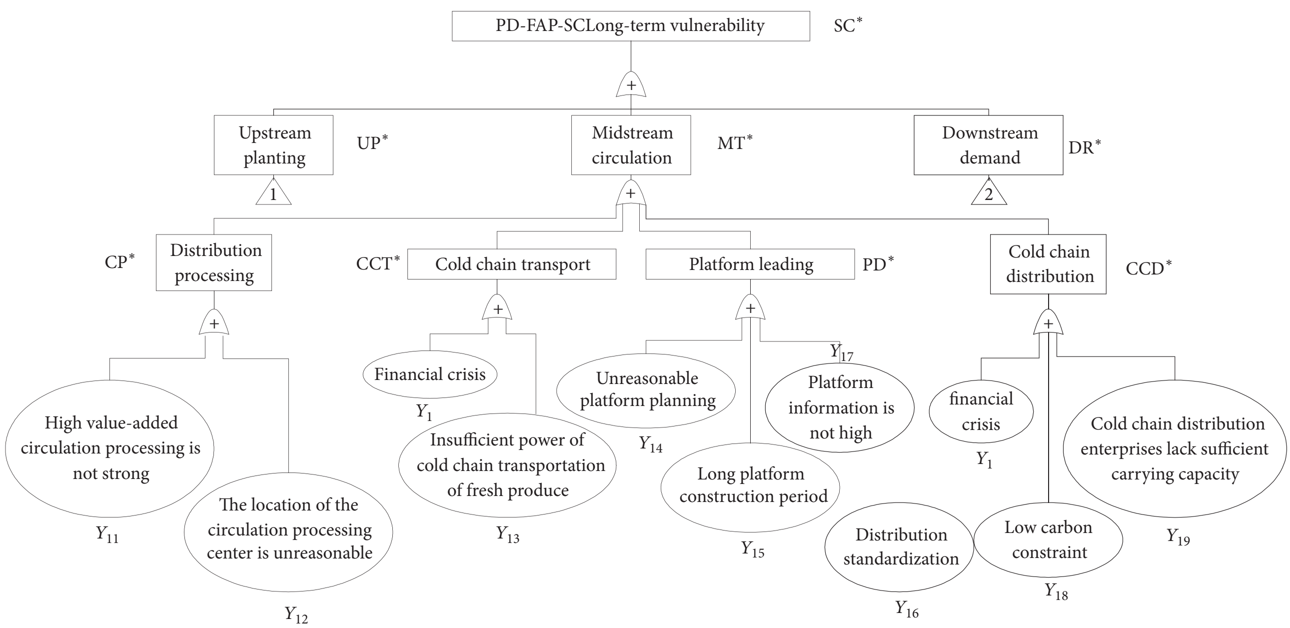

Figure 4: Fault tree of short-term vulnerability of PD-FAF-SC midstream transport links.

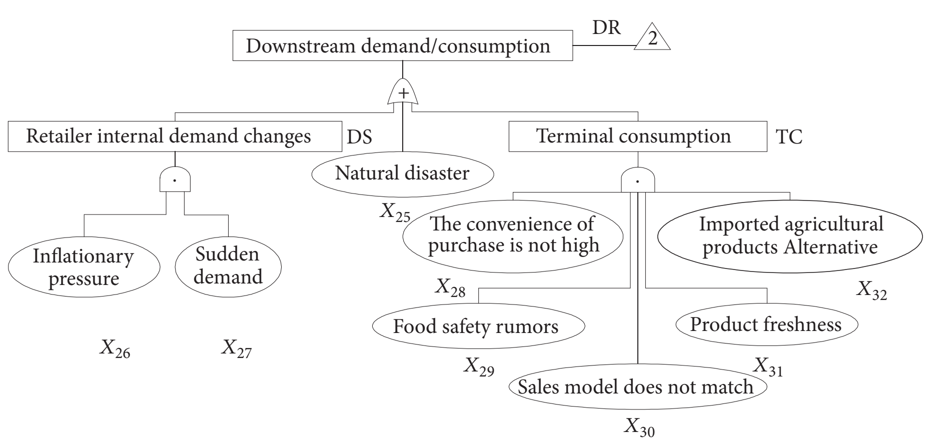

Figure 5: Fault tree for short-term vulnerability of PD-FAF-SC downstream demand links.

$$UP = FPS \cup PM \cup PPE \cup X_1 \cup X_{10} \begin{cases} P\left(UP = 1 \mid FPS = 0, PM = 0, PPE = 0, X_1 = 0, X_{10} = 0\right) = 0 \\ P\left(UP = 1 \mid else\right) = 1 \end{cases} \tag{4}$$

$$FPS = X_2 \cap X_3 \cap X_4 \begin{cases} P\left(FPS = 1 \mid X_2 = 1, X_3 = 1, X_4 = 1\right) = 1 \\ P\left(FPS = 1 \mid else\right) = 0 \end{cases} \tag{5}$$

$$PM = X_5 \cap X_6 \cap X_7 \begin{cases} P\left(PM = 1 \mid X_5 = 1, X_6 = 1, X_7 = 1\right) = 1 \\ P\left(PM = 1 \mid else\right) = 0 \end{cases} \tag{6}$$

$$PPE = X_8 \cap X_9 \begin{cases} P\left(PPE = 1 \mid X_8 = 1, X_9 = 1\right) = 1 \\ P\left(PPE = 1 \mid else\right) = 0 \end{cases} \tag{7}$$

$$MT = CCT \cup PD \cup CCD \cup DP \cup X_{14} \begin{cases} P\left(MT = 1 \mid CCT = 0, DP = 0, CCD = 0, X_{14} = 0, PD = 0\right) = 0 \\ P\left(MT = 1 \mid else\right) = 1 \end{cases} \tag{8}$$

$$DP = X_{11} \cap X_{12} \cap X_{13} \begin{cases} P\left(DP = 1 \mid X_{11} = 1, X_{12} = 1, X_{13} = 1\right) = 1 \\ P\left(DP = 1 \mid else\right) = 0 \end{cases} \tag{9}$$

$$CCT = X_{15} \cap X_{16} \cap X_{17} \cap X_{18} \begin{cases} P\left(CCT = 1 \mid X_{15} = 1, X_{16} = 1, X_{17} = 1, X_{18} = 1\right) = 1 \\ P\left(CCT = 1 \mid else\right) = 0 \end{cases} \tag{10}$$

$$PD = X_{19} \cap X_{20} \cap X_{21} \begin{cases} P\left(PD = 1 \mid X_{19} = 1, X_{20} = 1, X_{21} = 1\right) = 1 \\ P\left(PD = 1 \mid else\right) = 0 \end{cases} \tag{11}$$

