

Food Safety Risk Assessment in Whole Food Supply Chain Based on Catastrophe Model

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Abstract: The objective of this study was to develop a food safety-risk assessment model for the whole food supply chain. In order to assess whole risk of food safety, this study designed the evaluation index system from the perspective of the food chain, which considered agricultural production, food processing and food consumption three stages. Based on catastrophe model and stability theory, the risk of agricultural production, food processing and food consumption is evaluated. This study got the value of total food safety risk in China and from it the weak stage of food supply chain could be found out. The results were shown that the risk of agricultural production and food processing was on the decline, but the risk of food consumption fluctuated more in recent years. Therefore, this study put forward some advices, such as establishing a single department management mode; improving the construction of food safety related laws and regulations system; and strengthening the support system of food security technology.

Keywords: Catastrophe model, food safety, food supply chain, risk assessment

INTRODUCTION

In recent years, food safety issues frequently occurred all over the world, such as the BSE crisis in Europe, melamine in milk powder in China and dioxin pollution in Belgium (Liu *et al.*, 2013). From 2005 to 2009, there were more than 20 food safety breakdown clusters in the UK/EU, including norovirus in frozen raspberries; *Escherichia coli* O157 in lettuce; *Salmonella* Sefternberg in fresh basil and so on Soon *et al.* (2013). These food safety emergencies not only pose a threat to people's health, but also cause a huge economic loss to the consumers and the food industry (Rohr *et al.*, 2005). Food safety problems have become a hot issue of global concern.

Risk analysis, which has gained international acceptance as the most effective tool for managing food safety issues, can provide a systematic approach for improving food control systems for the production of safe food and for facing the increasing incidence of food borne illnesses (FAO/WHO, 1995, 2006). Risk assessment is one of the important components of risk analysis, which can be defined as a structured scientific process for estimating the probability and severity of risk with attendant uncertainty (Garrido *et al.*, 2010; Van Schothorst, 2002). There are many research results about food safety risk assessment, which could be divide two aspects. One aspect of research focus on the assessment model, including comprehensive index methods, overall condition assessment methods, Analytic Hierarchy Process (AHP) and fuzzy evaluation

methods (Du and Han, 2006; Liang and Cao, 2007; Liu and Chen, 2008). Another aspect of research focus on the evaluation index system, most literatures constructing a system from the food security of the state, such as macro regulation index, infrastructure projects, the overall status indicators and so on Hua and Liu (2008). From the food production chain of internal and external, Gijs and Hans (2009) arvin analyse the influence factors of food hazards and then put forward some advices to the index design.

However, the factors affecting food security involve in food production, processing and storage for all aspects of sales. In order to accurately assess the risk of food safety, it is important to consider the issue from the entire food supply chain. The recent Shiga-toxin producing *E. coli* O14:H4 outbreak in Germany has demonstrated the complexity of the modern produce supply chain (Soon *et al.*, 2013). Therefore, this study, based on the characteristics of food safety emergencies, uses the catastrophe model to comprehensively evaluate the food safety risk of the whole food supply chain, which includes processing of agricultural products, food production and food consumption store three stages.

MATERIALS AND METHODS

Catastrophe model: Catastrophe theory originated in the France scientist named Tom. Natural phenomenon always behaves as a "contradiction" process which is from the gradual change to mutation and then from

Table 1: Three commonly used catastrophe model

Catastrophe model	The number of control variables	Mutation function
Cusp catastrophe	2	$f(x) = x^4 + ax^2 + bx$
Swallowtail Catastrophe	3	$f(x) = \frac{1}{5}x^5 + \frac{1}{3}ax^3 + \frac{1}{2}bx^2 + cx$
Butter-fly catastrophe	4	$f(x) = \frac{1}{6}x^6 + \frac{1}{4}ax^4 + \frac{1}{3}bx^3 + \frac{1}{2}cx^2 + dx$

Table 2: Food safety risk assessment index system

Indicator of the target layer	Indicators of the criteria layer	Indicators of the specific layer
Degree of food safety risk (A)	Production process of agricultural products (B ₁)	Veterinary drug residue sampling percent of pass % (c ₁₁) Vegetable pesticide residue sampling percent of pass % (c ₁₂) Aquatic product sampling percent of pass % (c ₁₃) Raw meat sampling percent of pass % (c ₁₄)
	Process of food production (B ₂)	Overall qualified rate of food sanitation % (c ₂₁) Qualified rate of food additives and chemical residues % (c ₂₂) Qualified rate of food microorganism % (c ₂₃)
	Process of food consumption (B ₃)	Regular health qualification rate of food business units % (c ₃₁) The number of food poisoning incidents (c ₃₂) The number of food poisoning personnel (c ₃₃) The number of death because of food poisoning (c ₃₄)

