Analysis of Key Risks in Fresh Products Supply Chain Logistics Based on the N-K/SNA Model

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ABSTRACT The logistics risk of a fresh product supply chain involves many risk factors, such as the internal and external environments of the enterprise and each link in the production process. It is important to effectively control the logistics safety of fresh products in China by determining the large risk coupling relationship and key risk factors from a systematic perspective. This study sorts out the direct and indirect risk factors and their relationship, identifies related risk factors using the cause and effect feedback chart, constructs a risk factor analysis model by combining the coupling value of the N-K model, the 1-mode network block model of the social network analysis (SNA) model, and the centrality analysis of the 2-mode network, and comprehensively studies the key risk factors for fresh product supply chain logistics in China. The results show that storage and sorting have great risk value when coupled with other risk factors, therefore, special management should be adhered to. Second, the risks of the sorting plan, sorting quality inspection, distribution, loading and unloading, and distribution accidents are also key risk factors that need to be focused on, prevented and controlled. Finally, guided by the results, management and control suggestions are proposed to better prevent risks and improve the logistics management of fresh product supply chains.

INDEX TERMS Fresh products supply chain, risk coupling, N-K/SNA model, fuzzy probability, key risk.

I. INTRODUCTION With the implementation of the “rural revitalization” strategy and the rapid development of e-commerce, cold chain logistics has entered a new stage of development. The development of fresh e-commerce has brought many conveniences to people’s lives, and at the same time, it has also prompted great changes in cold chain logistics. [1] Many big companies have set up their own cold chain logistics companies. Jingdong’s logistics has already prepared the global cold chain logistics, while A Li’s logistics are beginning to stir. In this epidemic, the consumption enthusiasm for fresh food is rising, and all kinds of fresh food are safely delivered to consumers’ tables through cold chain transportation.

The data shows that the total size of China’s cold chain logistics market in 2020 is 383.2 billion yuan, an increase of 44.08 billion yuan over 2019, a year-on-year increase of 13%.

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According to the forecast by China Commercial Industry Research Institute, by 2022, the market size of China’s cold chain logistics industry will exceed 450 billion yuan (data from China Industrial Research Institute). The market scale and demand for cold chain logistics are increasing, and the products of cold chain logistics are also increasing [2]. Among them, fruits, vegetables and meat, poultry, and eggs account for an important proportion. Most consumers like fresh products best, and their most anticipated consumption is also fresh products. The demand for the fresh products in food industry is about 100 million tons every year, and the demand speed is increasing year by year. The rising consumption level of people has brought a golden period to the logistics industry of fresh products.

In recent years, there have been frequent logistics accidents of fresh products in China, including a series of incidents such as the rollover of the truck in Yantai Hongbo in December 2021, the incident of hairy belly in Shuangliu District of Chengdu in December 2020, and the incident of illegal beef...
In addition, fresh products have a short shelf life, are perishable, and require high timeliness and cost, which provides new opportunities and challenges for their sustainable development. In addition, the fresh products supply chain logistics needs to be equipped with advanced refrigeration equipment, which undoubtedly greatly increases the logistics and transportation costs. Therefore, it is necessary to solve the risk detection and management problems related to fresh products supply chain logistics to ensure food safety [3], [4]. In this situation, there are many risks in the business activities of cold chain logistics enterprises. If they can’t be found and disposed of in time, they will bring great losses to the fresh-keeping industry, and even have an adverse impact on the development of the whole market. Therefore, the key to risk prevention lies in how to prevent, identify, evaluate and guard against risks [5].

On the one hand, the research content of this paper deepens the risk management theory of fresh products. On the other hand, it helps relevant enterprise managers to reduce logistics risks and reduce corporate losses to a certain extent. The rest of this article is arranged as follows. Section II introduces the related literature of fresh product supply chain logistics risk. Section III briefly summarizes the theoretical basis of NK-SNA model based on risk factor identification. Section IV uses UCINET software to analyze the model results. Finally, Section V summarizes this article.

II. RELATED WORK
This section reviews and focuses on the research of domestic and foreign scholars on the logistics risk factors of the fresh product supply chain.

Foreign scholars mainly discuss the impact of logistics operation risks on food safety. From the perspective of identifying key risk factors, Duret et al. [6] used the global sensitivity analysis method to determine the main risk factors that affect food safety and used the ham cold chain as an example for research. Behnam et al. [7] identified the risks in the supply chain by measuring methods and network analysis methods and established a systematic quantitative analysis model of supply chain logistics risks. Bhaskar et al. [8] evaluated the key factors causing product losses in the Indian fruit and vegetable supply chain and provided suggestions for management decision-makers to improve the overall performance of the fruit and vegetable supply chain. From the perspective of controlling the quality loss of fresh products, Feng et al. [9] applied a wireless sensor network detection system for Hazard Analysis and used a Critical Control Point (HACCP) model to improve the transparency of Cold Chain Management (CCM) and improve the quality control of frozen shellfish in commercial life. Zhang et al. [10] think that the difficulty of quality and safety control in food enterprises is influenced by the cooperation among the main bodies in the supply chain and the information exchange among employees. Effective government supervision can enhance corporate social responsibility, improve close cooperation among the main bodies and enhance food quality and safety control. From the perspective of risk sources, Chopra et al. [11] analyzed the risk sources that affect the safety of the food supply chain, which mainly included nine areas; these are intellectual property risk, accounts receivable risk, production capacity risk, interruption risk, delay risk, procurement risk, forecast risk, inventory risk, and system risk, and put forward corresponding preventive measures. From the perspective of risk management, Jukka proposed a reference selection model of Social Customer Relationship Management (SCRM) in view of the dynamic and complex situation of supply chain risk management and the feedback application mechanism, analyzed the risk nature in the supply chain network by using the hierarchical structure analysis method, and proposed management measures [12]. Kim, et al. [13] put forward research that during the operation process from collecting cold chain logistics information to responding in time, an Intelligent Risk Management system (I-RM) can be used to monitor risk information in a dynamic form to effectively avoid risks.

