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Reliability Modeling Method of Fresh Food Supply Chain System based on Bayesian Network

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Abstract: By referring to the method of system reliability modeling in reliability engineering theory, the abstract problem of system operation failure of fresh supply chain is concretized. By constructing the operation sequence of each link in the system and the causal logic of event existence, the Bayesian network topology is constructed. The reliability model of the supply chain system is established to analyze the ability of the fresh supply chain from the production end to the consumption end of the supply chain system to operate smoothly. From the perspective of system reliability, the weak links of fresh supply chain are determined, which provides an effective model for accurately evaluating the system reliability of fresh supply chain.

Keywords: Fresh Supply Chain; System Reliability; Bayesian Network.

1. Introduction

Fresh agricultural products usually refer to the products produced by agricultural activities, including meat, vegetables, fruits and aquatic products. Compared with general commodities, fresh agricultural products have the characteristics of short preservation time, easy deterioration and difficult transportation. The production of fresh agricultural products has a relatively fixed natural cycle. During its growth period, it will be affected by many factors, which will disturb its stable supply. At the same time, the shelf life of fresh agricultural products after production is short, and it has a high dependence on cold chain logistics. With the improvement of the living standards of domestic residents, the consumption level of residents has increased, and the demand for fresh agricultural products has become increasingly strong. According to the data, the average weekly purchase of fresh agricultural products by Chinese residents is 4.8 times, and the overall market size is about 2 trillion yuan.

The research on the supply chain of fresh agricultural products has been widely concerned by scholars at home and abroad. The related research mainly focuses on inventory control, pricing strategy and coordination. However, the stable operation of the fresh supply chain in real life is affected by many factors. For example, in the face of special circumstances such as epidemics, natural disasters and car accidents, whether the end consumers can buy fresh agricultural products is an important basis for evaluating the reliability of the supply chain. Therefore, in recent years, the reliability research of each stage in the supply chain has attracted the attention of more and more experts, scholars and entrepreneurs, and how to evaluate the reliability of the complete fresh supply chain is an urgent problem to be solved.

This paper takes the fresh supply chain as the research object, and considers the supply chain network composed of producers, platforms and retailers. It is necessary to set an expected system failure, and then carry out a Finn analysis of the failure according to the level, determine the Bayesian network topology with the failure of the fresh supply chain as the expected system failure, and then use the Bayesian network to quantitatively model and analyze the possible impact of unexpected shocks and environmental fluctuations on each node in the network.

2. Research Status at Home and Abroad

In recent years, with the rapid development of science and technology, the domestic fresh supply chain has gradually diversified. In addition to the traditional model, such as the fresh e-commerce supply chain, it has also developed rapidly. In particular, the domestic epidemic has been repeated, including but not limited to Taobao, Jingdong, Pinduoduo and Hema and many other enterprises have entered the fresh supply chain. Ren Xiangyang et al. [3] pointed out that the current domestic and foreign research on fresh e-commerce supply chain mainly focuses on fresh e-commerce logistics and mode, fresh e-commerce distribution mode and fresh e-commerce supply chain optimization, while there are few studies on the reliability of fresh supply chain system. For example, Liu et al. [4] adopted a supply chain decision model based on blockchain to improve the performance of e-commerce supply chain. Aiming at optimizing the quantity and quality of fresh agricultural products, Zheng [5] considers the multi-stage discount coordination problem in the dual-channel fresh agricultural product supply chain.

The existing literature focuses on the model describing the elements and activities of the supply chain system, but the research on the reliability modeling of the actual supply chain system is still insufficient. At present, there are few literatures that directly study the reliability of fresh supply chain system, especially those based on the actual situation of fresh supply chain and the reliability modeling analysis of fresh supply chain. In the existing research, most scholars at home and abroad first use the fault tree method to determine the network topology, and then use the Go method [6] [7] and Bayesian network to directly model the reliability of the system. Through the questionnaire method, Topsis method, triangular fuzzy number processing and other methods to obtain relevant data, and then calculate the reliability of the system, and evaluate the fresh supply chain.

3. Failure Model of Fresh Food Supply Chain based on Bayesian Network

Bayesian network is a graphical network based on probabilistic reasoning, which consists of directed acyclic graph and conditional probability table. At present, Bayesian network has become one of the best ways to deal with uncertainty. Bayesian network topology is a probabilistic network structure based on Bayesian factors. It includes nodes, edges and arrows, and expresses the relationship between variables through unique directed edges. In this paper, the reliability of fresh supply chain system is studied. Firstly, the topology of fresh supply chain network needs to be determined. This paper considers a three-level and multi-node fresh supply chain system composed of suppliers, platforms and consumers. This section will analyze the failure causes of each node and combine the characteristics of Bayesian network topology to describe the complete Bayesian network topology of fresh supply chain, and obtain the corresponding conditional probability table.

