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Research on Food Security Early Warning System Based on Fuzzy Control

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Abstract: According to the particularity of China's food security, this study constructs a food security warning indicator based on fuzzy control. The new method uses a combination of fuzzy theory and analytic hierarchy process. Firstly, determine the indicators that affect food security and their weights, and then analyze the data of each indicator to delimit the warning threshold. Secondly, generate weights based on the indicator data and the corresponding warning threshold Basic probability assignment function. Finally, the early warning degree is obtained. At the same time, the validity of this method was verified by using the statistical yearbook data of 2009-2018. The research results show that the current level of food security in China is safe and stable, and the fuzzy control method proposed in this article can objectively reflect the food security alertness.
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1. Introduction

Food security has a bearing on the people's livelihood. In 1974, FAO first proposed the concept of food security (Gustavsson J et al.,2011). In 2012, the 18th National Congress referred to food security, energy security, and financial security as the three major economic security. The white paper on "Food Security in China" in 2019 regarded the food security as an important foundation of national security, and put forward a new concept of food security "to ensure basic self-sufficiency in grains and absolute security in rations." General Secretary Xi Jinping pointed out that 2019 is the key year for the first century-long goal of building a well-off society in an all-round way. Doing a good food security work is effective to effectively meet various risks and challenges, ensure sustainable and healthy economic development, and stabilize the overall social stability has great significance. Therefore, ensuring the security and stability of the national food situation involves the overall situation of economic development, national independence, and social stability, and it is also an important foundation for building a community of human destiny.

Since the establishment of China, under the leadership of the Communist Party, the grain possession per capita surpassed the world average, the self-sufficiency rate of grains has exceeded 95%, and its contribution to global poverty reduction has exceeded 70%. The current situation of China's food security is generally stable, and the relationship between food supply and demand has basically achieved balance, but this amount balance is a "overall balance"(Yuan Lihuang,2014). From the perspective of per capita level, China has a large population and a large demand for food; from the perspective of geographical environment, China has many mountains and deserts, and its available arable land resources are limited. 21% of the world's population is fed by 7% of the world's arable land, so China's food security "cannot be said to have passed lightly." At the same time, it was emphasized in the No. 1 document of 2019 that China's current economic operation is generally stable, but the external environment is complex and severe, the economy is facing downward pressure, and risks and difficulties have increased significantly. If there is a problem with the supply of food and important agricultural products, it will not only lead to rising prices, bring economic development into a passive situation of downward growth and rising prices, but also affect social stability. Therefore, it is important and urgent to further deepen agricultural supply-side reform, build an effective food early-warning monitoring system, reflect real-time changes in food security, and set up primary barriers to avoid food security risks and avoid the development of systemic risks.

2. Literature Review

The food security early warning system is a system that uses food security indicators and early warning theories to scientifically assess the current status and development trend of food security, predict changes in food security risks, and issue security alerts in a timely manner. As early as 1975, FAO established the world's earliest agricultural early warning system, the "Global Information and Early Warning System (on Food and Agriculture) "On this basis, as the country with the largest food consumption, China had also started research on the early warning system for food security. In 1989, the State Statistics Bureau published a research report on "Index System for Macroscopic Early-warning and Monitoring in Macroeconomy". After the first National Conference on Agricultural Early Warning Systems in 1991, various provinces (autonomous regions, municipalities) carried out dynamic tracking of agricultural conditions, established an agricultural information network and gradually explored the establishment of agricultural early warning systems and economic early warning systems in the region. At present, domestic and foreign scholars have developed various methods for measuring food security, which are mainly divided into three categories:

2.1 Indicator early warning model

In early research, food security issues were mainly measured through indicators. Gu Huanzhang et al. (1995) constructed an early warning system for grain supply and demand through the analysis of grain prices, and at the same time evaluated grain production and distribution through the difference between the grain purchase price and the market price. Although price analysis can reflect market food security issues, but it is difficult for a single indicator to judge the overall food security issue. Zhu Ze (1997) started a multi-indicator analysis based on the original index model. After considering the fluctuation of total grain output, self-sufficiency rate, reserve level, and safety factor, he built a multi-indicator early-warning analysis model to judge from a more holistic perspective Food security issues. However, due to the influence of objective factors, the models studied at that time were all linear models and did not consider the interrelationship between different factors.