Domestic scholars’ research on the supply chain risk of fresh products is mainly reflected in three aspects. First, risk identification. Meng and Li [14] combined the situation of Vietnamese fruit exports to China, explored the risks in the development of export logistics, and put forward risk control measures. Chen [15] conducted a comprehensive analysis and in-depth study on logistics, information, environment, and market risks by establishing a system dynamics model. Second, risk assessment. Xu and Tang [2] built a Graphical Evaluation Review Technique (GERT) network model of cold chain logistics quality based on quality value flow. Taking Shun Feng as an example, they identified and analyzed the key links of cold chain logistics quality control and proved the effectiveness of control measures. Wang [16] put forward a social network analysis model of the food supply chain based on a directed graph, as well as the concepts and calculation methods of K-step observability and K-step controllability of food nodes, which provided necessary technical support for food safety supervision departments to implement HACCP in the supply chain. Chen et al. [17] used GeNele software to establish a Dynamic Bayesian Network (DBN) risk assessment model to assess the risk probability of dairy cold chain logistics and analyzed the sensitivity of the assessment results, providing a new assessment paradigm. Third, risk control. Yuan and Li [18] improved the HACCP method’s selection and judgment of key links and significant hazards by introducing a fuzzy fault tree and establishing an international cold chain logistics quality control system for fresh agricultural products. Xie and Xue [19], through comparative analysis of foreign cold chain logistics research, analyzed the risk factors based on the overall operation process according to the development status of fresh agricultural product logistics in China and put forward control measures and develop strategies according to specific links.
In summary, domestic and foreign studies on fresh product supply chain risk mainly focus on risk factors, control strategies, and risk assessment [20], lacking systematic risk identification and scientific key risk assessment, and few studies assess the coupling mechanism of risk factors in the production process. Given this, this paper screens the risk factors with causal relationships in the logistics operations of fresh product supply chains through a system dynamics model. Then, the N-K/SNA fusion model is constructed to explore the coupling relationship of direct risk factors in the production process, in which fuzzy probability is used to correct qualitative data, the network density of risk factors at all levels is visually analyzed according to the model, and the core degree of a single risk factor is quantitatively analyzed. Finally, measures are put forward to reduce the risk of the whole supply chain according to the key risk factors and provide some theoretical support for the risk control of cold chain logistics.

### III. MATERIAL AND METHODS

#### A. CONSTRUCTION OF LOGISTICS RISK IDENTIFICATION MODEL FOR FRESH PRODUCTS SUPPLY CHAIN

In this paper, internal and external environmental analysis and production process analysis are used to identify the logistics risk factors for the fresh product supply chain. The internal and external environmental analysis method is based on the whole operating environment of the enterprise and its conditions and draws corresponding conclusions with the idea of system analysis. Production process analysis refers to the investigation and analysis of possible risks in each stage and the link of the supply chain logistics from the input of raw materials to the output.

After consulting the literature [20], [21], [22], [23], [24], [25], [26] and analyzing the actual cases, this paper takes all the logistics risk factors involved in the supply chain of fresh agricultural products into consideration, and finally determines 7 direct risk factors and 41 indirect risk factors (as shown in Figure 1). Combined with the common risk events—product corruption, product damage, and product rejection, the causal relationship between risk factors and risk events can be preliminarily judged. For example, the existence of “a market demand fluctuation” risk may affect “external” risk, and the existence of “a bullwhip effect” risk may lead to “product corruption”. According to the above analysis, the feedback graph model of fresh product supply chain logistics risk identification is constructed by Vensim simulation software, as shown in Figure 1.

**FIGURE 1. Feedback diagram of logistics risk identification of fresh product supply chain.**
reflect the possibility of risk events to a certain extent. This paper summarizes the risk factors that can cause risk events and their occurrence times. For the convenience of research, the indirect risk factors with occurrence times of 7, 8, and 9 are set as Grade I risks, and the rest are set as Grade II risks. A summary of these risks is in Table 1.

C. CONSTRUCTION OF THE COUPLED N-K MODEL

Before using the N-K model to analyze the coupling relationship between risk factors, it is necessary to determine the probability of risk factors. The probability of occurrence of logistics risk factors in the fresh food supply chain is often determined by the experience of managers, which varies with the experience and knowledge level of managers. The probability of occurrence of risk factors is very fuzzy [27]. The average value of fuzzy probability \( p \) can be used to correct the experience, as shown in Formulas (1) and (2).

\[
p = \frac{(x + 4y + z)}{6} \quad (1)
\]

\[
\sigma = \frac{(z - x)}{6} \quad (2)
\]

where \( p \) is the mean value of the fuzzy probability and \( \sigma \) is the deviation difference of the fuzzy probability. The values of \( p \) and \( \sigma \) can be estimated by the minimum probability value \( x \), the most likely probability value \( y \) and the maximum probability value \( z \) obtained by experience.

