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Food Supply Chain Safety Risk Evaluation Based on AHP Fuzzy Integrated Evaluation Method

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Abstract

With the improvement of people's living standards, the food safety issue occurs frequently. How to identify all kinds of risks, evaluate these risks scientifically and manage the risk control effectively are the challenge for each sully chain manager and the relevant researchers. In order to reduce the occurrence of the food safety issues and ensure the quality of the people's life, it is necessary to evaluate the food safety. Based on the food supply chain safety evaluation model, this paper uses AHP fuzzy integrated evaluation method with a new scale to evaluate food supply chain safety risk. The paper provides reference to ensure the safety of the food supply chain.

Keywords: *Food supply chain, Safety risk evaluation, New scale*

1. Introduction

The food safety issue is a major problem which is related to the people's health, livelihood, and the national economy. However, the food safety incidents occur frequently in recent years. These incidents bring the blow for the consumer's confidence and it leads to the crisis of trust. These incidents not only affect the health and the safety of the consumers, but also affect seriously the health development of the food industry. Consumers require the higher requirement for the safety degree of the food. In order to reduce the occurrence of the food safety issue and ensure the quality of life, it is necessary to evaluate the food safety.

Ting Chen, Yiying Jin, Xiaopeng Qiu and Xin Chen proposed a method based on data from the testing of food-waste feed with comprehensive evaluation of its product safety by integrating fuzzy mathematics effectively and the model of AHP [1]. The comprehensive evaluation method developed in this paper can effectively overcome the shortcomings of traditional single-factor evaluation and offer the qualitative and quantitative advantages of expert survey and basic data research as well. E. Lahou, L. Jacxsens, E. Verbunt, M. Uyttendaele evaluated the food safety of the hospital [2]. They evaluated the food safety management system of a hospital food service operation. Gao Yi and Liao Yang evaluated and studied the agricultural products supply chain risk [3]. From the view of the quality safety, Zhang Donglin and other people established the simultaneous equation model based on the logistic which was aiming at the quality control and risk evaluation of the agricultural products supply chain. And they gave the method of supply chain quality safety evaluation. Aiming at the unique attributes for the agricultural products supply chain quality safety, this method combined the qualitative analysis and the quantitative analysis. And it established the system method of the agricultural products supply chain risk evaluation. In addition, it can carry out the quality safety risk warning. This method achieved the goals of the agricultural products safety [4]. Ceng Guoji evaluated the risk and put forward the measures for the fresh agricultural products supply chain risk assessment. The method reduced the supply chain risk of the fresh agricultural products and improved their ability to resist the risks. Therefore, it improved the construction of the fresh agricultural products supply chain [5]. Based on

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the supply chain risk study, Zhang Mengyao analyzed the major risk factors for the food supply chain from the view of the characteristics of the food supply chain and the current situation of the food supply chain. Then, they established the evaluation system of the food supply chain risk and constructed the risk evaluation model of the food supply chain according to the construction principle of the risk evaluation index system [6]. Yao Bo recognized the risks of the whole agricultural products according to the three levels of the networking and summed up the agricultural supply chain risk factors under the networking environment. Then, the author used OWA operator to evaluate and order the risk factors [7]. In addition, Luo Aixue, Li Danyu, Song Weiguo, Zhao Zhihui and other people also studied and evaluated the agricultural supply chain risk [8-10].

Analytic hierarchy process was proposed by American expert T.L.Saaty in the seventies of 20th century. It was an evaluation decision method which combined the qualitative analysis and the quantitative analysis [11-12]. It has been closely watched by many scholars when it was proposed [13-15]. Many scholars combined the AHP method with other methods and proposed the improved AHP method. For example, there are AHP- entropy method [16-17], Grey-AHP method [18-19], DEA/AHP method [20-21] and AHP-TOPSIS method etc [22-23]. According to combining with other methods, AHP method obtained the strong vitality.

