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An Early Warning System for "Direct Farm" Mode Based Agricultural Supply Chain

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***Abstract*—The contradiction between the increasing demand for agricultural products and the backward circulation level of agricultural products in China is increasingly obvious. "Direct Farm" brings other potential risks while improving the circulation efficiency of agricultural products. In this context, we developed a risk early warning system of the "Direct Farm" based agricultural supply chain by Bayesian network method. Through the system's forward reasoning and reverse reasoning functions, we can help supply chain managers to forecast and analyze the risks of agricultural supply chain and take timely measures to avoid risks, so as to ensure the stable operation of the "Direct Farm" based agricultural supply chain.**

***Keywords*—"Direct Farm"; risk; agricultural products supply chain; Bayesian network**

I. INTRODUCTION

With the rapid development of China's economy and the tertiary industry, people's living standards have been continuously improving, and the demand for agricultural products has been increasing [1]. "Direct Farm" mode is one of the important ways to improve the circulation efficiency of agricultural products, it can effectively reduce the circulation link and the circulation risk of agricultural supply chain, but it also causes other potential risks, which seriously affects the stable operation of agricultural supply chain and hinders the promotion of "Direct Farm" in China [2].Therefore, it is of great significance to the development of "Direct Farm" and the improvement of the circulation level of agricultural products to effectively warn the risks of the "Direct Farm" mode based agricultural supply chain and to assist managers to take timely risk response measures to ensure the stable operation of agricultural supply chain.

Many scholars are interested in the risk of agricultural supply chain. Tah and Carr [3] pointed out that the main shortcomings of risk management in agricultural supply chain are technical means, management process and management tools. Larson [4] showed that the supply chain of agricultural products is itself high-risk, and the quality and safety risk of agricultural products runs through the whole process of the supply chain. Yanbo [5] shows that it is necessary to quantitatively evaluate the risk regularly and adjust the management strategy in time to ensure the stable operation of the supply chain because risks always exist in the supply chain of agricultural products. The research on risk modelling of agricultural supply chain has been paid more and more attention by scholars, and many valuable research results have been obtained. But there are some deficiencies in the existing research, the existing research on the dynamic and conductive mechanism of agricultural supply chain is insufficient, and there is little research on the risk of the agricultural supply chain that based on the "Direct Farm" mode. So, we decided to choose a more dominant method to study the risk of "Direct Farm" based agricultural supply chain. Bayesian network is one of the most effective models for uncertain knowledge representation and analysis, which is superior for risk research of complex systems. Supply chain is a dynamic complex system, but only a few scholars have applied Bayesian network to supply chain research. Ritesh et al. [6] provides a holistic measurement approach based on Bayesian network for predicting the complex behavior of risk propagation for improved supply chain risk management. Zheng Xiaojing [7] analyzed the probability of various risks and the possibility of co-occurrence of risk events by establishing a Bayesian network model of supply chain risk. Yang Yang [8] constructed a vulnerability assessment model of energy supply chain based on Bayesian network, and pointed out that the distribution of vulnerability points of energy supply chain in China's provinces conforms to Hu Huanyong Line.

In this paper, we use Bayesian network method to study the risk of agricultural supply chain. By quantifying various risks, we develop a risk early warning system of "Direct Farm" agricultural supply chain based on Bayesian network. The system can not only dynamically display the status of various risks, but also describe the interdependency between risks. Through the forward reasoning and reverse reasoning functions of the system by Netica(a software for Bayesian network reasoning), the risk can be warned and the decision-making basis for managers can be provided.