In the N-K model of fresh product supply chain logistics risk coupling relationship, \( N \) is the number of system components, and each component has \( N \) states, so the system has \( N^N \) states. \( K \) is the number of interdependent relationships among elements in the system, that is, the number of elements that have a correlation or influence with a certain element in the system. The minimum value of \( K \) is 0, and the maximum value is \( N - 1 \). If \( K = 0 \), the state of the system depends on the nature of the elements that make up the system. If \( K > 0 \), the state of the system is not only related to the nature of the elements of the system, but also affected by the interaction among the elements of the system. For the expression of
coupling among elements in a complex system, the interaction information $T$ in information theory can be used to study [28], and $T$ indicates the coupling degree among $N$ elements in the system.

According to the direct risk factors obtained in Table 1, the internal and external risks can be regarded as environmental risks, and then the interaction information can be calculated to evaluate the coupling degree of environmental risks, storage risks, sorting risks, distribution risks, and receiving risks. The greater the coupling value of a certain risk, the greater the possibility that this risk coupling will lead to a risk event [29].

The calculation of the interaction is shown in formula (3):

$$T_{MN}^{(a, b, c, d, e)} = \sum_{h=0}^{H} \sum_{i=0}^{I} \sum_{j=0}^{J} \sum_{k=0}^{K} \sum_{l=0}^{L} P_{hijkl} \times \log_2 \left( \frac{P_{hijkl}}{P_{h i a j k l} P_{h a j i k l} P_{h a j i k l} P_{h a j i k l}} \right)$$

where $T_{MN}^{(a, b, c, d, e)}$ represents Group $M$ Coupling Risk Values for Class $N$ Risk Factors, and $h, i, j, k, l$ belong.
to [0,1]. “0” means no occurrence, and “1” means occurrence. Types a, b, c, d, e represent environmental factors, storage factors, sorting factors, distribution factors, and receiving factors, respectively; \( P_{hijkl} \) indicates the probability that the environment is in state \( h \), the storage is in state \( i \), the sorting is in state \( j \), the distribution is in state \( k \), and the receipt is in state \( l \). \( P_{h***}, P_{i***}, P_{j***}, P_{s***}, \) and \( P_{***l} \) respectively indicate the probability of the environment in state \( h \), the probability of storage in state \( i \), the probability of sorting in state \( j \), the probability of distribution in state \( k \), and the probability of receipt in state \( l \). The larger the value \( T \) is, the greater the risk coupling value, the easier it is for risk coupling to occur, and the greater the possibility of this risk coupling leading to an accident.

There are four coupling types of direct risk factors in fresh food supply chain logistics: two factors, three factors, four factors and five factors. When two risk factors are coupled, there are 10 coupling forms, namely, environment-storage (a,b), environment-sorting (a,c), environment-distribution (a,d), environment-receiving (a,e), storage-sorting (b,c), storage-distribution (b,d), storage-receiving (b,e), sorting-distribution (c,d), sorting-receiving (c,e), and distribution-receiving (d,e). The calculation of the coupling value is shown in Formula (4):

\[
T_2^1 (a, b) = \sum_{h=0}^{H} \sum_{i=0}^{I} P_{hi***} \times \log_2 \left( \frac{P_{hi***}}{P_{h***i***}} \right) \tag{4}\n\]

When three risk factors are coupled, there are 10 coupling forms. Take environment-storage sorting (a, b, c) as an example. The calculation formula of the risk coupling value is shown in the following (5):

\[
T_3^1 (a, b, c) = \sum_{h=0}^{H} \sum_{i=0}^{I} \sum_{j=0}^{J} P_{hij**} \times \log_2 \left( \frac{P_{hij**}}{P_{h***i**j**}} \right) \tag{5}\n\]

When four risk factors are coupled, there are five coupling forms. Taking the environment-storage-sorting-distribution (a, b, c, d) as an example, the calculation formula of the risk coupling value is as follows (6):

\[
T_4^1 (a, b, c, d) = \sum_{h=0}^{H} \sum_{i=0}^{I} \sum_{j=0}^{J} \sum_{k=0}^{K} P_{hijk*} \times \log_2 \left( \frac{P_{hijk*}}{P_{h***i**j**k*}} \right) \tag{6}\n\]

When five risk factors are coupled, that is, environment-storage-sorting-distribution-receiving (a, b, c, d, e) coupling, the calculation formula of the risk coupling value is as follows (7):

\[
T_5 (a, b, c, d, e) = \sum_{h=0}^{H} \sum_{i=0}^{I} \sum_{j=0}^{J} \sum_{k=0}^{K} \sum_{l=0}^{L} P_{hijkl} \times \log_2 \left[ \frac{P_{hijkl}}{P_{h***i**j**k*k*l}} \right] \tag{7}\n\]

D. SNA MODEL CONSTRUCTION

UCINET (University of California at Irvine Network) is a powerful social network analysis software, which includes a large number of network analysis indicators, such as overall network density, centrality, block model, etc. It can also be used to graphically represent social networks and construct 1-mode network and 2-mode networks. In this paper, UCINET analysis software is used to analyze the logistics risk factors for fresh product supply chains using a 1-mode network and a 2-mode network.