$$CCD = X_{22} \cap X_{23} \cap X_{24} \begin{cases} P\left(CCD = 1 \mid X_{22} = 1, X_{23} = 1, X_{24} = 1\right) = 1 \\ P\left(CCD = 1 \mid else\right) = 0 \end{cases} \tag{12}$$

$$DR = X_{25} \cup DS \cup TC \begin{cases} P\left(DR = 1 \mid X_{25} = 0, DS = 0, TC = 0\right) = 0 \\ P\left(DR = 1 \mid else\right) = 1 \end{cases} \tag{13}$$

$$DS = X_{26} \cap X_{27} \begin{cases} P\left(DS = 1 \mid X_{26} = 1, X_{27} = 1\right) = 1 \\ P\left(DS = 1 \mid else\right) = 0 \end{cases} \tag{14}$$

$$TC = X_{28} \cap X_{29} \cap X_{30} \cap X_{31} \cap X_{32} \begin{cases} P\left(TC = 1 \mid X_{28} = 1, X_{29} = 1, X_{30} = 1, X_{31} = 1, X_{32} = 1\right) = 1 \\ P\left(TC = 1 \mid else\right) = 0 \end{cases} \tag{15}$$

$$SC = US \cup MT \cup DR \begin{cases} P\left(SC = 1 \mid UP = 0, MT = 0, DR = 0\right) = 0 \\ P\left(SC = 1 \mid else\right) = 1 \end{cases} \tag{16}$$

In the upper formula, if $DR = X_{25} \cup DS \cup TC$ represent event X_{25} or event DS or event TC, the event DR will occur; $PPE = X_8 \cap X_9$ indicates through the logical AND gate that if event X_8 coincides with event X_9, the event PPE will occur. Other cases refer to the explanation.

3.3.4. Short-Term Vulnerability Calculation of PD-FAF-SC Based on Bayesian Networks. The Bayesian network parameters of PD-FAF-SC are determined by the priori probability of each root node and the connection relation, and the probability that the upstream supply is difficult to meet the downstream demand by the influence of the bottom event factor is calculated. Assuming that all root node events in the network are independent of each other, the priori probability when each root node event in the Bayesian network of PD-FAF-SC can be observed $\theta_n = P(X_n = 1), 1 \le n \le 32$. According to the priori probability of each root node of PD-FAF-SC, the probability of solving each intermediate event is as follows:

First, upstream planting links:

$$\begin{aligned} P(FPS = 1) &= \sum_{X_2,X_3,X_4} (FPS = 1 \mid X_2, X_3, X_4) \\ &= \sum_{X_2,X_3,X_4} (FPS = 1 \mid X_2, X_3, X_4) P(X_2, X_3, X_4) \\ &= \sum_{X_2,X_3,X_4} (FPS = 1 \mid X_2, X_3, X_4) P(X_2) P(X_3) \\ &\cdot P(X_4) = \sum_{X_2,X_3,X_4} (FPS = 1 \mid X_2, X_3, X_4) \\ &\cdot P(X_2 = 1) P(X_3 = 1) P(X_4 = 1) = \theta_2\theta_3\theta_4 \end{aligned} \tag{17}$$

This is because $P(FPS = 1 \mid X_2 = 1, X_3 = 1, X_4 = 1) = 1$ $P(X_2) = \theta_2, P(X_3) = \theta_3, P(X_4) = \theta_4$.

Similarly calculated:

$$\begin{aligned} P(PM = 1) &= \sum_{X_5,X_6,X_7} (PM = 1, X_5, X_6, X_7) \\ &= \theta_5\theta_6\theta_7 \end{aligned} \tag{18}$$

$$P(PPE = 1) = \sum_{X_8,X_9} (PPE = 1, X_8, X_9) = \theta_8\theta_9 \tag{19}$$

$$\begin{aligned} P(UP = 1) &= \sum_{FPS,PM,PPE,X_1,X_{10}} (UP \\ &= 1, FPS, PM, PPE, X_1, X_{10}) \\ &= \sum_{FPS,PM,PPE,X_1,X_{10}} (UP \\ &= 1 \mid FPS, PM, PPE, X_1, X_{10}) P(FPS) P(PM) \\ &\cdot P(PPE) P(X_1) P(X_{10}) = 1 - [1 - P(FPS = 1)] \\ &\cdot [1 - P(PM = 1)] [1 - P(PPE = 1)] [1 - P(X_1)] \\ &\cdot [1 - P(X_{10})] = 1 - (1 - \theta_1)(1 - \theta_2\theta_3\theta_4)(1 \\ &- \theta_5\theta_6\theta_7)(1 - \theta_8\theta_9)(1 - \theta_{10}) \end{aligned} \tag{20}$$

Second, the midstream circulation links:

$$\begin{aligned} P(DP = 1) &= \sum_{X_{11},X_{12},X_{13}} (DP = 1, X_{11}, X_{12}, X_{13}) \\ &= \theta_{11}\theta_{12}\theta_{13} \end{aligned} \tag{21}$$

$$\begin{aligned} P(CCT = 1) &= \sum_{X_{15},X_{16},X_{17},X_{18}} (CCT \\ &= 1, X_{15}, X_{16}, X_{17}, X_{18}) = \theta_{15}\theta_{16}\theta_{17}\theta_{18} \end{aligned} \tag{22}$$

$$\begin{aligned} P(PD = 1) &= \sum_{X_{19},X_{20},X_{21}} (PD = 1, X_{19}, X_{20}, X_{21}) \\ &= \theta_{19}\theta_{20}\theta_{21} \end{aligned} \tag{23}$$

$$\begin{aligned} P(CCD = 1) &= \sum_{X_{22},X_{23},X_{24}} (CCD = 1, X_{22}, X_{23}, X_{24}) \\ &= \theta_{22}\theta_{23}\theta_{24} \end{aligned} \tag{24}$$

$$\begin{aligned} P(MT = 1) &= \sum_{X_{14},DP,CCT,PD,CCD} (MT \\ &= 1 \mid DP, X_{14}, CCT, PD, CCD) = 1 - [1 - \theta_{14}] [1 \\ &- \theta_{11}\theta_{12}\theta_{13}] [1 - \theta_{15}\theta_{16}\theta_{17}\theta_{18}] [1 - \theta_{19}\theta_{20}\theta_{21}] [1 \\ &- \theta_{22}\theta_{23}\theta_{24}] \end{aligned} \tag{25}$$