Aiming at the characteristics of the agricultural products supply chain risk evaluation, this paper establishe the food supply chain safety risk evaluation system. At the same time, this paper put forward the AHP fuzzy integrated evaluation method with a new scale. And we use the method to evaluate the food supply chain safety risk. The structure of this paper is as follows. The first part is the introduction. In this part, we introduce the research status of the food supply chain risk evaluation and AHP method. The second part is the construction of the indexes. In the second part, according to the characteristics of the food supply chain, we establish the food supply chain safety risk evaluation system. The third part is the AHP fuzzy integrated evaluation method with a new scale. In this part, we put forward a new scaling method. We put forward AHP fuzzy integrated evaluation method a new scaling combining with this method. The fourth part is the experiment analysis and the last part is the conclusion.

2. The Construction of the Indexes

2.1 The Principle of Choosing the Indexes

The first principle is the comprehensive principle. This principle requires that the whole index system includes comprehensively all kinds of safety influence factors about the food supply chain. Therefore, designing the evaluation index system needs to do the following things. The first thing is that the studied objects must be comprehensive. It needs to cover all aspects of the food safety. The second thing is that the studied process must be comprehensive. The safety control is a complex system. It involves various macro factors and micro factors. Only in this way, can it reflect relatively the safety level of the food supply chain. When constructing the indexes, we should make the food supply chain as a whole to consider from the whole system. Then, we can identify the safety risks in each link of the food supply chain.

The second principle is the objectivity. The safety risk of the food supply chain has a certain of objectivity. The identification of the risks must also comply with the principle of the objectivity. We could not fabricate the unreadable risk factors by our subjective understanding. The identified risk factors should stick to the status of the supply chain safety risk and reflect the actual situation.

The third principle is the continuity. The food supply chain is dynamic. The internal operating situation and the user demand can change. The safety risk of the food supply chain is constantly changing. The risks in different stages show different states. The risk is not important in the past. However, it is very important and serious now. Similarly, the risk which is paid attention now may disappear with the management measures. At the same time, it may appear the new risks. It means that the risk identification is a continuous process. We need to look at the risk from the view of the development.

The fourth principle is the independence. The various factors contain the redundant information inevitably. Therefore, each index should be as accurate as possible when choosing the index system. These indexes must reflect effectively the safety influence factors about one aspect in the food supply chain. Each index has its specific function. And we will avoid the duplication and overlapping as far as possible.

The fifth principle is the real effectiveness. The principle of the real effectiveness is one of the most important principles for choosing the evaluation index. Only to guarantee the real effectiveness of the index, can we do the evaluation objectively and scientifically. Then, we can guarantee the validity of the comprehensive evaluation index and do the final scientific decision. If we guarantee the real effectiveness of the indexes, we must do the following things. Firstly, we must guarantee the source of the index content is real and reliable. And the calculation method is correct. Secondly, we determine the evaluated factors scientifically and rationally. Then, we design the risk questionnaire, collect data and analyze the results by using the scientific methods.

2.2 The Construction of the Index System

According to the principle of choosing the indexes, we establish the food supply chain safety risk evaluation indexes. It is shown in the following table.

Table 1. The Food Supply Chain Safety Risk Evaluation Indexes

The food supply chain safety risk evaluation indexes	Internal risks	Unqualified product quality
		Delayed supply time
		Insufficient inventory control ability
		Insufficient production capacity
		Equipment risks
		Poor sanitation
		Poor quality of employees
	External risks	Natural disasters
		Infectious diseases
		Risks of policies and regulations
		Improved quality standards
		Serious fakes
	Logistics risks	Food spoilage during the transit
		Interrupt logistics
		Lost food
		Food spoilage during machining process
		Food spoilage during sales process
	Market risks	Uncertain demands
		In short supply
		Price fluctuations
		Malignant competition
		Consumers' cognition
		Unreasonable sales price
		Unsmooth marketing channel
	Information risks	Unsmooth information communication
		Bullwhip effect
	Cooperation risks	Unreasonable profit distribution
		Partner selection

		Partner management
		Distrust among the enterprises
		Enterprise cultural differences
		Different enterprise strategic targets
	Food safety supervision risks	Unsound food safety supervision mechanism
		Imperfect food quality management system
		Internal personnel supervision responsibility risk
	Other risks	Reputation risk
		Moral risk
		Structural risk
		Credit risk
		Technical risk

In this index system, there are 8 two level indexes and 40 three level indexes. They can reflect better the situation for the food supply chain safety risk.