Overall network analysis of the 1-mode network: 1-mode network is a network composed of a set of actors and the relationships among them. First, the overall network density reflects the compactness of the overall network nodes. If the density of the whole network is higher, the influence of the network on the nodes may be greater. The overall network density is the ratio of the total number of relationships existing in the network to the maximum possible relationship. The calculation is shown in Formula (8), where \( I \) is the total number of relationships existing in the network, indicating the number of nodes in the network. Second, a block model is used to analyze the logistics risk factors for the fresh product supply chain. The CONCOR method is used to divide the risk factors into blocks, and the values of each block (i.e., whether each block is 1-block or 0-block) are determined according to the density index, and descriptive analysis is performed for each block according to the values.

\[
D = N/n \times (n - 1) \tag{8}\n\]

where: \( n \) is the number of nodes in the network, that is, risk factors, then \( n (n - 1) \) represents the maximum possible number of relationships among risk factors; \( N \) is the number of relationships actually included in the network.

Individual network analysis of 2-mode network [32]: the network formed by the relationship between one set of actors and another set of actors is called 2-mode network. In the individual network analysis methods of complex networks, centrality analysis is often involved, including degree centrality, closeness centrality, and betweenness centrality [33]. The degree centrality of a point in a 2-mode network is the total number of events that the point belongs to, and a higher degree centrality resides at the core of the network. The degree centrality of a point in a 2-mode network is the number of nodes directly connected to a certain node. The calculation formula of node \( o \) is as follows (9):

\[
C (o)_p = \sum_{q=1}^{n} a_{oq} \tag{9}\n\]

And when node \( o \) is directly connected to node \( q \) only, \( a_{oq} = 1 \), otherwise its value is 0, and \( n \) represents the total number of nodes in the network.

The closeness centrality is the proximity of a node to all other nodes in the network. The closer a node is to other
nodes, the more efficient it is in transmitting the information. Proximity centrality is the inverse function of the sum of shortcut distances between a node and other nodes in the network, and its formula is expressed as follows (10):

\[ C_t(n_r) = \left[ \sum_{s=1}^{g} u(n_r, n_s) \right]^{-1} \quad r \neq s \]  

(10)

where \( u(n_r, n_s) \) is the distance between nodes. The betweenness centrality refers to the control degree of the nodes in the network to the network resources of the whole system. It is also the degree to which a point in the network is in the middle of other “point pairs” [34]. If a node is on the shortest path of many other pairs of nodes, it has a high intermediate centrality, which means that the node can control information transmission more easily and affect the whole network. Its formula is expressed as follows (11):

\[ C_B(o) = \sum_{s}^{n} \sum_{q}^{n} b_{sq}(o) \]

\[ = \sum_{s}^{n} \sum_{q}^{n} \frac{g_{oq}(o)}{g_{oq}} \quad s \neq q \neq o, \quad s < q \]  

(11)

where \( b_{sq}(0) \) indicates the probability that the middle point \( o \) is on the shortcut between point \( s \) and point \( q \), reflecting the control ability of point \( o \) to point \( s \) and point \( q \); \( g_{oq}(0) \) indicates the number of shortcuts through point \( o \) between point \( s \) and point \( q \).

E. ESTABLISHMENT OF THE N-K/SNA MODEL

The N-K model reflects the possibility of risk events under different combinations of risk factors, so it is difficult to determine the core factors that should be considered in risk management. The SNA model analyzes the core factors based on the relationship structure among risk factors, but different factors and combinations of factors have different action degrees on inducing risk events, so only using the SNA model may lead to deviation [34]. Based on screening related risk factors which are based on system dynamics, this paper fuses the N-K and SNA models (see Figure 5). First, the N-K model is used to evaluate the possibility of risk events caused by the coupling of direct risk factors. Second, the block model of the 1-mode network in SNA is used to analyze the close relationship between direct and indirect risk factors, and the centrality of the 2-mode network is used to analyze the indirect risk factors as the core of the network. Finally, the final results are summarized and judged to obtain the key risk factors.

IV. RESULTS AND FINDINGS

A. ANALYSIS OF CALCULATION RESULTS OF THE N-K MODEL

The direct risk factors obtained from system dynamics are taken as the research object, including the environment, storage, sorting, distribution and receipt. According to the statistical analysis of logistics risk events in the fresh product supply chain, combined with expert evaluation, the probability of risk events caused by single-factor coupling, double-factor coupling, and multifactor coupling can be obtained, and the mean value, deviation degree, and fuzzy probability can be further obtained by formula (1), and formula (2) calculation. The results are shown in Table 2.

According to Formulas (4)~(7), the risk coupling value under the coupling effect of different risk factors can be calculated, as shown in Table 3 below. By analyzing Table 3, the following contents can be obtained.

1) Longitudinal comparison shows that the more coupling factors there are, the greater the coupling value. Avoiding multifactor coupling is important to control the occurrence of risk events.