Third, downstream demand and end-consumption links:

$$P(DS = 1) = \sum_{X_{26},X_{27}} (DS = 1, X_{26}, X_{27}) = \theta_{26}\theta_{27} \tag{26}$$

$$\begin{aligned} &P(TC = 1) \\ &= \sum_{X_{28},X_{29},X_{30},X_{31},X_{32}} (TC = 1, X_{28}, X_{29}, X_{30}, X_{31}, X_{32}) \\ &= \theta_{28}\theta_{29}\theta_{30}\theta_{31}\theta_{32} \end{aligned} \tag{27}$$

$$\begin{aligned} P(DR = 1) &= \sum_{X_{25},DS,TC} (DR = 1, X_{25}, DS, TC) \\ &= 1 - [1 - \theta_{25}] [1 - \theta_{26}\theta_{27}] [1 - \theta_{28}\theta_{29}\theta_{30}\theta_{31}\theta_{32}] \end{aligned} \tag{28}$$

Based on the conditional probability of the intermediate events in the upper, middle, and lower reaches, the probability of the occurrence of PD-FAF-SC short-term vulnerability can be found in (29):

$$\begin{aligned} P(SC = 1) &= \sum_{UP,MT,DR} (SC = 1, UP, MT, DR) = 1 \\ &- [1 - P(UP = 1)] [1 - P(MT = 1)] \\ &\cdot [1 - P(DR = 1)] = 1 - (1 - \theta_1)(1 - \theta_2\theta_3\theta_4) \\ &\cdot (1 - \theta_5\theta_6\theta_7)(1 - \theta_8\theta_9)(1 - \theta_{10})(1 - \theta_{14}) \\ &\cdot (1 - \theta_{11}\theta_{12}\theta_{13}) \times (1 - \theta_{15}\theta_{16}\theta_{17}\theta_{18}) \\ &\cdot (1 - \theta_{19}\theta_{20}\theta_{21})(1 - \theta_{22}\theta_{23}\theta_{24})(1 - \theta_{25}) \\ &\cdot (1 - \theta_{26}\theta_{27})(1 - \theta_{28}\theta_{29}\theta_{30}\theta_{31}\theta_{32}) \end{aligned} \tag{29}$$

3.4. Construction and Calculation of Long-Term Vulnerability Model for PD-FAF-SC

3.4.1. Long-Term Vulnerability Model Construction. In order to distinguish it from the calculation of short-term vulnerability, long-term supply chain vulnerability is represented by SC^*, and similar node links such as upstream planting link are represented by UP^*, etc. As the economic crisis risk factors will have a long-term impact on many aspects of the supply chain, this paper uses the unified Y_1. Figures 6–8 show the fault tree structure for long-term vulnerability in the middle and lower reaches of the PD-FAF-SC.

3.4.2. Long-Term Vulnerability Calculation Based on Bayesian Networks. In accordance with the above idea of short-term vulnerability calculation, the fault tree of long-term vulnerability is first transformed into Bayesian network and given parameters settings to construct a quantitative analysis method.

3.4.3. Transform PD-FAF-SC Fault Tree into Bayesian Network. Through the fault tree structure of PD-FAF-SC shown in Figures 6–8, and referring to the corresponding relationship between nodes, the logic gate in the long-term vulnerability fault tree is transformed into the conditional probability of Bayesian network; see formulas (30)-(40):

$$UP^* = LCE \cap SCE \begin{cases} P\left(UP^* = 1 \mid LCE = 1, SCE = 1\right) = 1 \\ P\left(UP^* = 1 \mid else\right) = 0 \end{cases} \tag{30}$$

$$LCE = Y_1 \cup Y_2 \cup Y_3 \cup Y_4 \cup Y_5 \begin{cases} P\left(LCE = 1 \mid Y_1 = 0, Y_2 = 0, Y_3 = 0, Y_4 = 0, Y_5 = 0\right) = 0 \\ P\left(LCE = 1 \mid else\right) = 1 \end{cases} \tag{31}$$

$$SCE = Y_1 \cup Y_6 \cup Y_7 \cup Y_8 \cup Y_9 \cup Y_{10} \begin{cases} P\left(SCE = 1 \mid Y_1 = 0, Y_6 = 0, Y_7 = 0, Y_8 = 0, Y_9 = 0, Y_{10} = 0\right) = 0 \\ P\left(SCE = 1 \mid else\right) = 1 \end{cases} \tag{32}$$

$$MT^* = DP^* \cup CCT^* \cup PD^* \cup CCD^* \begin{cases} P\left(MT^* = 1 \mid DP^* = 0, CCT^* = 0, PD^* = 0, CCD^* = 0\right) = 0 \\ P\left(MT^* = 1 \mid else\right) = 1 \end{cases} \tag{33}$$

$$DP^* = Y_{11} \cup Y_{12} \begin{cases} P\left(DP^* = 1 \mid Y_{11} = 0, Y_{12} = 0\right) = 0 \\ P\left(DP^* = 1 \mid else\right) = 1 \end{cases} \tag{34}$$

$$CCT^* = Y_1 \cup Y_{13} \begin{cases} P\left(CCT^* = 1 \mid Y_{13} = 0, Y_1 = 0\right) = 0 \\ P\left(CCT^* = 1 \mid else\right) = 1 \end{cases} \tag{35}$$

$$PD^* = Y_{14} \cup Y_{15} \cup Y_{16} \cup Y_{17} \begin{cases} P\left(PD^* = 1 \mid Y_{14} = 0, Y_{15} = 0, Y_{16} = 0, Y_{17} = 0\right) = 0 \\ P\left(PD^* = 1 \mid else\right) = 1 \end{cases} \tag{36}$$

$$CCD^* = Y_1 \cup Y_{18} \cup Y_{19} \begin{cases} P\left(CCD^* = 1 \mid Y_1 = 0, Y_{18} = 0, Y_{19} = 0\right) = 0 \\ P\left(CCD^* = 1 \mid else\right) = 1 \end{cases} \tag{37}$$

$$DR^* = RE \cap FDE \begin{cases} P\left(DR^* = 1 \mid RE = 1, FDE = 1\right) = 1 \\ P\left(DR^* = 1 \mid else\right) = 0 \end{cases} \tag{38}$$

$$RE = Y_1 \cup Y_{20} \cup Y_{21} \cup Y_{22} \cup Y_{23} \cup Y_{24} \begin{cases} P\left(RE = 1 \mid Y_1 = 0, Y_{20} = 0, Y_{21} = 0, Y_{22} = 0, Y_{23} = 0, Y_{24} = 0\right) = 0 \\ P\left(RE = 1 \mid else\right) = 1 \end{cases} \tag{39}$$

$$FDE = Y_1 \cup Y_{25} \cup Y_{26} \cup Y_{27} \cup Y_{28} \begin{cases} P\left(FDE = 1 \mid Y_1 = 0, Y_{25} = 0, Y_{26} = 0, Y_{27} = 0, Y_{28} = 0\right) = 0 \\ P\left(FDE = 1 \mid else\right) = 1 \end{cases} \tag{40}$$