3. The AHP Fuzzy Integrated Evaluation Method with a New Scale

The analytic hierarchy process is proposed by the professor Satty who is in the University of Pittsburgh in the early 70 century. It is multi objective comprehensive evaluation method. He proposed the hierarchy weight decision analysis method. The steps are as follows.

The first step is to construct the hierarchical structure model and establish the criterion layer and the index layer

The second step is structural comparison matrix

$$A=(a_{ij})_{n\times n} \quad (i=1,2,\cdots,n), a_{ij}=1, a_{ij}=1/a_{ji} \tag{1}$$

A is the Judgment matrix. We set a_{ij} which shows the relative comparison value of a_i index and a_j index.

Among them,

$$a_{ij}>0, \frac{1}{a_{ij}}=a_{ji}, a_{ii}=1.\ a_{ii}=1 \tag{2}$$

The third step is to Judgment whether matrix A is normalized or not.

$$a_{ij}=a_{ij}\Big/\sum_{k=1}^{n}a_{kj} \quad (i=1,2,\cdots,n) \tag{3}$$

The fourth step is to sum the row of Judgment matrix A:

$$\omega_i=\sum_{j=1}^{n}a_{ij} \quad (i=1,2,\cdots,n) \tag{4}$$

The fifth step is to normalize ω_i.

$$\omega_i=\omega_i\Big/\sum_{i=1}^{n}\omega_i \quad (i=1,2,\cdots,n) \tag{5}$$

The sixth step is to derive the maximum eigenvalue and its eigenvector according to

$$A\omega = \lambda_{\max}\omega \tag{6}$$

The seventh step is to check the consistency.

We define

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{7}$$

CI is the index of consistency.

When the Judgment matrix has the character of consistency, $CI = 0$

If $\lambda_{\max} - n$ is large, CI is large. And the consistency is worse.

For checking whether the Judgment matrix has the character of consistency, we compare CI with the index of consistency RI that is shown in table.2.

Table 2. The Index of Consistency from 1-9 Orders

order	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

The scales of the traditional method are from one to nine. It is shown as table 3. This kind of scaling method has bigger difference from the thinking scale of people. For example, the two factors x_1 and x_2, when x_1 is important than x_2, the weight ratio is 3:1. The importance degree of the former is 3 times of the latter. It has bigger difference from our concept of "a little important". Therefore, it causes that the evaluation results are not reasonable.

Table 3. Scale Meaning of Importance Degree

a_{ij}	Index important degree
1	a_i is same important as a_j
3	a_i is a little more important than a_j
5	a_i is more important than a_j
7	a_i is a highly more important than a_j
9	a_i is a extremely more important than a_j
2,4,6,8	The importance between a_i and a_j among the above

Aiming at the shortcomings of the traditional scaling method, many scholars studied it. For example, Zuo Jun proposed three scale method from 0 to 2. Wang Hao and other people proposed 9/9~9/1fractional scaling method and 10/10~18/2. When we studied 1~9 scaling method, we found that when x_1 is important than x_2, the important degree of the former is 3 to 5 times of the latter. On the basis, we use a new scaling method. The method is $\log(\frac{100}{10}) \sim \log(\frac{400}{2})$ scaling method. The comparison between the new scaling method and the original method is shown in the following table.

Table 4. The Description Comparison between the New Scaling and other Scaling Methods