II. METHODOLOGY

A. Bayesian Network

A Bayesian network (BN) is a directed acyclic graph where the nodes represent variables and the directed arcs define statistical relationships. The graphs are representations of joint probability distributions. If there is a directed arc from a variable X_1 to a variable X_2, the arc indicates that a value taken by X_2 depends on the value taken by X_1, or X_1 ‘‘influences’’ X_2. X_1 is called the parent of X_2 and X_2 the child of X_1. Nodes without parents are defined through their prior probability distributions, while nodes with parents are defined through conditional probability distributions. Conditional independence relationships are implicit in the directed acyclic graph: all nodes are conditionally independent of their ancestors, given their parents. Consider a BN has n nodes, which are X_1-X_n. The chain rule of probability theory allows factoring joint probabilities, as given in the following formula. By this formula, the answer that the system will give under some certain probability states can be calculated.

$$P(X_1,\dots,X_n)=\prod_{i=1}^{n} P\left(X_i \middle| \pi(X_i)\right) \tag{1}$$

In (1), $\pi(X_i)$ denotes the parent node of X_i. Through forward reasoning, the probability that the state of the node X_i is a_k is obtained as follows:

$$P(X_i=a_k)=\sum_{X_i=a_k} P(X_1,\dots,X_n) \tag{2}$$

Reverse reasoning, the state of a node is known, and the posterior probability distribution of its parent node is obtained according to the conditional probability formula. If a state of X_i is known to occur, the posterior probability of a state of node X_j (X_j is a parent of X_i) is:

$$P\left(X_j \middle| X_i\right)=\frac{P\left(X_i \middle| X_j\right)P\left(X_j\right)}{P\left(X_i\right)} \tag{3}$$

B. Process of Risk Early Warning System Development

We divide the construction of "Direct Farm" agricultural supply chain risk early warning system into two stages: qualitative construction stage and quantitative construction stage. The detailed process is shown in Figure 1.

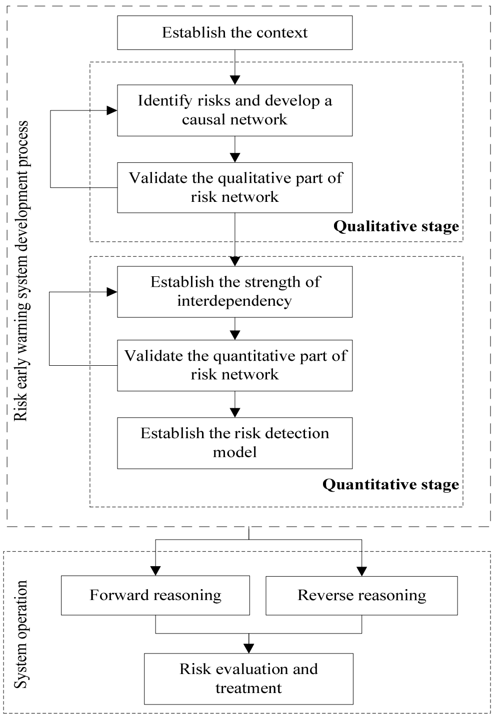


FIGURE I. PROCESS OF RISK EARLY WARNING SYSTEM DEVELOPMENT

III. SYSTEM DEVELOPMENT

A. Risk Identification and BN Construction

At present, there are various patterns of "Direct Farm" in China, such as "supermarket-wholesale market-cooperatives-farmer" mode, "supermarket-cooperative-farmer" mode, "joint direct purchase" mode, "supermarket direct sale" mode and so on [9]. In this paper, as shown in Figure.2, we take "farmers-cooperatives-supermarkets" mode based agricultural supply chain as the research object, because of its widespread implementation. According to relevant literature and combined with the characteristics of "Direct Farm". In this paper, the "Direct Farm" based agricultural supply chain risk is divided into three main risk items: supply risk (SR), technology and management risk (TR), docking risk (DR). The external risk (ER) has an impact on all aspects of the supply chain risk, and then affects the overall risk level, as shown in Figure 3.