The relationship between "OR" and "AND" gates indicates that the long-term vulnerability fault tree of PD-FAF-SC is expressed as formula (41):

$$SC^* = UP^* \cup MT^* \cup DR^* \begin{cases} P\left(SC^* = 1 \mid UP^* = 0, MT^* = 0, DR^* = 0\right) = 0 \\ P\left(SC^* = 1 \mid else\right) = 1 \end{cases} \tag{41}$$

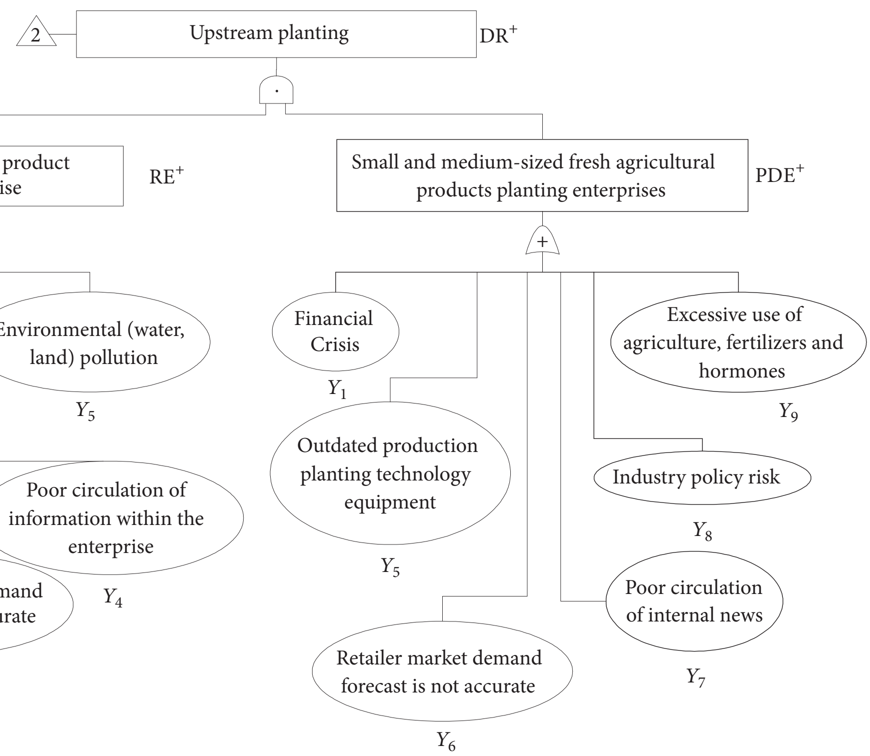

Figure 6: Fault tree of long-term vulnerability of PD-FAF-SC upstream planting link.

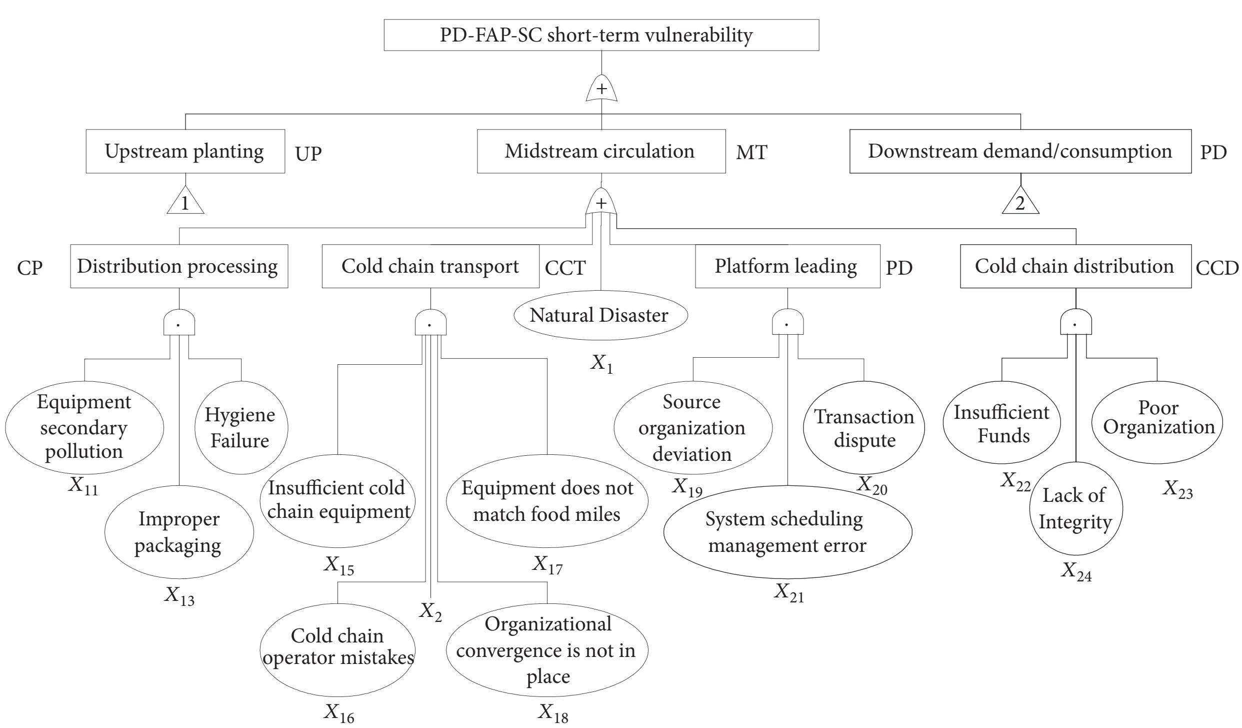

Figure 7: Fault tree of long-term vulnerability of PD-FAF-SC transit links.