	1~9	10/10~ 8/2	$e^{0/4} \sim e^{8/4}$	$In(\frac{100}{10}e) \sim In(\frac{400}{2}e)$
Equally important	1	10/10(1.000)	$e^{0/4}$ (1.000)	$In(\frac{100}{10}e)$ (1.000)
Small important	2	11/9(1.222)	$e^{1/4}$ (1.284)	$In(\frac{140}{9}e)$ (1.1919)
A little important	3	12/8(1.500)	$e^{2/4}$ (1.649)	$In(\frac{180}{8}e)$ (1.3522)
Even more important	4	13/7(1.857)	$e^{3/4}$ (2.117)	$In(\frac{220}{7}e)$ (1.4973)
Obviously important	5	14/6(2.333)	$e^{4/4}$ (2.718)	$In(\frac{260}{6}e)$ (1.6368)
Very important	6	15/5(3.000)	$e^{5/4}$ (3.490)	$In(\frac{300}{5}e)$ (1.7782)
Highly important	7	16/4(4.000)	$e^{6/4}$ (4.482)	$In(\frac{340}{4}e)$ (1.9294)
Vitally important	8	17/3(5.667)	$e^{7/4}$ (5.755)	$In(\frac{380}{3}e)$ (2.1027)
Extremely important	9	18/2(9.000)	$e^{8/4}$ (7.390)	$In(\frac{400}{2}e)$ (2.3010)

In order to verify the accuracy of the scaling method, we compare the scaling method from the memory, scale uniformity, weight isotony, weight fitting and the judgment consistency etc. firstly, we give the judgment matrix.

Table 5. Judgment Matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9
A1	1	0.8390	0.7395	0.6679	0.6109	0.5624	0.6183	0.4755	0.4346
A2	1.1919	1	0.8390	0.7395	0.6679	0.6109	0.5624	0.6183	0.4755
A3	1.3522	1.1919	1	0.8390	0.7395	0.6679	0.6109	0.5624	0.6183
A4	1.4973	1.3522	1.1919	1	0.8390	0.7395	0.6679	0.6109	0.5624
A5	1.6368	1.4973	1.3522	1.1919	1	0.8390	0.7395	0.6679	0.6109
A6	1.7782	1.6368	1.4973	1.3522	1.1919	1	0.8390	0.7395	0.6679
A7	1.9294	1.7782	1.6368	1.4973	1.3522	1.1919	1	0.8390	0.7395
A8	2.1027	1.9294	1.7782	1.6368	1.4973	1.3522	1.1919	1	0.8390
A9	2.3010	2.1027	1.9294	1.7782	1.6368	1.4973	1.3522	1.1919	1

Scale memory refers that the difficulty degree when we memory the scale. When we construct the judgment matrix and calculate the weight, the scale memory has a great influence on constructing the judgment matrix. From the table 5, we can see that the memory of the 1~9 scaling method is the best. The memory of other scaling methods is not good.

Then, we verify the uniformity of the scale. We use the average distance among the scaling values to test the average value b . The calculation is as follows.

$$b = \max(d/D, D/d) \tag{8}$$

$$d = \max(d_{ij}) / \min(d_{ij}), j = i+1; i = 1, 2, \cdots, 8 \tag{9}$$

$$D = \max\left(D_{ij}\right) / \min\left(D_{ij}\right), j = i+1; i = 1, 2, \cdots, 8 \quad (10)$$

$$d_{ij} = s_j - s_i, j = i+1; i = 1, 2, \cdots, 8 \quad (11)$$

$$D_{ij} = s_j / s_i, j = i+1; i = 1, 2, \cdots, 8 \quad (12)$$

Where, s_j and s_i are two adjacent scaling values in the same scale.

According to the above formula, we calculate the average value b of the scaling distance under the scaling method. The calculation results are shown in table 6.

Table 6. The Average Distance of the Scaling value in Different Scaling Methods

	1~9	10/10~8/2	$e^{0/4} \sim e^{8/4}$	$In(\frac{100}{10}e) \sim In(\frac{400}{2}e)$
d	1	15	5.757	4.211
D	1.778	1.300	1	1.103
b	1.778	11.538	5.757	3.674

From the above table, we can know that the uniformity of 1~9 scaling method and $In(\frac{100}{10}e) \sim In(\frac{400}{2}e)$ scaling method is better. The uniformity of $e^{0/4} \sim e^{8/4}$ scaling method is good. The uniformity of 10/10~8/2 scaling method is bad.