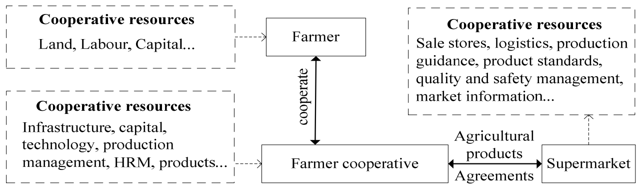


FIGURE II. "FARMERS + COOPERATIVES + SUPERMARKETS" MODE

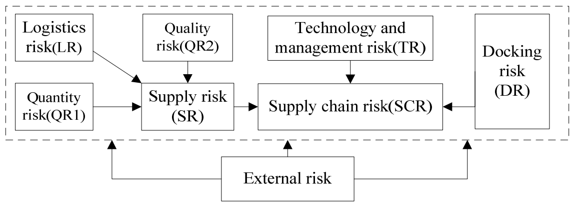


FIGURE III. THE RELATIONSHIP BETWEEN RISKS

Through field research, questionnaires and interviews with relevant experts, the main risk factors are shown in Table 1. In this paper, risk factors are divided into risk source factors and risk state factors. Risk source factors refer to risk factors that are not affected by other risk factors, corresponding to the root node in the BN (S3, T1, T2, T3, T4, T5, D1, D5, E1, E2, E3, E5, E7). The risk state factor refers to the risk factor that will be affected by other risk factors, corresponding to the non-root node in the BN (S1, S2, S4, S5, S6, S7, S8, S9, T6, D2, D3, D4, D6, E4, E6). After several modifications according to the expert opinions, the final BN structure is shown in Figure.4.

TABLE I. MAJOR RISK FACTORS

Node	Factor
S1	Stale products
S2	Quality and safety issues
S3	Unapproved GM crops
S4	Demand exceeds supply
S5	Supply exceeds demand
S6	Low yield
S7	Cargo loss
S8	Delivery delay
S9	Traffic accident
T1	Lack of infrastructure
T2	Employee operational accidents
T3	Quality inspection technology failure
T4	Cryogenic technical fault
T5	Insufficient grasp of the market
T6	Improper corporate strategy
D1	Unreasonable agreement
D2	Low organizational efficiency
D3	Insufficient cooperation
D4	Lack of cooperation intention
D5	Insufficient capacity of famer Cooperative
D6	short duration of famer Cooperative
E1	Natural disaster
E2	severe weather
E3	Inadequate government subsidies
E4	Consumer preferences
E5	Public opinion direction
E6	Price fluctuation
E7	Economic crisis

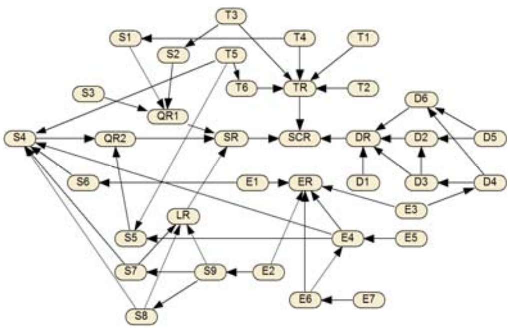


FIGURE IV. FINAL BN STRUCTURE

B. Bayesian Network Node Setting and Value Assignment

After the construction of BN structure is completed, the next step is to set and assign values to each node, that is, to obtain the prior probability values of each node and assign corresponding probability values to the different states of them. In the process of setting nodes, different state levels are set according to the characteristics of different nodes. For example, the state of SCR node at the top level is divided into five levels: very high (VH), high (H), medium (M), low (L) and very low (VL). The status of the DR node is divided into three levels: high (H), medium (M) and low (L). And there are two levels of S1: occurrence (Y) and nonoccurrence (N). In this paper, the assignment results are obtained through statistical data and survey data, as well as consulting with experts in the field and relevant industry personnel. All nodes are assigned and checked in this paper (no complete assignment table is provided in this paper due to space limitation). The complete prior probability chart of "Direct Farm" mode based agricultural product supply chain is shown in Figure.5. In practice, managers in supply chain should first revise the assignment of risk source factor nodes according to their own comprehensive data, and then make reasonable amendments to the assignment of risk state factor nodes according to the actual situation to improve the accuracy of the system.