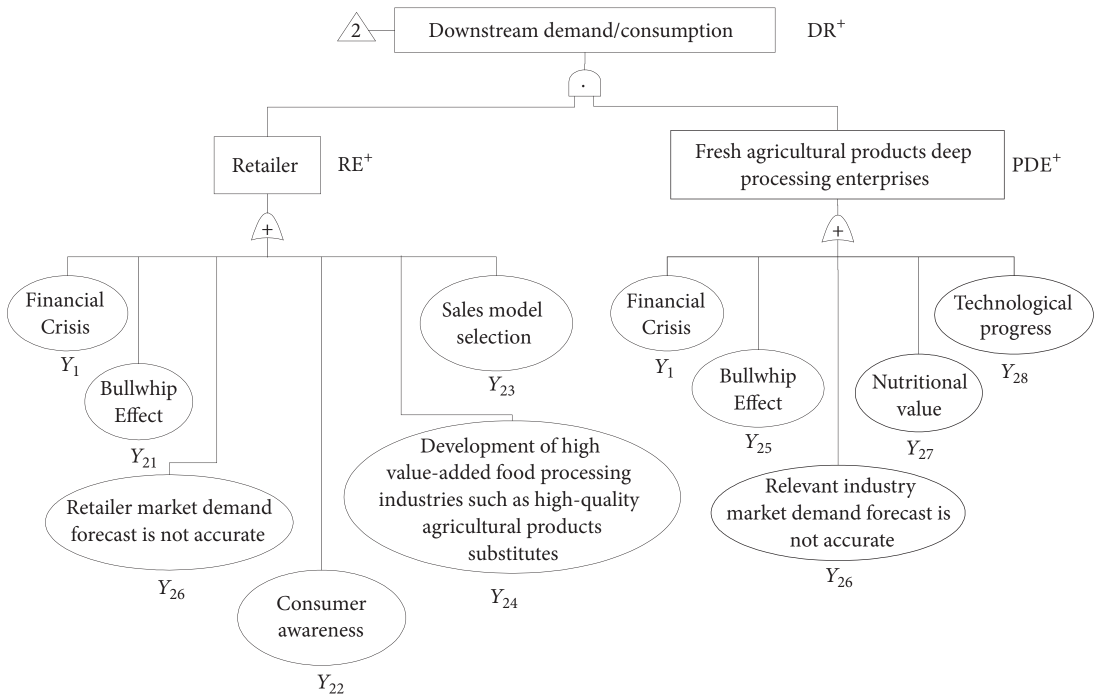

FIGURE 8: Fault tree for long-term vulnerability of PD-FAF-SC downstream demand links.

3.4.4. Long-Term Vulnerability Calculation of PD-FAF-SC Based on Bayesian Networks. The long-term vulnerability assessment of PD-FAF-SC uses the priori probability $\rho_N = P(Y_N = 1)$, $1 \leq N \leq 28$, which can be observed at the occurrence of each root event in Bayesian network, and the probability relations between each node to calculate the probability of long-term vulnerability step by step.

First, upstream planting links:

$$P(LCE = 1) = \sum_{Y_1,Y_2,Y_3,Y_4,Y_5} P(LCE = 1, Y_1, Y_2, Y_3, Y_4, Y_5) = 1 - \prod_{j=1}^{5}(1-\rho_j) \tag{42}$$

$$P(SCE = 1) = \sum_{Y_1,Y_6,Y_7,Y_8,Y_9,Y_{10}} P(SCE = 1, Y_1, Y_6, Y_7, Y_8, Y_9, Y_{10}) = 1 - (1-\rho_1)\prod_{j=6}^{10}(1-\rho_j) \tag{43}$$

$$P(UP^* = 1) = \sum_{LCE,SCE} P(UP^* = 1, LCE, SCE) = \left[1 - \prod_{j=1}^{5}(1-\rho_j)\right]\left[1 - (1-\rho_1)\prod_{j=6}^{10}(1-\rho_j)\right] \tag{44}$$

Second, the midstream circulation links:

$$P(DP^* = 1) = \sum_{Y_{11},Y_{12}} P(DP^* = 1, Y_{11}, Y_{12}) = 1 - (1-\rho_{11})(1-\rho_{12}) \tag{45}$$

$$P(CCT^* = 1) = \sum_{Y_1,Y_{13}} P(CCT^* = 1, Y_1, Y_{13}) = 1 - (1-\rho_1)(1-\rho_{13}) \tag{46}$$

$$P(PD^* = 1) = \sum_{Y_{14},Y_{15},Y_{16},Y_{17}} P(PD^* = 1, Y_{14}, Y_{15}, Y_{16}, Y_{17}) = 1 - \prod_{j=14}^{17}(1-\rho_j) \tag{47}$$

$$P(CCD^* = 1) = \sum_{Y_1,Y_{18},Y_{19}} P(CCD^* = 1, Y_1, Y_{18}, Y_{19}) = 1 - (1-\rho_1)(1-\rho_{18})(1-\rho_{19}) \tag{48}$$

$$P(MT^* = 1) = \sum_{DP^*,CCT^*,PD^*,CCD^*} P(MT^* = 1, DP^*, CCT^*, PD^*, CCD^*) = 1 - (1-\rho_1)^2 \cdot \prod_{j=11}^{19}(1-\rho_j) \tag{49}$$

Third, downstream demand and end-consumption links:

$$P(RE=1)=\sum_{Y_1,Y_{20},Y_{21},Y_{22},Y_{23},Y_{24}} P(RE=Y_1,Y_{20},Y_{21},Y_{22},Y_{23},Y_{24})=1-(1-\rho_1)\prod_{j=20}^{24}(1-\rho_j) \quad (50)$$

$$P(FDE=1)=\sum_{Y_1,Y_{25},Y_{26},Y_{27},Y_{28}} P(FDE=1,Y_1,Y_{25},Y_{26},Y_{27},Y_{28})=1-(1-\rho_1)\prod_{j=25}^{28}(1-\rho_j) \quad (51)$$

$$P(DR^*=1)=\sum_{RE,FDE} P(DR^*=1,RE,FDE)=\left[1-(1-\rho_1)\prod_{j=20}^{24}(1-\rho_j)\right]\left[1-(1-\rho_1)\cdot\prod_{j=25}^{28}(1-\rho_j)\right] \quad (52)$$

According to the conditional probability of the above three types of events, the probability of the long-term vulnerability SC^* of the top event PD-FAF-SC can be obtained as follows:

$$\begin{aligned}P(SC^*=1)&=\sum_{UP^*,MT^*,DR^*} P(SC^*=1,UP^*,MT^*,DR^*)=1-\left\{1-\left[1-\prod_{j=1}^{5}(1-\rho_j)\right]\cdot\left[1-(1-\rho_1)\prod_{j=6}^{10}(1-\rho_j)\right]\right\}\times(1-\rho_1)^2\\&\cdot\prod_{j=11}^{19}(1-\rho_j)\times\left\{1-\left[1-(1-\rho_1)\prod_{j=20}^{24}(1-\rho_j)\right]\cdot\left[1-(1-\rho_1)\prod_{j=25}^{28}(1-\rho_j)\right]\right\}\end{aligned} \quad (53)$$

4. Empirical Analysis

This paper takes the fresh agricultural products trading center in North China as an example. The trading center was established in 2010. It is a typical PD-FAF-SC, whose vulnerability is affected by the environment of logistics, capital flow, and information flow, and it mainly acts on three links in the upper, middle, and lower reaches of the supply chain. Based on the statistical data of trading center over the years, field visits, and expert interviews, the empirical analysis of short-term and long-term vulnerability based on PD-FAF-SC vulnerability is carried out by using the above theoretical results to clarify the risk transfer model of fresh agricultural products trading center supply chain, establishing a dynamic monitoring model for vulnerability.