Table 3: The original data of food safety risk assessment index

		Year									
		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Food Production Process	Index										
Production process of agricultural products (B ₁)	$x_{c_{11}}$	90.5	92.4	95.1	95.8	97.2	97.8	98.6	99.9	99	99.95
	$x_{c_{12}}$	83.6	82.7	91	91.5	93	95.3	96.3	96.4	96.8	97.4
	$x_{c_{13}}$	83	87	95	97.5	98.8	99.8	94.7	96.7	96.7	96.8
	$x_{c_{14}}$	94.2	97.8	96	97.2	98.5	98.4	98.6	99.5	99.6	99.6
Food production (B ₂)	$x_{c_{21}}$	89.5	90.5	89.8	87.5	90.8	88.3	91.6	91.57	93.27	95.27
	$x_{c_{22}}$	88.91	90.49	91.01	93.62	89.2	88.23	91.5	96.13	97.22	98.23
	$x_{c_{23}}$	79.05	84.97	85.59	86.58	90.16	80.9	89.1	98.2	98.13	98.57
Food consumption (B ₃)	$x_{c_{31}}$	89.1	90	88.3	88.6	86.2	91.1	91.7	90.4	91.7	99.4
	$x_{c_{32}}$	7127	12876	14000	9021	18063	13280	13095	11007	7383	8324
	$x_{c_{33}}$	138	323	283	235	196	258	154	181	184	137
	$x_{c_{34}}$	128	379	397	256	589	506	431	271	220	189

mutation to gradual change. Tom set up catastrophe model to comprehensively evaluate mutation phenomenon. Catastrophe model firstly decomposes the target which we need to evaluate and then uses fuzzy mathematics to produce mutations fuzzy potential function. According to derivate formula, the total mutations fuzzy potential function can be calculated, so the comprehensive evaluation result is obtained. Tom divided these phenomena of mutation into seven kinds: folding catastrophe, butterfly catastrophe, cusp catastrophe, swallowtail catastrophe, the elliptic umbilic catastrophe, hyperbolic umbilic catastrophe and parabolic umbilic catastrophe. In using catastrophe model to evaluate the problems in sociology and economics, the most commonly used for the cusp catastrophe model, swallowtail catastrophe model and butterfly catastrophe model, as showed in Table 1.

In Table 1, the mutation function f(x) represents the potential function of the state variables x. The letters a, b, c, d are coefficients of state variable, which represent the control amount of state variables. We

respectively calculate first-order and second-order derivatives of state variables x in the potential function and then get normalization equation of three catastrophe modeles as follows:

Normalization equation of Cusp Catastrophe:

$$x_a = \sqrt{a}, x_b = \sqrt[3]{b} \tag{1}$$

Normalization equation of Swallowtail Catastrophe:

$$x_a = \sqrt{a}, x_b = \sqrt[3]{b}, x_c = \sqrt[4]{c} \tag{2}$$

Normalization equation of Butter-fly Catastrophe:

$$x_a = \sqrt{a}, x_b = \sqrt[3]{b}, x_c = \sqrt[4]{c}, x_d = \sqrt[5]{d} \tag{3}$$

In the above equation, x_a, x_b, x_c, x_d represent the values of x corresponding to a, b, c, d. The degree of importance of each control variable set as $a > b > c > d$. This method eliminates the subjectivity of the researchers given the "weight" of indicators.

Food safety risk assessment index system: Because of the complexity of the food safety problems, the key issue in risk assessment is to consider all the links of the complex process of food production and distribution until they reach the consumer. This ranges from harvesting, storage, processing, packaging, sale and consumption. But the existed researches about food safety risk assessment mainly aimed at the intermediate stages of the food chain and the moment of food processing and did not consider the beginning and the end of the chain (Dome'nech *et al.*, 2007). In this study, the whole food supply chain is considered, which includes production process of agricultural products, food processing and food consumption.

At the same time, we combine the principles of designing index, such as comprehensiveness, sensitivity, practicability and maneuverability and so on, to set up the food safety risk assessment index system, as showed in Table 2.

Data: Using catastrophe model, based on the production chain of agricultural product, food processing, food consumption and other aspects of the process, this study focus on Chinese food security situation to analyse in recent years. Index data are mainly used annual data of 2002-2012, which come from the "China Health Statistics Yearbook", "China Statistical Yearbook", "China Food Industry Yearbook" and the relevant literature, as showed in Table 3.