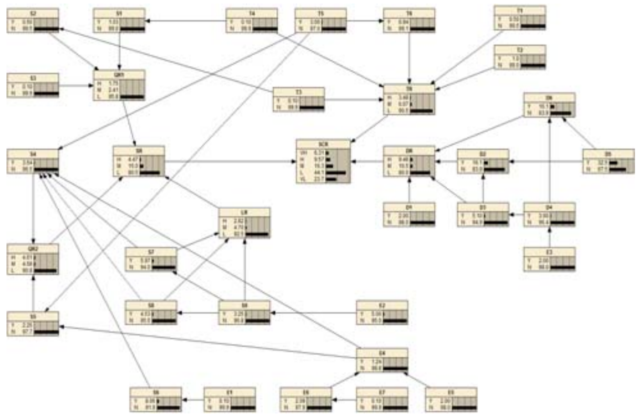


FIGURE V. THE BN FOR "DIRECT FARM" MODE BASED AGRICULTURAL PRODUCT SUPPLY CHAIN RISK

C. The Risk Detection Model

As the output part of risk early warning system, the risk detection model shows the risk level of risk nodes. In this system, we only care about the risk state of five-state node and three-state node because two-state node corresponds to risk factors rather than risk items.

Let RV(N) = the risk value of node N.

RL(N) = the risk level of node N.

$p(N_i)$ = the probability of i state of node N.

We assign appropriate weights (the weights reference Li Min's research as in [10]) to different states of risk to get risk value of each risk items. For five-state node,

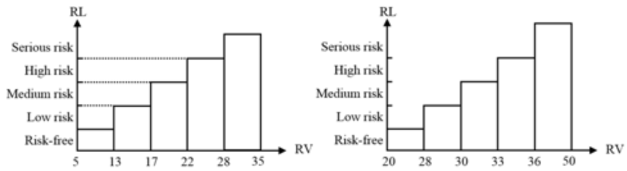
$$RV(N)=\frac{7p(N_{VH})}{20}+\frac{3p(N_H)}{10}+\frac{p(N_M)}{5}+\frac{p(N_L)}{10}+\frac{p(N_{VL})}{20} \quad (4)$$

then the output of RL(N) is shown in Figure 6(a).

And for three-state node,

$$RV(N)=\frac{p(N_H)}{2}+\frac{3p(N_M)}{10}+\frac{p(N_L)}{5} \quad (5)$$

then the output of RL(N) is shown in Figure 6(b).



(a) For five-state node (b) For three-state node

FIGURE VI. THE OUTPUT OF RL

IV. SYSTEM OPERATION

The system is used for forward reasoning and reverse reasoning of risk. Forward reasoning is to modify the value of the corresponding risk nodes in BN according to the received risk-related information, and then observe the changes of each node and analyze the influence of the changing node on other risk items. Reverse reasoning is to find out the key influencing factors by adjusting the assignment of a certain risk item and observing the changes of relevant nodes.

A. Forward Reasoning

After receiving the new information, managers can modify the assignment of some nodes, observe the transmission and mutual influence of other risk factors, and then analyze the risk level of the "Direct Farm" mode based agricultural supply chain and give early warning of the risk. Give two examples as follows:

1) The impact of severe weather

Assuming that the weather forecast accuracy is 90%, if the weather forecast predicts that the region will be hit by heavy rain in the next few days, the status of some relevant nodes before the prediction is shown in the Figure 7(a). After receiving the new information of weather forecast, the occurrence probability of severe weather (E2) increased from 5% to 90%, as shown in Figure 7(a) and Figure 7(b), and the probability of other relevant nodes also changed accordingly.