4.1. The Calculation of FAF-SC Short-Term Vulnerability

4.1.1. Short-Term Vulnerability Calculation. After the data statistics, the priori probability θ_i of each root node X_i of Bayesian network where the short-term vulnerability of the PD-FAF-SC occurs can be given. The posteriori probability of Bayesian network is realized by java programming, and then the probability of short-term vulnerability SC and other intermediate events of the parent node in Bayesian networks can be obtained by using the sum (17)-(29) of Figures 3–5 as shown in Table 3.

4.1.2. Short-Term Vulnerability Analysis. Analysis of Table 3 data: the short-term vulnerability of PD-FAF-SC in trading center is P (SC = 1) = 1.645×10^{-3}, which has higher risk and is still basically controllable throughout the country. Among them, through the calculation of conditional probability of each node, the main reason for the short-term vulnerability of PD-FAF-SC is concentrated in the upstream planting links: P (UP = 1) = 1.327×10^{-3} which accords with the domestic setting that the upstream production supply link of PD-FAF-SC is the short-term supply chain node and the main bottleneck link at the present stage.

The cause of short-term vulnerability of FAF-SC in trading center also exists in the midstream circulation links: P (MT = 1) = 0.115×10^{-3}. In China, the production of fresh agricultural products is obviously regional and seasonal, while fresh agricultural products are essential for daily life. The fluctuation of consumption demand is relatively less fluctuating under normal conditions which will result in the deviation of the supply of fresh agricultural products P(X19 = 1) = 8.383×10^{-3}, mainly due to factors such as technical error in platform and delays or errors in information transmission. When the upstream supply exceeds the demand in the peak season and the supply is far less than the demand in the off-season, the probability of the imbalance between the upstream and downstream supply and demand is large, which increases the vulnerability of FAF-SC. In recent years, although the investment in cold chain infrastructure in China has been heating up, the overall infrastructure is relatively weak. The infrastructure, technical strength, and integrity of the management of the cold chain of circulation enterprises are not up to the current demand for the circulation of fresh agricultural products in China. The probability of lack of integrity in cold chain management reaches P(X24 = 1) = 7.174×10^{-3}, and the probability of insufficient factor of cold chain equipment is P(X15 = 1) = 6.172×10^{-3}, which is the primary risk factor of cold chain transportation and cold chain distribution, which affects the smooth operation of domestic PD-FAF-SC.

For the supply chain of fresh agricultural products, the probability of short-term vulnerability of downstream consumer retail is P(DR = 1) = 0.203×10^{-3} and the freshness of fresh agricultural products is the decisive factor to determine the sales volume, P (X31 = 1) = 83.47×10^{-3}. With the improvement of people's living standards, the general public's awareness of food safety has gradually increased. However, the influence of food safety rumors is becoming more and more serious and even causes panic P(X29 = 1) = 0.865 × 10-3, causing downstream retailers to cut off their sales, leading to a large backlog of products produced by upstream agricultural growers or farmers, and even rotten in the ground, which is also one of the factors that influence the vulnerability of trading center PD-FAF-SC.

4.2. FAF-SC Long-Term Vulnerability Calculation

4.2.1. Long-Term Vulnerability Calculation. Consistent with the idea of short-term supply chain vulnerability assessment, the priori probability ρ_j is given for each root node Y_j of the Bayesian network where PD-FAF-SC long-term vulnerability occurs, and then the probability of short-term vulnerability SC and other intermediate events of parent nodes in Bayesian network can be obtained by using Figures 5–7 sum formula (42)-(53), as shown in Table 4.

4.2.2. Long-Term Vulnerability Analysis. According to the calculation results in Table 3, the long-term vulnerability of PD-FAF-SC in trading center is shown as P (SC∗ = 1) = 6.73 × 10^{-5}, which is higher than the risk caused by the sudden factors in the short-term supply chain. Most of the factors are long-term cumulative effects that are nonbursty, so the probability of long-term vulnerability is much lower than the short-term vulnerability. Judging from the occurrence probability of each intermediate node, there is no doubt that the transfer link is the first factor of forming the long-term vulnerability of the supply chain: P (MT∗ = 1) = 6.35 × 10^{-5}, which is the main bottleneck of the operation and development of PD-FAF-SC in trading center. It is also the core factor to improve the supply chain resilience efficiency. The main factor restricting the circulation of the middle reaches lies in the low level of information integration of the platform in the platform's leading operation: P (MT∗ = 1) = 6.35×10^{-5} which may result in a delay in the transmission of information flow, the lack of transportation capacity (Y13) of cold chain transportation and professional auxiliary facilities, and the cold chain transport organization are not in place (X18), causing the short-term fragility of trading center. In addition, the low strategic awareness of high value added in circulation processing (Y11) and the low carbon constraints of green logistics (Y18) are also the main factors contributing to the vulnerability of the middle reaches. This also accords with the characteristics and present situation of the lack of circulation and transportation capacity of China's fresh agricultural products and the shift to the development of low carbonization. The long term vulnerability of PD-FAF-SC in trading center is also partly caused by P (UP∗ = 1) = 0.0126 × 10^{-5}. The long-term vulnerability that occurred in the upstream planting links is characterized by the vulnerability of small- and medium-sized fresh agricultural products production enterprises P(SCE = 1) = 6.84×10^{-5}. At present, the "company + farmer" supply chain mode of agricultural products has occupied about 45% of China's agricultural industrialization management mode [16]. The influence of insufficient information communication, climate change, and other natural disasters is higher than that of the large fresh agricultural production enterprises' vulnerability P (LCE = 1) of 1.65×10^{-5}. Orders or trade defaults occur from time to time, which to some extent affects the healthy development of PD-FAF-SC. However, the bullwhip effect caused by incomplete information and the inaccurate demand prediction (Y3P7) and poor information communication (Y4P8) are common in Chinese large-, medium-, and small-scale enterprises producing fresh agricultural products, resulting in the fact that the supply cannot well match the downstream demand for fresh agricultural products. The uncertainty of demand prediction includes not only the mismatch of product quantity, but also the variety richness of fresh agricultural products supplied upstream, and the product quality and nutritional value cannot meet the diversified demand of downstream consumers. In order to prevent maliciously lowering the price of fresh agricultural products, reduce the high loss rate of agricultural products, and further aggravate the agricultural environmental pollution, China has been perfecting various agricultural cooperation ways in recent years, and improving the integration and concentration of agricultural industries.