2) Among the two-factor risk coupling values, the distribution-receipt risk coupling value is the largest. Among the three-factor risk coupling values, the risk coupling value of storage-sorting distribution is higher than that of the other three-factor coupling modes. Among the four-factor risk coupling values, environment-storage-sorting-receiving is higher than the other factors.
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### TABLE 2. Incidence probability of risk factor coupling events.

| Coupling mode         | Symbol | Minimum probability a | Most probable probability b | Maximum probability c | Mean value p | Deviation difference σ |
|-----------------------|--------|------------------------|----------------------------|-----------------------|--------------|------------------------|
| Single factor coupling| N00000 | 0                      | 0.0000                     | 0                     | 0.0000       | 0.0000                 |
|                       | N10000 | 0                      | 0.0052                     | 0.04                  | 0.0101       | 0.0067                 |
|                       | N01000 | 0                      | 0.0143                     | 0.0220                | 0.0132       | 0.0037                 |
|                       | N00100 | 0                      | 0.0231                     | 0.0380                | 0.0217       | 0.0063                 |
|                       | N00010 | 0                      | 0.0242                     | 0.0420                | 0.0231       | 0.0070                 |
|                       | N00001 | 0                      | 0.0306                     | 0.0380                | 0.0267       | 0.0063                 |
|                       | N11000 | 0                      | 0.0071                     | 0.0072                | 0.0059       | 0.0012                 |
|                       | N10100 | 0                      | 0.0046                     | 0.0080                | 0.0081       | 0.0047                 |
|                       | N10010 | 0                      | 0.0327                     | 0.0099                | 0.0071       | 0.0117                 |
|                       | N10001 | 0                      | 0.0176                     | 0.0502                | 0.0201       | 0.0084                 |
|                       | N01100 | 0                      | 0.0582                     | 0.0162                | 0.0124       | 0.0270                 |
|                       | N01010 | 0                      | 0.0285                     | 0.0282                | 0.0237       | 0.0047                 |
|                       | N01001 | 0                      | 0.0217                     | 0.0900                | 0.0161       | 0.0150                 |
|                       | N00110 | 0                      | 0.1673                     | 0.0409                | 0.0347       | 0.0682                 |
|                       | N00011 | 0                      | 0.0215                     | 0.1002                | 0.0310       | 0.0167                 |
|                       | N00101 | 0                      | 0.0187                     | 0.1060                | 0.0301       | 0.0177                 |
|                       | N11000 | 0                      | 0.0381                     | 0.0401                | 0.0321       | 0.0067                 |
|                       | N10100 | 0                      | 0.0427                     | 0.0254                | 0.0327       | 0.0042                 |
|                       | N10010 | 0                      | 0.0019                     | 0.1192                | 0.0211       | 0.0199                 |
|                       | N10110 | 0                      | 0.0206                     | 0.1362                | 0.0364       | 0.0227                 |
|                       | N10010 | 0                      | 0.0468                     | 0.0798                | 0.0445       | 0.0133                 |
|                       | N10011 | 0                      | 0.0604                     | 0.0830                | 0.0541       | 0.0138                 |
|                       | N01110 | 0                      | 0.0514                     | 0.1192                | 0.0541       | 0.0199                 |
|                       | N01111 | 0                      | 0.0469                     | 0.0698                | 0.0429       | 0.0116                 |
|                       | N01101 | 0                      | 0.0218                     | 0.1044                | 0.0319       | 0.0174                 |
|                       | N00111 | 0                      | 0.0378                     | 0.1698                | 0.0668       | 0.0283                 |
|                       | N11110 | 0                      | 0.0185                     | 0.1762                | 0.0417       | 0.0294                 |
|                       | N11111 | 0                      | 0.0719                     | 0.1308                | 0.0697       | 0.0218                 |
|                       | N11011 | 0                      | 0.0885                     | 0.0918                | 0.0743       | 0.0153                 |
|                       | N10111 | 0                      | 0.0178                     | 0.2108                | 0.0470       | 0.0351                 |
|                       | N01111 | 0                      | 0.0547                     | 0.1204                | 0.0565       | 0.0201                 |
|                       | N11111 | 0                      | 0.0563                     | 0.0409                | 0.0162       | 0.0182                 |

### TABLE 3. Risk coupling value under the coupling effect of different risk factors.

| Coupling factor | Risk coupling value | Ranking |
|-----------------|--------------------|---------|
| T1 (a,b)        | 0.0022             | 22      |
| T1 (a,c)        | 0.0031             | 21      |
| T1 (a,d)        | 0.0004             | 25      |
| T1 (b,c)        | 0.0020             | 23      |
| T1 (b,d)        | 0.0004             | 25      |
| T1 (b,e)        | 0.0020             | 23      |
| T1 (c,d)        | 0.0078             | 19      |
| T1 (c,e)        | 0.0127             | 16      |
| T1 (c,e)        | 0.0062             | 20      |

3) Storage and sorting factors appear repeatedly in the top five coupled risk values, which shows that the operation process of storage and sorting poses a great threat to the risk events of fresh products.

### B. ANALYSIS OF SNA MODEL RESULTS

1) **CLASSIFICATION OF LOGISTICS RISK FACTORS IN THE FRESH PRODUCTS SUPPLY CHAIN**

In this paper, 27 risk factors obtained in Table 1 are selected, and three types of risk events caused by them are classified, as shown in Table 4.