2.2 Multi-factor fusion early warning model

Lu Xinye et al. (2005) considered the correlation between different indicators in the process of studying food security, chose to weight multiple indicators to obtain a comprehensive index, and built a multidimensional autoregressive model (VAR), which gave early warning tips by analyzing the results of the model. Men Kepei et al. (2009) explained food security through weighted production, consumption, and bad seed indicators, combined with the AHP-GRA method to empirically explain China's food security level from 2001 to 2007, and finally calculated standardized parameter indicators as early warning basis. The theoretical foundations of the above two research methods are relatively weak, and mainly rely on empirical data to judge the tension of food security. Su Xiaoyan et al. (2011) also considered the weighted composite index, combined with DS evidence theory and AHP theory, and combined the 11 indicators by weighting to generate a basic probability assignment function and reflect the current food security risk according to the function result. The construction of this model has a certain theoretical basis, but it still lacks the support of mathematical derivation.

2.3 Modern early warning model

Based on previous research, scholars analyzed food security issues qualitatively and quantitatively by incorporating different theoretical models and mathematical deductions. Wang Hejun et al. (2011) used fuzzy least squares vector machine to derive the optimal solution of the objective function and the final output model. After determining the membership function and membership of the vector machine, he optimized the parameters of the vector machine through the chaotic genetic algorithm, and finally obtains different level of food security, and made the final food warning judgment based on this. Deng Yong et al. (2010) in the design process model, first fitted the final function equation through fuzzy set theory and DSE theory, then calculated the values of different attributes according to the function, and combined the different values according to the Demspter rule, and finally made a comprehensive judgment. Lei Xunping et al. (2012) combined extension theory and entropy theory to calculate the correlation degree of food security using a composite index of different indicators, and gave different degrees of membership according to the calculated value of the correlation degree. Finally, corresponding early warning levels were given for different results.

In summary, although a large number of studies have calculated food security, but the food security early warning system is a complex system that involves many factors, both quantitative and qualitative data. And there is no uniform standard for the determination of various factors and the division of warning limits, so the uncertainty is greater. It is precisely because of these problems that it is difficult to establish a reasonable mathematical evaluation model. However, due to the uncertainty of the food security early warning process, it is more reasonable to construct a food security early warning model under the framework of fuzzy set theory and Dempster-Shafer evidence theory (Wang Hejun et al., 2011). At the same time, as a method of uncertain reasoning, fuzzy theory provides a natural and powerful method for the expression and synthesis of uncertain information, and has been widely used in information fusion and decision analysis (Su Xiaoyan et al.,2011).

Therefore, based on the fuzzy evidence early-warning model adopted by Deng Yong et al. (2010), this study makes appropriate amendments, scientifically analyzes and evaluates selected food security-related indicators, and uses the statistical yearbook data from 2009 to 2018, in order to make early warning analysis of China's food security situation.

3. Construction of Early Warning Indicators for Food Security

3.1 Determination of indicators

To carry out food security early warning, we must first construct early warning indicators that can reflect food security. There are many factors affecting food security. In the process of selecting factor indicators, this article follows the principles of representativeness, comprehensiveness, and operability, refers to existing research indicators, and combines the national food security goals of China's Food Security. And the same time considering the situation of food supply, demand, reserves, circulation four aspects. By using the AHP to construct a food security early warning indicator system. The nine indicators selected are shown in Fig.1.