3.1. Cause Analysis of Node Failure

To determine the network topology used to calculate the reliability of the fresh supply chain, the first is to analyze the characteristics of the fresh supply chain and define the system failure that does not want to occur. In this paper, it is reflected as ' fresh supply chain system failure '. Then we need to analyze the direct cause of the event, that is, to determine the parent node of the node. This part can be determined by referring to the structure of the fresh supply chain. There are three types: 1) the failure of the initial section of the fresh supply chain, that is, the failure of farmers; 2) The order phase of the fresh supply chain fails, that is, the platform fails; 3) The end of the fresh supply chain allocation failure, namely the distributor failure. After determining the logical connection of this part, use the appropriate way to connect.

In the future, to ensure that the constructed network topology is in line with the actual situation of the fresh supply chain, it is first necessary to ensure the accuracy of the analysis of the failure causes of each node. Therefore, before building a complete fresh supply chain network topology, we must have a thorough understanding of the operation of the system and its functions. The fresh supply chain system is an organic whole composed of fresh products, people, equipment, transportation tools and information interaction equipment. The main function is to complete the target transfer of products in a certain space and time range. From the overall point of view, it is the research focus of the current supply chain system to analyze the whole process operation of the supply chain in the specified space and time range from the systematic point of view, to realize the stable operation and gradual optimization of the supply chain system. Compared with the general supply chain, the fresh supply chain not only needs to consider the characteristics of fresh products such as short preservation time and easy deterioration, but also pays more attention to the transmission efficiency and service level of the supply chain. Therefore, in order to ensure the stable operation of the system in the fresh supply chain, the functions of each node in the supply chain need to be supported by various factors. The fresh food supply chain is mainly composed of four main nodes: supplier, platform, distributor and customer. Each node has its own failure factors.

Suppliers in the fresh supply chain are generally defined as farmers, who produce all kinds of fresh agricultural products and belong to the front end of the fresh supply chain. Because of its particularity, fresh agricultural products need to go through a complete natural production cycle. In this production cycle, the influence of human and nature is huge. Once the production cycle of fresh products encounters irresistible natural disasters, or the operator 's production operation has a negative effect during this cycle, it may lead to the failure of fresh products, that is, the failure of the supply side.

There is usually a trading platform in the fresh food supply chain. Especially in the current rapid development of Internet technology, there are a large number of companies in the fresh food industry. All parties have launched corresponding electronic platforms to improve the fresh food supply chain and ensure the stable supply of fresh goods. Because of its characteristics, the platform itself needs to maintain the stability of operation and the accurate transmission of information. It should choose the appropriate processing system to avoid all kinds of negative effects caused by operation and operation errors.

The indispensable part of the fresh supply chain is the distribution part. The distributor can transfer the fresh products stably transmitted at the front end of the supply chain to the end of the fresh supply chain, that is, the consumers, which is also a node with many influencing factors in the fresh supply chain. This node not only needs to ensure the integrity and fresh quality of fresh agricultural products, but also needs to ensure the accuracy of orders to ensure that consumers can meet their needs at the right time. Therefore, in this process, the arrangement and cooperation of personnel, the use and scheduling of equipment and the natural environment will have a huge impact.

3.2. Construction of Fresh Supply Chain Bayesian Network Topology

During the operation of the fresh food supply chain, each node will be affected by some natural objective and subjective factors, resulting in the expected supply chain delivery tasks being affected or consumer demand not being met. As mentioned above, the situation that consumer demand cannot be met will become the top event of system failure, that is, the failure of fresh supply chain. According to the system structure of the fresh supply chain, the three causes of " farmer failure, " " platform failure " and " distributor failure " can lead to the failure of the fresh supply chain, as the parent node of the node " fresh supply chain system failure. " Considering that the failure of these three nodes can directly lead to the top event, the edge and arrow are used to connect with the child nodes, and the arrows of the three edges point to the child nodes. These three nodes need to continue to combine the above analysis and determine the direct causes that will lead to the failure of each node. For example, the direct causes of farmers ' failure nodes can be divided into: production pollution, natural disasters and supply failure of production factors. And according to the logical connection between each influencing factor and the node, the edge is connected with the arrow. After completing the analysis of the influencing factors of the first layer, we consider the direct causes of node failure step by step. For example, the direct causes of the failure of production factor supply can be divided into raw material price increase, inflation pressure and seasonal factors, and establish appropriate links between nodes. By analogy, the node is analyzed step by step until it is decomposed to the most primitive, failure mechanism and probability distribution that affect the node, which can be summarized by relevant literature and data, until it is difficult to analyze the parent node of the node.