2) **NETWORK MODEL OF LOGISTICS RISK FACTORS IN THE FRESH PRODUCT SUPPLY CHAIN**

According to the causality feedback diagram model of system dynamics, the influence relationships among related risk factors in the fresh product supply chain are collected. If there is an influence relationship, it is “1”; otherwise, it is “0”. It is converted into a 27*27 data square matrix to form the adjacency matrix of logistics risk factors in the fresh product supply chain, forming UCINET 1-mode network data. Based on the 1-mode network data, a record table of 27 safety risk factors causing fresh product events is established, forming UCINET 2-mode network data, as shown in Table 5. Based on 2-mode network data, using UCINET software Layout → Graph-Theoretical Layout → MDS, a multidimensional scale of 27 logistics risk factors and 3 risk events is generated, as shown in Figure 6.

### C. IDENTIFICATION OF CORE LOGISTICS RISK FACTORS

In the 1-mode network, the core block is analyzed by using the block model and the overall network density, and the
### TABLE 4. Classification of product events caused by fresh products supply chain.

| Numbering | Product accidents caused by                                      | Risk dimension |
|-----------|------------------------------------------------------------------|----------------|
| P1        | Storage cold chain technology P1                                 | corruption     |
| P2        | Storage, loading and unloading P2                                | damage         |
| P3        | Maintenance degree P3                                            | corruption     |
| P4        | Information storage and timeliness P4                           | corruption     |
| P5        | Storage situation P5                                            | refuse         |
| P6        | Storage plan P6                                                  | corruption     |
| P7        | Storage quality check P7                                         | corruption     |
| P8        | stock-taking P8                                                  | refuse         |
| P9        | Cold chain sorting technology P9                                 | corruption     |
| P10       | Pick and tally P10                                               | damage         |
| P11       | Product packaging P11                                            | corruption     |
| P12       | Information sorting timeliness P12                              | corruption     |
| P13       | Sorting plan risk P13                                            | damage         |
| P14       | Sorting quality inspection P14                                   | corruption     |
| P15       | Internal and external review P15                                 | refuse         |
| P16       | Distribution, loading and unloading P16                         | damage         |
| P17       | Distribution cold chain technology P17                           | corruption     |
| P18       | Refrigerated transport P18                                       | refusal        |
| P19       | Distribution information P19                                     | refuse         |
| P20       | Traffic jam P20                                                  | corruption     |
| P21       | Unexpected distribution situation P21                           | damage         |
| P22       | Receiving plan risk P22                                          | corruption     |
| P23       | Receiving address record P23                                     | refusal        |
| P24       | Order consistency P24                                            | refusal        |
| P25       | Natural disaster P25                                             | corruption     |
| P26       | Temperature detection technology P26                             | damage         |
| P27       | Bullwhip effect P27                                              | corruption     |

### FIGURE 6. Multidimensional scale of logistics risk factors and risk events in fresh products supply chain.

### FIGURE 7. Flow chart of core logistics risk factor identification.

Risk factors for the core block are determined. The 2-mode network mainly measures the important position of a single risk factor in the network from the perspective of the occurrence of risk events, which helps to identify key risk factors. Therefore, based on the results of 1-mode network analysis,

### TABLE 5. Risk factors causing risk event classification.

| Risk factor | Product damaging | Product spoilage | Product rejection |
|-------------|------------------|-----------------|------------------|
| P1          | 1                | 1               | 0                |
| P2          | 1                | 1               | 0                |
| P3          | 0                | 1               | 0                |
| P4          | 0                | 1               | 0                |
| P5          | 0                | 0               | 1                |
| P6          | 1                | 1               | 0                |
| P7          | 1                | 1               | 0                |
| P8          | 1                | 1               | 1                |
| P9          | 0                | 1               | 0                |
| P10         | 1                | 0               | 0                |
| P11         | 0                | 0               | 1                |
| P12         | 0                | 1               | 0                |
| P13         | 1                | 1               | 0                |
| P14         | 1                | 1               | 1                |
| P15         | 0                | 0               | 1                |
| P16         | 1                | 1               | 1                |
| P17         | 0                | 1               | 1                |
| P18         | 1                | 1               | 1                |
| P19         | 0                | 0               | 1                |
| P20         | 0                | 1               | 1                |
| P21         | 1                | 1               | 1                |
| P22         | 1                | 1               | 1                |
| P23         | 0                | 0               | 1                |
| P24         | 0                | 0               | 1                |
| P25         | 1                | 1               | 1                |
| P26         | 0                | 1               | 1                |
| P27         | 0                | 1               | 1                |
TABLE 6. Network block matrix of logistics risk factors in fresh products supply chain.

| Block | Risk factor          |
|-------|----------------------|
| B1    | P1, P8, P7, P5       |
| B2    | P3, P6, P4, P2, P25  |
| B3    | P26, P20             |
| B4    | P22, P27             |
| B5    | P10, P14, P9, P13    |
| B6    | P15, P12, P11        |
| B7    | P18, P16, P17, P21   |
| B8    | P19, P23, P24        |

TABLE 7. Density matrix of network block model of logistics risk factors in fresh products supply chain.