Then, we test the fitting of the scaling weights. The fitting of the scaling weights refers that the scaling value of one scale uses this scaling method to calculate weights w. And we use this scaling method to weight directly. Then, we get the fitting degree of the weight w'. We use the following formula to describe the fitting degree. If $\overline{\Delta w}$ is smaller, it refers that the weight fitting of this scaling method is better. The expression of $\overline{\Delta w}$ is as follows.

$$\overline{\Delta w} = \left(\left|w_1 - w_1'\right| + \left|w_2 - w_2'\right| + \cdots + \left|w_9 - w_9'\right|\right) / 9$$

We calculate the weighted weight of the scaling method and the results are as follows.

Table 7. The $\overline{\Delta w}$ in Different Scaling Method

Scale	1~9	10/10~ 8/2	$e^{0/4} \sim e^{8/4}$	$In(\frac{100}{10}e) \sim In(\frac{400}{2}e)$
$\overline{\Delta w}$	0.03481	0.01555	0.00001	0.00122

From the above table, we can see that $e^{0/4} \sim e^{8/4}$ scaling method and $In(\frac{100}{10}e) \sim In(\frac{400}{2}e)$ scaling method have better fitting. However, 1~9 scaling method and 10/10- 8/2 scaling method have bad fitting.

Finally, we judge the consistency of this method. When $C.R. < 0.1$, the judgment matrix is the consistent matrix. The smaller the $C.R.$ is, the better the consistency of the matrix is. When $C.R. = 0$, the judgment matrix is the consistent matrix. The calculation method of the consistent index $C.R.$ is as follows.

$$C.I. = \frac{\lambda_{\max} - n}{n-1} \quad (13)$$

$$C.R. = \frac{C.I.}{R.I.} \quad (14)$$

$R.I.$ is a constant which is given in statistical significance.

We get $C.R.$ in different scaling methods and it is shown as follows.

Table 8. $C.R.$ in Different Scaling Methods

Relevant amounts	1~9	10/10~8/2	$e^{0/4} \sim e^{8/4}$	$In(\frac{100}{10}e) \sim In(\frac{400}{2}e)$
$\lambda_{\max}$	9.40198	9.2452	8.99996	9.0120
$C.I.$	0.05025	0.00301	-0.00001	0.0015
$C.R.$	0.03484	0.00207	0.00001	0.00103

In order to compare and analyze the performances of all kinds of scaling methods, we list the comprehensive comparison table in order to understand the performance merits more intuitively.

Table 9. The Comparison of the Scaling Methods

Relevant amount	1~9	10/10~8/2	$e^{0/4} \sim e^{8/4}$	$In(\frac{100}{10}e) \sim In(\frac{400}{2}e)$
Scaling memory	Good	Poor	Poor	Poor
Scaling uniformity	Good	Poor	Poor	Good
Weight order preserving	Good	Good	Good	Good
Weight fitting	Poor	Poor	Good	Good
Consistency of judgment matrix	Poor	Poor	Good	Good

From the table we can see that the comprehensive performance of $In(\frac{100}{10}e) \sim In(\frac{400}{2}e)$ is the best. Therefore, we select $In(\frac{100}{10}e) \sim In(\frac{400}{2}e)$ scaling method as the improved fuzzy AHP scaling method.

After we determine to use $In(\frac{100}{10}e) \sim In(\frac{400}{2}e)$ scaling method as the method in this paper, we use fuzzy integrated evaluation method to evaluate comprehensively. The steps are as follows.

Firstly, we establish the index system and the comment sets $V = \{V_1, V_2, \cdots, V_j\}; (j = 1, 2, \cdots, m)$.

Secondly, we construct the two level index judgment matrix and we derive the maximum eigenvalue and its eigenvector.

Thirdly, repeating the step (2), we calculate the weight of the different index.

Fourthly, according to the comment sets, we obtain the third index evaluation matrix. We multiply the evaluation matrix and the comprehensive weight of the third index. Then we get the evaluated results of the second index. We make the results as the input of the second indexes in order to make the first index evaluation result. At last, we get the index evaluation result.

Finally, we multiply the comment sets and the index evaluation result to get the final score of the evaluation score.

4. Experiment Analysis

We evaluate the safety risk for the food supply chain. Firstly, we use the new scale to calculate the weight of each index. The weight of the index is shown in table 10.