By analyzing the characteristics of the fresh supply chain, and analyzing the causes of failure of each node and the logical relationship between each other, combined with the description of the Bayesian network topology, the final Bayesian network topology of the fresh supply chain is determined. Figure 1 is the Bayesian network topology of the fresh supply chain determined by consulting relevant literature and synthesizing the above analysis. Table 1 is the specific node and corresponding name of the failure of the fresh supply chain system.

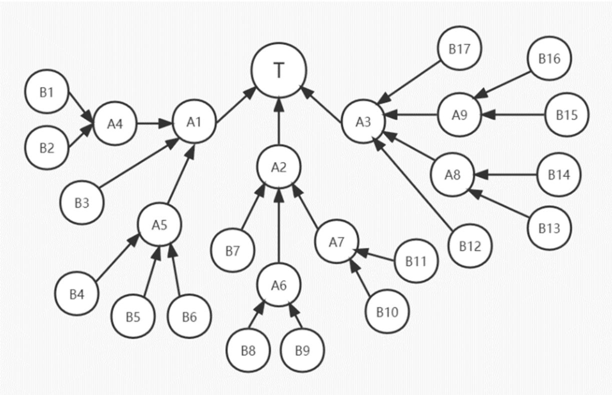

Fig 1. Bayesian network topology

Table 1. Bayesian network node name

Noda	Node Name	Node	Node Name
T	Supply chain failure	B5	Inflation pressure
A1	Farmers fail	B6	Seasonal factors
A2	Platform failure	B7	Failure of supply
A3	Distributor failure	B8	Platform collapse
A4	Production pollution	B9	Order confusion
A5	Production factor supply failure	B10	Financial issues
A6	Technical issues	B11	Business model issues
A7	Operational issues	B12	Failure of supply
A8	Transport failure	B13	Traffic jams
A9	Order error	B14	Vehicles, personnel issues
B1	Excessive use of costs, pesticides, etc.	B15	Error in order processing
B2	Water pollution	B16	Audit error
B3	Natural disasters	B17	Natural disasters
B4	Raw material price rise		

3.3. Determination of Conditional Probability Table

Calculating node reliability through Bayesian networks requires a given Bayesian network topology and a conditional probability table (connection strength) for each node. Since the probability of the bottom event in the fault tree can be directly used for the calculation of the corresponding root node in the Bayesian network, only the conditional probability table of the intermediate node needs to be obtained to meet the requirements of the Bayesian network modeling calculation. The conditional probability table can be directly transformed by the logic gates in the fault tree.

Table 2. A1 conditional probability

A4	B5	A5	P(A1=1|A4,B5,A5)	P(A1=0|A4,B5,A5)
1	1	1	1	0
1	1	0	0.6	0.4
1	0	1	0.65	0.35
1	0	0	0.75	0.25
0	1	1	0.63	0.37
0	1	0	0.9	0.1
0	0	1	0.7	0.3
0	0	0	0	1

Table 3. A2 conditional probability

B7	A6	A7	P(A2=1|B7, A6,A7)	P(A2=0|B7, A6,A7)
1	1	1	1	0
1	1	0	0.7	0.3
1	0	1	0.6	0.4
1	0	0	0.85	0.15
0	1	1	0.62	0.38
0	1	0	0.78	0.22
0	0	1	0.75	0.25
0	0	0	0	1

Table 4. A3 conditional probability

B12	A8	A9	B17	P (A3=1|B12, A8, A9, B17)	P (A3=0|B12, A8, A9, B17)
1	1	1	1	1	0
1	1	1	0	0.56	0.44
1	1	0	1	0.66	0.34
1	1	0	0	0.7	0.3
1	0	1	1	0.65	0.35
1	0	1	0	0.71	0.29
1	0	0	1	0.8	0.2
1	0	0	0	0.85	0.15
0	1	1	1	0.55	0.45
0	1	1	0	0.66	0.34
0	1	0	1	0.7	0.3
0	1	0	0	0.75	0.25
0	0	1	1	0.7	0.3
0	0	1	0	0.72	0.28
0	0	0	1	0.9	0.1
0	0	0	0	0	1