|    | B1  | B2  | B3  | B4  | B6  | B7  | B8  |
|----|-----|-----|-----|-----|-----|-----|-----|
| B1 | 0.167 | 0.400 | 0.125 | 0.000 | 0.333 | 0.000 | 0.250 |
| B2 | 0.450 | 0.450 | 0.100 | 0.800 | 0.133 | 0.050 | 0.000 |
| B3 | 0.250 | 0.100 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| B4 | 0.000 | 0.300 | 0.250 | 0.500 | 0.333 | 0.125 | 0.167 |
| B5 | 0.000 | 0.000 | 0.250 | 0.250 | 0.500 | 0.063 | 0.000 |
| B6 | 0.000 | 0.000 | 0.000 | 0.167 | 0.000 | 0.000 | 0.778 |
| B7 | 0.000 | 0.000 | 0.125 | 0.500 | 0.000 | 0.500 | 0.000 |
| B8 | 0.000 | 0.000 | 0.187 | 0.833 | 0.000 | 0.000 | 0.500 |

this paper uses the centrality analysis of the 2-mode network to identify the core risk factors. The risk factors for the 2-mode network with large centrality are selected, with the core block and risk level I as the key risk factors for fresh product supply chain logistics. See Figure 7 for the specific identification process.

1) ANALYSIS OF THE 1-MODE MESH BLOCK MODEL

Using UCINET software Net-Work → Roles & Positions → Concor, the network block matrix and network block model density matrix of logistics risk factors in the fresh product supply chain are obtained, as shown in Tables 6 and 7. Using UCINET software, through the network → cohesion → density → old density procedure, the overall network density value of the logistics risk factor network of the fresh product supply chain is 0.326. Replacing the value greater than 0.326 with 1 and the value less than 0.326 with 0 in Table 7 yields the following Table 8.

According to Burt’s theory of location division [35], it can be concluded from Table 8 that Block 3 is in an isolated position, in which Block 3 only has the sending relationship, and Block 3, Block 4, Block 5, Block 7 and Block 8 are in the first personal position (both sending and receiving relationships, and their internal relations are close). Block 1 and Block 6 are in the position of broker (there are both sending and receiving relationships, but the internal relationship is not close). Although Block 1 and Block 6 have both sending and receiving relationships, the ratio of the total number of sending and receiving relationships to the number of nodes in the block is low, both lower than 2. Therefore, Block 2, Block 4, Block 5, Block 7, and Block 8, which are in the first person’s position, are considered blocks that may be in the core position in this paper.

2) 2-MODE NETWORK CENTRALITY ANALYSIS

The degree centrality, closeness centrality, and betweenness centrality of risk factors are obtained by using UCINET software through network → centrality → 2-mode centrality, as shown in Table 9.

As seen from Table 9, the top 12 factors of centrality, the core block, and level I risk are P13, P14, P16, P21, P22, and P25. These six risk factors are close to centrality and have high intermediate centrality. Therefore, the core risk factors for fresh product supply chain logistics are P13 (sorting plan risk), P14 (sorting quality inspection), P16 (distribution handling), P21 (unexpected distribution situation), P22 (receiving plan risk), and P25 (natural disaster), which are at the core of the network. As seen from Figure 6 above, the risk of the sorting plan and distribution handling is more likely to cause product damage; the risk of the receiving plan is more likely to cause product corruption; distribution accidents and natural disasters are more likely to cause product rejection, and the degree of product damage caused by quality inspection is basically the same as that of product corruption. It can be seen that in future risk prevention, enterprise managers should focus on core risk factors and formulate a responsive and perfect enterprise system.

3) ANALYSIS OF KEY FACTORS BASED ON THE N-K/SNA MODEL

By comparing the criticality of the risk factors in the subsystems with large risk coupling values in Table 3 with the criticality of the risk factors in Table 9, the direct risk factors with large risk coupling values and the core risk factors obtained in Table 9 are selected, and finally, four key risk factors, namely, sorting plan risk, sorting quality inspection, distribution handling, and delivery accidents, are obtained. The risk of a sorting plan exists in the whole sorting process, which involves picking and tallying, quality inspection, loading, and
unloading, which inevitably changes the state of products. Fresh products need to constantly be adapted to the new environment and they face the risk of corruption and damage if they are slightly improper. The quality inspection of sorting is the most important in the sorting process, and the failure of inspection directly affects the corruption of fresh products. In the process of distribution, loading, and unloading, it is easy to cause fresh products to collide with each other, causing physical goods damage or internal temperature rise. Accidents in distribution, such as the improper operation of drivers and external environmental influences, directly lead to heavy losses for enterprises.

Based on the above analysis, the following suggestions are put forward to the relevant management departments of fresh products enterprises:

1. Try to avoid multifactor risk coupling. Risk spreads according to the production process, and it is easy to form multifactor coupling. For the storage and sorting links, the enterprise management department can increase the input of manpower, technology, and logistics storage resources, optimize each sub-link, improve the cold chain management, perfect the monitoring system, and establish a unified and standardized management system.

2. Sorting plan risk, sorting quality inspection, delivery handling, and delivery accidents are the key risk factors for the whole system. By improving the scientific effectiveness of the sorting plan, strengthening sorting quality inspection, upgrading the delivery handling system and preventing delivery accidents, the logistics operation risk can be reduced, and then the quality and safety of fresh agricultural products can be guaranteed.