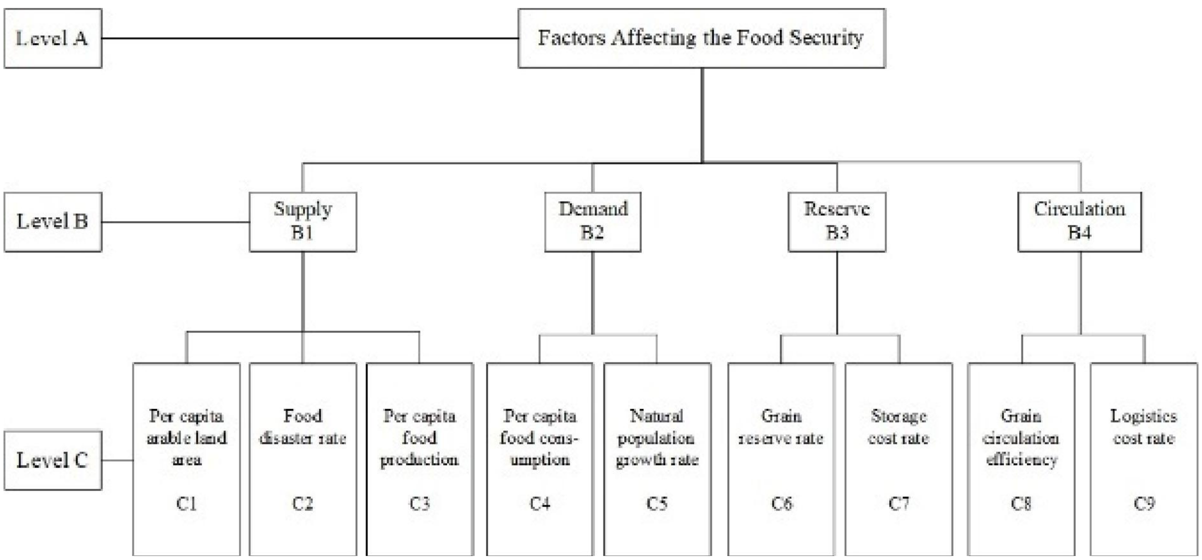

Fig. 1. Selection of early warning indicators for food security

3.1.1 Supply side

Per capita arable land area: The amount of stock land resources will have a restrictive effect on food production. Per capita arable land area reflects the unit's potential food production capacity. In general, the more arable land per capita, the stronger the unit's potential food production capacity, and the higher the food security.

Food disaster rate: The actual food output will be affected by many factors such as climate and moisture. Therefore, the grain disaster rate will reduce the current food output. Generally speaking, the higher the rate of food disasters, the lower the actual food output, and the lower the food security.

Per Capita food Production: Actual grain output reflects the margin of food security in the region. Per capita food production shows the output unit food supply index. Obviously, the more food production per capita, the higher the food security.

3.1.2 Demand side

Per capita food consumption: There are differences in individual food consumption, but per capita consumption can well indicate the level of regional food consumption. The higher the per capita food consumption, the higher the food risk factor in the region and the lower the food security.

Natural population growth rate: Population growth will exert pressure on all natural resources, and food resources are no exception. The faster the natural population growth, the greater the food consumption. An increase in a country's natural population growth rate will reduce food security.

3.1.3 Reserves side

Grain reserve rate: Grain reserve is the amount of grain reserve carried forward at the beginning of a new crop year, and is mainly used as a means of protecting the poor harvest of grain. Increasing the food reserve rate can reduce the degree of food risk and increase the level of food security.

Storage cost rate: During the food storage process, the actual storage volume of grain will be reduced due to costs such as storage rent and grain damage. Generally speaking, the higher the cost of food storage, the higher the risk of storage and the lower the food security.

3.1.4 Circulation side

Grain circulation efficiency: In the process of interregional grain allocation, there will be differences in the efficiency of grain circulation due to the differences in logistics equipment, road facilities and the distance between grain silos. In general, the improvement of the efficiency of food circulation will increase the level of food security in a country.

Logistics cost rate: During the transportation of grain, there will be leakage, highway tolls, and transportation vehicle costs, which reduces the actual circulation output. Thus, increasing the logistics cost rate will reduce the amount of food flowing into the market and also reduce the level of food security.

The data of the above indicators from 2009 to 2018 are shown in Table 1.