Table 10. The Safety Risk Index Weight of the Food Supply Chain

Index	Weight
Unqualified product quality	0.25
Delayed supply time	0.16
Insufficient inventory control ability	0.21
Insufficient production capacity	0.09
Equipment risks	0.10
Poor sanitation	0.13
Poor quality of employees	0.06
Natural disasters	0.27
Infectious diseases	0.13
Risks of policies and regulations	0.08
Improved quality standards	0.20
Serious fakes	0.32
Food spoilage during the transit	0.35
Interrupt logistics	0.10
Lost food	0.15
Food spoilage during machining process	0.20
Food spoilage during sales process	0.20
Uncertain demands	0.28
In short supply	0.04
Price fluctuations	0.14
Malignant competition	0.12
Consumers’ cognition	0.05
Unreasonable sales price	0.17
Unsmooth marketing channel	0.20
Unsmooth information communication	0.40
Bullwhip effect	0.60
Unreasonable profit distribution	0.30
Partner selection	0.10
Partner management	0.10
Distrust among the enterprises	0.15
Enterprise cultural differences	0.13
Different enterprise strategic targets	0.22
Unsound food safety supervision mechanism	0.33
Imperfect food quality management system	0.33
Internal personnel supervision responsibility risk	0.33
Reputation risk	0.30
Moral risk	0.30
Structural risk	0.10
Credit risk	0.20
Technical risk	0.10

After getting the index weights, we need to score the safety risk for the food supply chain. We take the internal risk as an example and get the table 11.

Table 11. The Score of Each Indexes

The first index layer	The second index layer	The third index layer	Comment	Score
The food supply chain safety risk evaluation Indexes	Internal risk	Unqualified product quality	excellent	0
			fine	0
			good	1
			qualified	0
			poor	0
		Delayed supply time	excellent	0
			fine	0.8
			good	0.2
			qualified	0
			poor	0
		Insufficient inventory control ability	excellent	0
			fine	0.6
			good	0.4
			qualified	0
			poor	0
		Insufficient production capacity	excellent	0
			fine	1
			good	0
			qualified	0
			poor	0
		Equipment risks	excellent	0
			fine	0.8
			good	0.2
			qualified	0
			poor	0
		Poor sanitation	excellent	0
			fine	0.2
			good	0.6
			qualified	0.2
			poor	0
		Poor quality of employees	excellent	0
			fine	0.2
			good	0.8
			qualified	0
			poor	0

Then, we define the comment sets as follows.

$$V = \{V_1, V_2, V_3, V_4, V_5\} = \{excellent,\ fine,\ good,\ pass,\ poor\} = \{90, 80, 70, 60, 50\}$$

We input the third index scores and the last evaluation index is as follows.

$$S = \begin{bmatrix} 0.0281 & 0.8390 & 0.1283 & 0.0046 & 0 \end{bmatrix} \cdot (90, 80, 70, 60, 50)^T$$
$$= 81.39$$

From the experiment analysis, we can see that the results of AHP fuzzy integrated evaluation method with a new scale are correct. Therefore, the method is scientific, operability and efficient. AHP fuzzy integrated evaluation method with a new scale can apply to other fields and it has the strong adaptation.

5. Conclusion

Food is the most basic consumer goods. Food safety is a hot topic that people discuss. How to identify the various risks in the food supply chain, evaluate the risks and control these risks is a problem what each supply chain manager faces. This paper uses AHP fuzzy integrated evaluation method with a new scale to evaluate the safety risk of the food supply chain. The main works of this paper are as follows. Firstly, we introduce the AHP method and the food safety evaluation. Secondly, we establish the safety risk evaluation system of food supply chain. Thirdly, aiming at the shortcomings of the traditional AHP scaling method, this paper proposes $In(\frac{100}{10}e) \sim In(\frac{400}{2}e)$ scaling method and AHP fuzzy integrated evaluation method with a new scale. Finally, we apply AHP fuzzy integrated evaluation method with a new scale to evaluate the safety risk of the food supply chain. The research content of this paper provides reference for the protection of the food supply chain.

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