In view of the risk of sorting plan, the focus of this risk prevention is to cultivate the management ability of managers. It can be prevented by organizing regular meetings of relevant managers, jointly formulating sorting plans and going out to other enterprises to investigate, and learn; in view of the risk of sorting quality inspection, the consumption of fresh products is the largest in the sorting process, and the risk is easily coupled. Measures such as increasing the number of fresh product quality inspections and using advanced equipment to achieve inspections without contacting fresh products can be taken to ensure the accurate classification of fresh products and the minimization of quality loss. In view of the distribution handling risk, at present most enterprises distribution handling links can not be fully mechanized, largely relying on manpower to carry out logistics activities, so the risk prevention focuses on people. We can improve the comprehensive quality of employees in an all-round way by strengthening the quality education of employees, organizing career guidance, regular assessment, regularly checking the work content of employees, and implementing appropriate rewards and punishments. In response to the risk of distribution accidents, establish a new product distribution early warning mechanism to ensure timely detection, timely warning and timely disposal. First, do a good job of sampling and inspection of outbound products, in line with the standard can be out of the library. The second is to strengthen the management of fresh product distribution vehicles, transport personnel shall not be unauthorized to open the box and contact products to ensure that the carriage clean non-toxic, harmless, odorless, pollution-free.

V. CONCLUSION

The logistics system of the fresh product supply chain is complex and diverse, and many of its links may bring unpredictable risks. Based on obtaining 27 related risk factors rooted in system dynamics, this paper introduces the N-K/SNA model into the field of cold chains and expands the

| Risk factor | Degree centrality | Closeness centrality | Betweenness centrality | Type of block | Class type |
|-------------|-------------------|----------------------|------------------------|---------------|------------|
| P1          | 0.333             | 0.696                | 0                      | Non-core block | Class II   |
| P2          | 0.333             | 0.567                | 0                      | Core block    | Class II   |
| P3          | 0.333             | 0.696                | 0                      | Core block    | Class II   |
| P4          | 0.333             | 0.696                | 0                      | Core block    | Class II   |
| P5          | 0.333             | 0.714                | 0                      | Non-core block | Class II   |
| P6          | 0.333             | 0.696                | 0                      | Core block    | Class II   |
| P7          | 0.333             | 0.696                | 0                      | Non-core block | Class II   |
| P8          | 0.333             | 0.714                | 0                      | Non-core block | Class II   |
| P9          | 0.333             | 0.696                | 0                      | Core block    | Class II   |
| P10         | 0.333             | 0.567                | 0                      | Core block    | Class II   |
| P11         | 0.667             | 0.902                | 0.024                  | Non-core block | Class II   |
| P12         | 0.333             | 0.696                | 0                      | Non-core block | Class II   |
| P13         | 0.667             | 0.775                | 0.019                  | Core block    | Class II   |
| P14         | 1                 | 1                    | 0.075                  | Core block    | Class I    |
| P15         | 0.333             | 0.714                | 0                      | Non-core block | Class II   |
| P16         | 1                 | 1                    | 0.075                  | Core block    | Class I    |
| P17         | 0.667             | 0.902                | 0.024                  | Core block    | Class II   |
| P18         | 0.667             | 0.902                | 0.024                  | Core block    | Class II   |
| P19         | 0.333             | 0.714                | 0                      | Core block    | Class II   |
| P20         | 0.667             | 0.902                | 0.024                  | Non-core block | Class II   |
| P21         | 0.667             | 0.775                | 0.019                  | Core block    | Class I    |
| P22         | 1                 | 1                    | 0.075                  | Core block    | Class I    |
| P23         | 0.333             | 0.714                | 0                      | Core block    | Class II   |
| P24         | 0.333             | 0.714                | 0                      | Core block    | Class II   |
| P25         | 1                 | 1                    | 0.075                  | Core block    | Class I    |
| P26         | 0.667             | 0.902                | 0.024                  | Non-core block | Class I    |
| P27         | 0.667             | 0.902                | 0.024                  | Core block    | Class II   |
risk management and control theory of cold chain logistics. First, the N-K model is established from five aspects: environment, storage, sorting, distribution, and receiving risks, and the 1-mode network based on social network theory is used to evaluate the risk coupling. Then, the network criticality of risk factors is further analyzed by using the 2-mode network of SNA, and the key risk factors are determined by both of them. It provides a brand-new theoretical basis for logistics risk analysis of fresh product supply chains. At the same time, this paper only studies the generality of logistics risk of fresh product supply chains based on fuzzy probability. However, there are many kinds of fresh products, and different fresh products have different production processes. There are also some differences in the identified risk factors, which lead to different key risk factors. These differences will lead to different risk factors network models and network correlation. The future research direction is to study the key factors of different fresh products. At present, China’s cold chain logistics industry is developing late, and the technology and equipment are not mature enough. Therefore, risk identification based on the current situation is only aimed at the current severe risks. With the gradual improvement of the logistics industry, unknown risks will be constantly met in future development. It is necessary to adopt more current research methods to discover the key risk factors in the fresh product supply chain logistics industry. In addition, from the perspective of research methods in this paper, the N-K model used in this paper only divides the state of risk events into 0 and 1, without distinguishing the severity of accidents. Therefore, the idea of risk function classification can be added to the future research.

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