Although, in the long run, the development of deep processing enterprises for agricultural products offsets the obvious seasonal effects of some short-term fresh agricultural products retailers, making the long-term vulnerability of downstream demand and retail consumption links smaller (P ∗ DR∗ = 1) = 0.00891× 10^{-5}, however the open import environment, such as imported fresh agricultural products, has a great impact on China's fresh agricultural products industry, P (Y24 = 1) = 10.4×10^{-5}, where it is expected that the supply and demand of domestic fresh agricultural products will be impacted for a long time in a certain period.

4.3. Model Calculation. According to the statistical results of the survey, among the 378 typical supply chain risk management accidents causing social impact, 67 supply chain disruptions occurred, accounting for 17.8% of the total number. As we see, supply chain disruption is a key issue to be concerned in PD-FAP-SC of trading centre. Taking a supply chain disruption scenario as an example, this paper sets up a vulnerability dynamic monitoring model. During the eight-year operation of fresh agricultural products trading center, the "Precursor Incident" data of supply chain vulnerability are shown in Tables 3 and 4, and the Beta distribution parameters of short-term and long-term supply chain vulnerability are shown in Table 5.

Based on the information mentioned in Table 5, the posterior probability of supply chain vulnerability can be calculated, as shown in Table 6.

It follows that, with the increase of various uncertain factors and disturbances in the short-term supply chain, the

Table 3: Priori probability of the root nodes of the Bayesian network of the short-term vulnerability of the trading center PD-FAF-SC, the probability of the parent node, and the intermediate node (10^{-3}).

Number	Priori probability Base event		Node occurrence probability Intermediate event		Top event	Number	Priori probability Base event		Node occurrence probability Intermediate event		Top event
X1	θ_1	0.815	0.815			X17	θ_{17}	12.58	8.245×10^{-11}		
X2	θ_2	0.702	FPS 1.301×10^{-7}			X18	θ_{18}	0.827			
X3	θ_3	0.339				X19	θ_{19}	8.383	PD 3.076×10^{-7}	0.115	
X4	θ_4	0.547				X20	θ_{20}	0.249			
X5	θ_5	0.677	PM 0.532×10^{-7}	UP 1.327		X21	θ_{21}	0.147			
X6	θ_6	0.874				X22	θ_{22}	0.366	CCD 6.784×10^{-7}		
X7	θ_7	0.089				X23	θ_{23}	0.258			
X8	θ_8	0.504	PPE 1.663×10^{-4}		SC 1.645	X24	θ_{24}	7.174			
X9	θ_9	0.33				X25	θ_{25}	0.203	DS 5.151×10^{-5}		
X10	θ_{10}	0.513	0.513			X26	θ_{26}	0.303			
X11	θ_{11}	0.314	CP 2.765×10^{-9}			X27	θ_{27}	0.169			
X12	θ_{12}	0.109				X28	θ_{28}	0.779		DR 0.203	
X13	θ_{13}	0.074		MT		X29	θ_{29}	0.865	TC 1.020×10^{-12}		
X14	θ_{14}	0.115				X30	θ_{30}	0.108			
X15	θ_{15}	6.17	CCT			X31	θ_{31}	83.47			
X16	θ_{16}	0.128				X32	θ_{32}	0.167			

Data sources: *Compilation of National Agricultural Products Cost-Benefit Data, China Commodity Exchange Market Statistics Yearbook, International Agricultural Products Trade Statistics Yearbook*, exchange center platform information database, and expert interview data.

Table 4: Priori probability of the root nodes of the Bayesian network of the long-term vulnerability of the trading center PD-FAF-SC, the probability of the parent node, and the intermediate node (10^{-5}).

Number	Prior probability Base event		Node occurrence probability Intermediate event		Top event	Number	Prior probability Base event		Node occurrence probability Intermediate event		Top event
Y1	ρ_1	5				Y16	ρ_{16}	0.308			
Y2	ρ_2	1.23	LCE 1.65			Y17	ρ_{17}	31.68			
Y3	ρ_3	3.23				Y1	ρ_1	5	CCD※ 1.153		
Y4	ρ_4	1.47				Y18	ρ_{18}	2.78			
Y5	ρ_5	5.54		UP※ 0.0126		Y19	ρ_{19}	3.75			
Y1	ρ_1	5				Y1	ρ_1	5			
Y6	ρ_6	1.54				Y20	ρ_{20}	4.12			
Y7	ρ_7	42.3	SCE 6.84		SC※ 6.73	Y21	ρ_{21}	6.33	RE 3.894		
Y8	ρ_8	3.79				Y22	ρ_{22}	4.60			
Y9	ρ_9	8.97				Y23	ρ_{23}	8.52		DR※ 0.0089	
Y10	ρ_{10}	6.78				Y24	ρ_{24}	10.4			
Y11	ρ_{11}	7.91	DP※ 0.978			Y1	ρ_1	5			
Y12	ρ_{12}	1.87				Y25	ρ_{25}	6.54	FDE 2.287		
Y1	ρ_1	5	CCT※ 0.774	MT※ 6.35		Y26	ρ_{26}	2.60			
Y13	ρ_{13}	2.74				Y27	ρ_{27}	3.74			
Y14	ρ_{14}	2.55	PD※ 3.821			Y28	ρ_{28}	5.01			
Y15	ρ_{15}	3.67									

Data sources: *Compilation of National Agricultural Products Cost-Benefit Data, China Commodity Exchange Market Statistics Yearbook, International Agricultural Products Trade Statistics Yearbook*, exchange center platform information database, and expert interview data.

Table 5: Parameters of Beta distribution.

Beta distribution	Mean value	variance	a	b
Short-term supply chain	0.018	0.00003	8	214
Long-term supply chain	0.0025	0.00007	3	126

Table 6: Posterior probability of supply chain vulnerability.