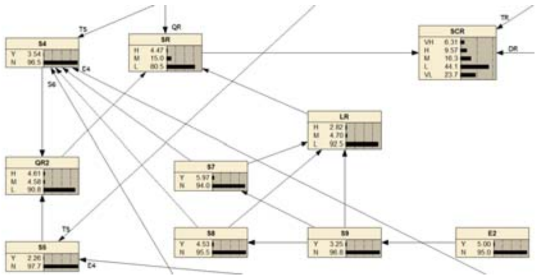


FIGURE VII. (A). THE STATE OF THE RELEVANT NODES BEFORE E2 NODE CHANGED

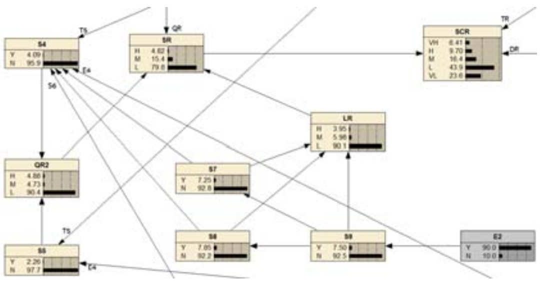


FIGURE VII. (B). THE STATE OF THE RELEVANT NODES AFTER E2 NODE CHANGED

It can be observed that the relevant risk items have not changed significantly, indicating that the severe weather will not bring great impact on the "Direct Farm" mode based agricultural product supply chain. And we can conclude that compared with the traditional agricultural product supply chain, the circulation link of "Direct Farm" has the characteristics of fewer circulation links and more standardized circulation process, which makes its logistics more robust and can reduce the risk impact of severe weather on the supply chain. It confirms Yang Qingsong's research results as in [2].

2) The impact of government subsidies.

Assuming that the local government modifies the subsidy policy, which will lead to the reduction of subsidies for " Direct Farm ". It is assumed that the probability of insufficient government subsidy (E3) will change from 2% to 80% (In practice, the probability here should be adjusted in a reasonable way). The state of relevant nodes before and after the modification of E3 node is shown in Figure 8(a) and Figure 8(b). The RV and RL of the related risk items are obtained from the lamp model as shown in Table 2. The risk level of DR changed from risk-free to medium risk, and the risk level of SCR changed from low risk to medium risk. It can be considered that insufficient government subsidies will cause greater risks. By observing the changes of relevant nodes in BN, we find that insufficient government subsidies will greatly reduce the cooperation intention of members, resulting in insufficient cooperation, which will lead to inefficiency of organizations, and have a negative impact on the duration of farmer cooperatives, thus have a serious negative impact on the operation of the supply chain system. Accordingly, the local government should actively play its role of guidance and incentive, formulate a series of reasonable subsidy policy of "Direct farm" to improve the enthusiasm of the members to participate in "Direct farm" and ensure a stable docking state so as to promote the development of "Direct farm" in the region, enhance the circulation level of agricultural products.

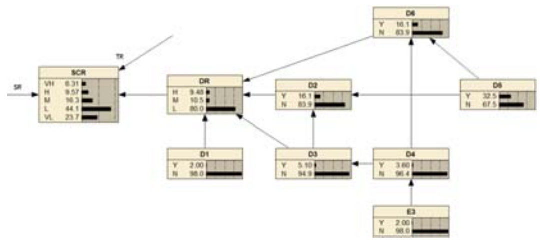


FIGURE VIII. (A). THE STATE OF THE RELEVANT NODES BEFORE E3 NODE CHANGED

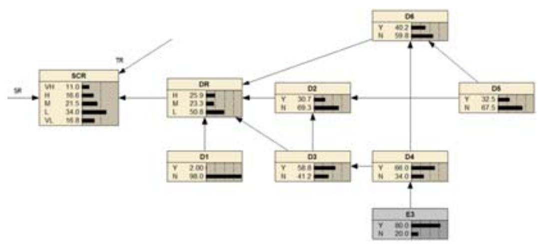


FIGURE VIII. (B). THE STATE OF THE RELEVANT NODES AFTER E3 NODE CHANGED

TABLE II. CHANGES IN RV AND RL OF RELATED RISK ITEMS OF E3

Risk Item	RV		RL	
	Change before	*Change after*	*Change before*	*Change after*
DR	23.9	30.1	Risk-free	Medium risk
SCR	13.9	17.4	Low risk	Medium risk