Table 5. A4 conditional probability

B1	B2	P (A4=1|B1, B2)	P (A4=0|B1, B2)
1	1	1	0
1	0	0.56	0.44
0	1	0.66	0.34
0	0	0.7	0.3

Table 6. A5 conditional probability

B4	B5	B6	P(A5=1|B4,B5,B6)	P(A5=0|B4,B5,B6)
1	1	1	1	0
1	1	0	0.65	0.35
1	0	1	0.68	0.32
1	0	0	0.75	0.25
0	1	1	0.7	0.3
0	1	0	0.8	0.2
0	0	1	0.73	0.27
0	0	0	0	1

Table 7. A6 conditional probability

B8	B9	P(A6=1|B8, B9)	P(A6=0|B8, B9)
1	1	1	0
1	0	0.76	0.24
0	1	0.85	0.15
0	0	0	1

Table 8. A7 conditional probability

B10	B11	P(A7=1|B10,B11)	P(A7=0|B10,B11)
1	1	1	0
1	0	0.68	0.32
0	1	0.77	0.23
0	0	0	1

Table 9. A8 conditional probability

B13	B14	P(A8=1|B13,B14)	P(A8=0|B13,B14)
1	1	1	0
1	0	0.78	0.22
0	1	0.66	0.34
0	0	0	1

Table 10. A9 conditional probability

B15	B16	P(A9=1|B15,B16)	P(A9=0|B15,B16)
1	1	1	0
1	0	0	1
0	1	0	1
0	0	0	1

4. Fresh Supply Chain Reliability Examples

Table 11. Prior probability table

Node Name	Node	Probability of failure	Probability of normal
Excessive use of costs, pesticides, etc.	B1	0.0320	0.9680
Water pollution	B2	0.0247	0.9753
Natural disasters	B3	0.0980	0.9020
Raw material price rise	B4	0.0457	0.9543
Inflation pressure	B5	0.0398	0.9602
Seasonal factors	B6	0.0876	0.9124
Failure of supply	B7	0.1029	0.8971
Platform collapse	B8	0.0523	0.9477
Order confusion	B9	0.0858	0.9142
Financial issues	B10	0.1030	0.8970
Business model issues	B11	0.0870	0.9130
Failure of supply	B12	0.0832	0.9168
Traffic jams	B13	0.0756	0.9244
Vehicles, personnel issues	B14	0.1590	0.8410
Error in order processing	B15	0.0850	0.9150
Audit error	B16	0.0320	0.9680
Natural disasters	B17	0.0980	0.9020

The existing literature judges the probability of the occurrence of the bottom event by means of expert investigation method, literature collection method, etc. [9] [10]. There are abundant data in the existing literature. This paper summarizes the literature and obtains the prior probability of each bottom node used in this paper as shown in Table 11.

Under the condition that the prior probability of the underlying event node and the conditional probability of the intermediate node are known, it is generally calculated by the following formula:

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

In this paper, due to the large amount of data, the prior probability table and the corresponding conditional probability table can be input into MATLAB, and the Bayesian toolbox is used for programming calculation, and then the probability of occurrence of farmers ' failure nodes in the fresh supply chain is obtained:

$$P(A_1 = 1) = \sum_{B_1B_2LB_6A_4A_5} P(B_1B_2LB_6A_4A_5, T=1) = \sum_{B_1B_2LB_6A_4A_5} P(T=1 \mid B_1B_2LB_6A_4A_5) \cdot \sum_{B_1B_2} (A_4 \mid B_1, B_2) \cdot \sum_{B_4B_5B_6} (A_5 \mid B_4, B_5, B_6) \cdot P(B_1) \cdot L \cdot P(B_6) = 0.1811$$

The reliability of the farmer node is: $R = 1 - 0.1811 = 0.8189$ That is, in the fresh supply chain, the probability of farmer node failure is 0.1811. Similarly, the probability of platform failure and distributor failure can be calculated by the above formula. The probability of intermediate nodes is shown in Table 12:

Table 12. Intermediate node probability

Node Name	Failure	Non-failure
Farmers Fail	0.1811	0.8189
Platform Fail	0.1483	0.8517
Retailer Fail	0.2226	0.7774

The system reliability is obtained.

$$R_S = 0.7774 \cdot 0.8517 \cdot 0.8189 = 0.5422$$

5. Conclusion

The core goal of the fresh supply chain is to deliver fresh products to consumers on time, accurately and with high quality. Therefore, the fresh supply chain system needs to have higher reliability as a guarantee, and it is very important to select an effective system reliability calculation method. Based on the traditional system reliability analysis method, this paper visualizes the reliability of fresh supply chain system, and considers the modeling of system reliability based on Bayesian network. The feasibility of the method is proved by a practical example, which proves that the reliability modeling method of fresh supply chain system based on Bayesian network is effective.

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