Time	The 0th year	The 1st year	The 2nd year	The 3rd year	The 4th year
Short-term supply chain	0.018	0.022	0.025	0.032	0.048
Long-term supply chain	0.0025	0.0016	0.0011	0.0008	0.0004

posterior probability of supply chain vulnerability increases year by year to 0.048, an increase of nearly three times. The probability of occurrence of long-term supply chain vulnerability drops to 0.0004, which is nearly 6 times lower, which benefits from the fact that the degree of information internalization of the platform-led supply chain is greatly enhanced, and the change rule conforms to the elastic property of the supply chain.

The calculation results prove that the BN model included "Precursor Incident" and dynamic variation rule of supply chain vulnerability can be reflected, to provide guidance for the formulation of prevention and controlling strategies of supply chain vulnerability. With the continuous growth of each transaction subject in the platform-dominated supply chain, it is necessary to appropriately increase the investment in information system, improve the level of platform information integration, and reinforce the detection to key nodes, to reduce the occurrence of "Precursor Incident". Meanwhile, after the occurrence of "Precursor Incident," supply chain managers should pay full attention and conduct a thorough risk investigation and focus on improving the weak links in vulnerability exposed in the event, so as to control the vulnerability in an acceptable range, to improve the flexibility of the supply chain and avoid risks that may cause harm or loss to the sustainable development of people's lives and industries. The model can be further developed. For example, new data sources, such as monitoring data and expertise from different supply chain actors, could be included in the model to improve the accuracy of the larger range and future models.

5. Conclusions

(1) Because the fresh agricultural products supply chain is a complex large scale system, its vulnerability analysis is a problem. Aiming at the dynamic change characteristics of vulnerability in the operation process of platform-oriented fresh agricultural product supply chain, "Precursor Incident" information is extracted, and the quantitative calculation method and idea of dynamic vulnerability based on bow-tie model and Bayesian network model are proposed.

(2) The application of Bayesian network model can make full use of the "Precursor Incident" information in the production process for modelling calculation, analyze and predict the risk change trend, overcome the ambiguity of comprehensive risk assessment, and improve the prediction accuracy of supply chain vulnerability assessment, which can provide intuitive reference for the prevention and control of supply chain risk.

(3) The calculation results of accidents caused by supply chain vulnerability events show that increasing evidence information "Precursor Incident" will result in remarkable growth of supply chain vulnerability. It is suggested that supply chain managers shall proceed with a complete and thorough accident investigation to "Precursor Incident" and highlight improving weak safety links, reducing the number of "Precursor Incidents" and then control and lower vulnerability and advance the supply chain resilience.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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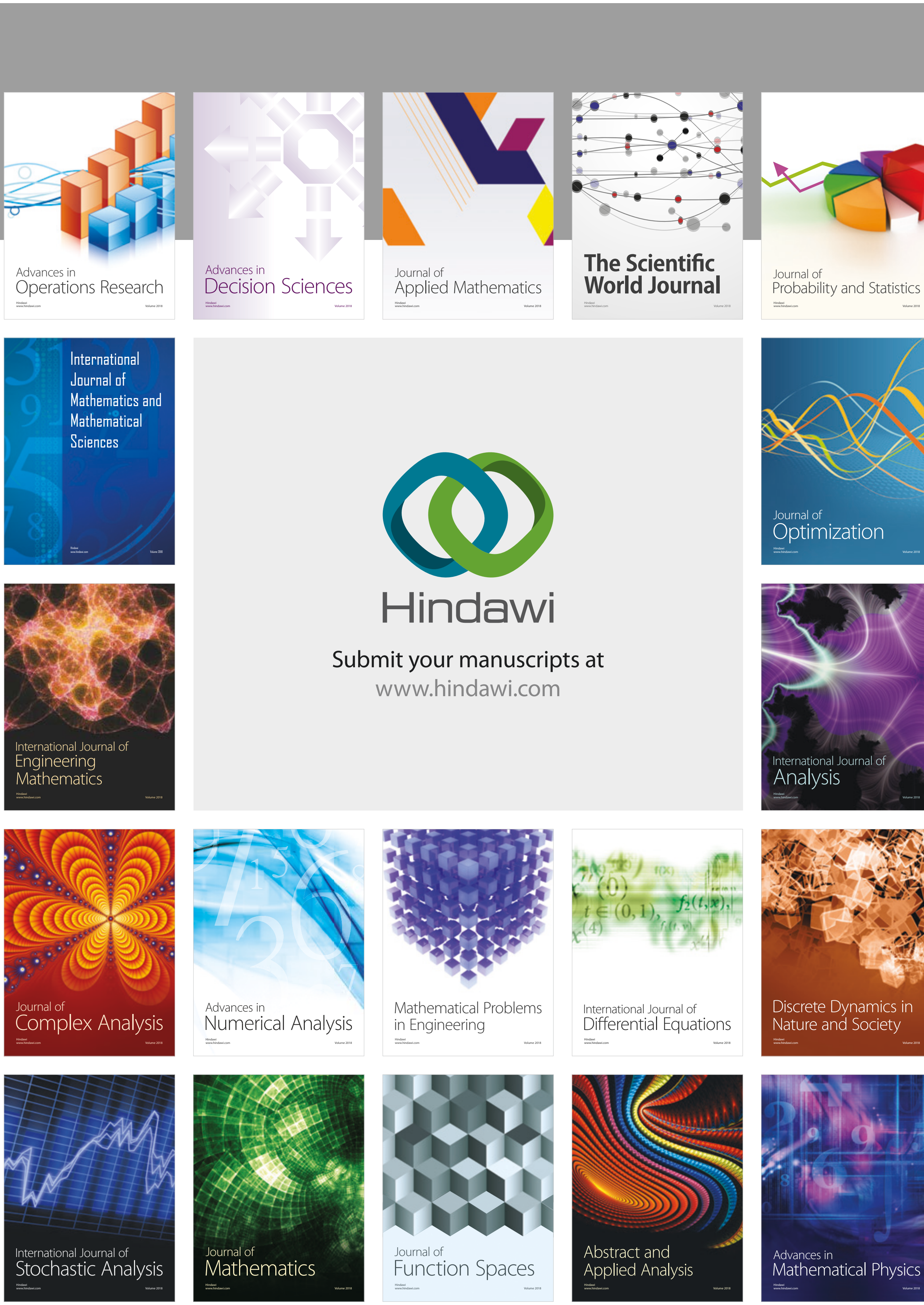
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