RESULTS AND DISCUSSION

Agricultural production, food processing and food consumption these three processes are corresponding to butterflies catastrophe, swallowtail catastrophe and butterflies catastrophe and these three sub-systems are complementary relationship. The first step of calculation is to standardize the original data, using linear scaling transformation method to transform the original data between 0 and 1.

If evaluation index is positive, the correction equation is as follows:

$$y_{ij} = (\max P_{ij} - P_{ij}) / (\max P_{ij} - \min P_{ij}) \quad (4)$$

If the index for reverse index, the correction equation is as follows:

$$y_{ij} = (P_{ij} - \min P_{ij}) / (\max P_{ij} - \min P_{ij}) \quad (5)$$

After standardization, using the above equation (1), (2), (3), the standard data can be calculated by the recursive quantification. According to the principle of "complementary", we calculate the mutations function values, that is, the risk degree of three food production processes. These three sub-processes are complementary relationship. Therefore, we use the normalization formula to integrate the different periods of food safety risk assessment until the top "total food safety risks". The value of total risk degree is showed in Table 4.

The calculated value of food safety risk is between 0~1. The value is close to 1 that means the vulnerability of food safety is higher and the degree of food safety is lower. The value is close to 0 indicates the risk degree and vulnerable degree are lower and the degree of safety is higher. If the value of food safety risk degree is 0, it indicates that there should be an optimization of the food safety system. Otherwise, it expresses a food safety system is very fragile, almost always in crisis.

From Table 4, we can see the different change trend of food safety risk in three food supply processes. The risk of agricultural production process was at the highest point in 2002 and then declined year by year, but in 2008, the risk went up a little. And the trend of risk in food processing is the same to agricultural production process, it declined from 2002 to 2006, but rose to 0.974 in 2007 and then declined year by year to the lowest point in 2011. Compared with agricultural production process and food processing, the risk of food consumption process irregularly changed in this ten years. It has experienced "up-down-up-down" changes in the process. So there are no clear trends of risk in food consumption process we can conclude. The value of food safety risk in food consumption was the highest in 2006 and the lowest in 2011.

According to the total risk evaluation results show that, food safety risk in general is declined from 2002 to 2011. As showed in Table 4, the overall food safety risk in China was the highest in 2003 and the lowest in 2011. It means that the constant improvement of

Table 4: The assessment results of food safety risk

Index		Year									
		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
The risk value of different process	x_{B_1}	0.9948	0.9077	0.7819	0.7147	0.6074	0.4350	0.5638	0.3967	0.3292	0.1625
	x_{B_2}	0.9462	0.8718	0.8797	0.8859	0.8451	0.9742	0.7994	0.5518	0.4535	0.1259
	x_{B_3}	0.2885	0.8841	0.9032	0.7720	0.9376	0.8694	0.7626	0.7556	0.6208	0.2864
The total risk value of food safety	x_A	0.9040	0.9592	0.9391	0.9144	0.9029	0.8722	0.8712	0.7941	0.7432	0.4728

Chinese food safety system in recent years has achieved some success, but the situation is not stable, still need to enhance the level of Chinese food safety supervision and management.

CONCLUSION

In this study, we establish food safety risk assessment system for the entire food supply chain. Using the catastrophe model, combining with statistical data in China, this study comprehensively evaluates Chinese food safety risk within ten years. The evaluation results are basically consistent with China's realities. Judging from the value of food safety risk, the overall food safety in China is in a positive situation, the risks of agricultural production and food processing have a steady decline trend. But the risk of food consumption is unstable, change greatly in these ten years. It is necessary to still pay attention to food safety problems. Therefore, this study puts forward the following suggestions to strengthen food safety risk management in China.

First, based on the whole food supply chain, establishing a single food safety supervision and management department to implement whole-process supervision functions. Currently, the supervision of food safety at different stages is implemented by different departments in China. This management mechanism is easy to cause unclear responsibilities and management confusion. Therefore, food safety supervision in our country should be adjusted to a single department management mode which has a clear allocation of power and responsibility.

Second, improving the construction of food safety related laws and regulations system as soon as possible. China should improve food safety related legal content, such as adding some detection index of food safety to the relevant laws and regulations, updating related legal provisions to increase punishment level for offense and irregularities, especially in the restaurants and other places of food consumption.

Finally, strengthening the support system of food security technology. China should gradually improve the food safety standard system based on the industrial chain and speed up China's food safety standards system in line with international standards. Based on the national food safety inspection system, our country can improve the food safety inspection technology in each stage of food supply.

ACKNOWLEDGMENT

This research is financially supported by National Natural Science Foundation of China (Grant No. 70973007).

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