B. Reverse Reasoning

Reverse reasoning is used to analyze the impact of various influencing factors on risk items, so as to assist managers in rational allocation of resources and minimize the risk level of supply chain. Take SR, DR and TR as examples. The probability of VH, H, M, L and VL in the five states of SCR was set from 6.84%, 10.9%, 21.9%, 45.6% and 14.7% to 40%, 30%, 10% and 10% respectively. It was observed that the states of TR, SR and DR also changed correspondingly with the change of SCR, as shown in Figure 9(a) and Figure 9(b). Then the RV and RL of the related risk items are obtained from the lamp model as shown in Table 3. The risk level of DR changed from risk-free to medium risk, while the risk level of SR and TR remained risk-free. It can be concluded that docking risk is the key risk item of "Direct Farm" mode based agricultural supply chain, and when considering the optimal allocation of resources, managers should give priority to the management of docking risk to ensure the stable operation of the supply chain.

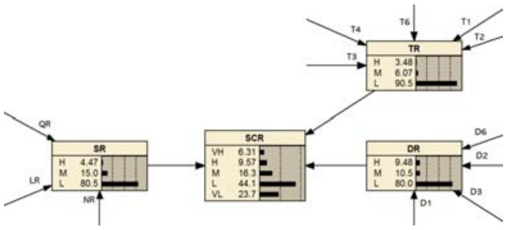


FIGURE IX. (A). THE STATE OF THE RELEVANT NODES BEFORE SCR NODE CHANGED

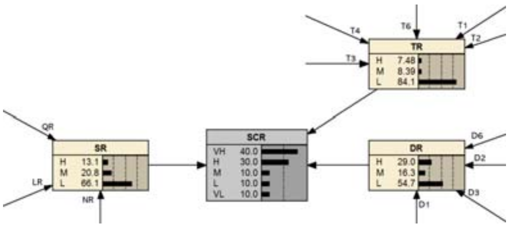


FIGURE IX. (B). THE STATE OF THE RELEVANT NODES AFTER SCR NODE CHANGED

TABLE III. CHANGES IN RV AND RL OF RELATED RISK ITEMS OF SCR

Risk Item	RV		RL	
	Change before	*Change after*	*Change before*	*Change after*
DR	23.9	30.3	Risk-free	Medium risk
SR	22.8	26	Risk-free	Risk-free
TR	21.7	23	Risk-free	Risk-free

V. CONCLUSION AND FUTURE RESEARCH

The contradiction between China's growing demand for agricultural products and the backward level of agricultural products circulation is becoming more and more obvious. It is of great significance to promote the development of new modes of agricultural product circulation such as "Direct Farm" and improving the level of risk management is one of the effective ways to promote their development. This paper analyzes the risk of agricultural product supply chain under the "Direct Farm" model, quantifies the transmission relationships between various risk factors and risk factors and embodies them in a BN structure, and sets up a risk detection model. Therefore, a complete "Direct Farm" based mode agricultural supply chain risk warning system is established to help the relevant managers of the supply chain to take timely measures to reduce losses and ensure the stable operation of the supply chain. However, the risk early warning system constructed in this paper has certain limitations. This is because the risk factors faced by the "Direct Farm" supply chain in different regions are different. This article only selectively targets some regions, and the risk factors and states have certain limitations. Therefore, the system structure or assignment should be modified according to the actual situation in different regions. The next focus of research should be to address the universality of the system.

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