Table 1: Food security indicator data from 2009 to 2018

Years	C1	C2	C3	C4	C5	C6	C7	C8	C9
2009	809	0.173	24.50	137.43	0.497	0.33	0.026	88.1	0.047
2010	802	0.151	24.27	139.38	0.483	0.34	0.028	89.5	0.049
2011	792	0.102	23.61	143.98	0.479	0.32	0.025	92.1	0.052
2012	784	0.094	23.24	146.96	0.487	0.34	0.032	95.5	0.055
2013	779	0.117	23.09	148.70	0.494	0.35	0.034	103.4	0.048
2014	775	0.103	23.22	141.01	0.506	0.41	0.028	100.2	0.060
2015	868	0.091	23.31	134.50	0.508	0.49	0.040	98.5	0.057
2016	862	0.101	23.12	132.80	0.541	0.52	0.036	100.3	0.052
2017	866	0.068	23.06	130.12	0.559	0.58	0.032	99.2	0.059
2018	870	0.078	23.08	130.24	0.456	0.62	0.035	103.4	0.055

3.2 Division of warning limits

Determining the police limit is to determine the boundary with or without the police, which is the basis for determining the police degree. There are two types of methods for determining the threshold: statistical methods and systematic methods. The statistical methods are further divided into the majority principle, half-number principle, mean principle, minority principle, and mode principle (Mei Fangquan et al., 2006). This study mainly uses the principle of averaging in statistical methods to divide warning limits, and divides warning limits into four areas: no warning, light warning, moderate warning, and heavy warning. The specific process is divided into the following 3 steps:

3.2.1 Determine the directionality of the indicator

The division of warning limits involves the directionality of indicators. Although the positive and negative values of any indicator exceed a certain limit, it is an unsafe performance, but under normal circumstances, it can be considered that the more per capita arable land area, per capita food production, grain circulation efficiency, and grain reserve rate are the better, so they are positive indicators. However, food disaster rate, per capita food consumption, natural population growth rate, storage cost rate, and logistics cost rate are just the opposite, which are negative indicators. The directionality of the nine indicators is shown in Table 2.

Table 2: Directionality of food security indicators

Food security indicators	direction	Food security indicators	direction
C1	(+)	C6	(+)
C2	(-)	C7	(-)
C3	(+)	C8	(+)
C4	(-)	C9	(-)
C5	(-)		

3.2.2 Processing of indicator data

The above-mentioned directional index data is processed, and calculate the maximum value max, minimum value and deviation respectively, as shown in Table 3.

Table 3: Food security indicator data range

Food security indicators	C1	C2	C3	C4	C5	C6	C7	C8	C9
max	870.00	0.17	24.50	148.70	0.56	0.62	0.04	103.40	0.06
min	775.00	0.07	23.06	130.12	0.46	0.32	0.03	88.10	0.05
Δ	95.00	0.11	1.44	18.58	0.10	0.30	0.02	15.30	0.01
p	23.75	0.03	0.36	4.65	0.03	0.08	0.00	3.83	0.00
Min+p	798.75	0.09	23.42	134.77	0.48	0.40	0.03	91.93	0.05
Min+2p	822.50	0.12	23.78	139.41	0.51	0.47	0.03	95.75	0.05
Min+3p	846.25	0.15	24.14	144.06	0.53	0.55	0.04	99.58	0.06

3.2.3 Index warning limit division

The results of the classification of the six indicators are shown in Table 4.

Table 4: Alarm limit classification of index data

Variable type	Input variable			
	No warning	Light warning	Moderate warning	Heavy warning
C1	846.3,870	822.5,846.3	798.8,822.50	775,798.8
C2	0.07,0.09	0.09,0.12	0.12,0.15	0.15,0.17
C3	24.2,24.5	23.7,24.2	23.4,23.7	23.1,23.4
C4	130.1,132.8	132.8,139.4	139.4,144.1	144.1,148.7
C5	0.46,0.48	0.48,0.51	0.51,0.53	0.53,0.56
C6	0.55,0.62	0.47,0.55	0.4,0.47	0.32,0.4
C7	0.025,0.033	0.029,0.033	0.033,0.036	0.036,0.04
C8	99.58,103.4	95.75,99.58	91.93,95.75	88.1,91.93
C9	0.047,0.05	0.05,0.054	0.054,0.057	0.057,0.06
Food security factor	-1.5，-1.235，-0.97	-0.97，-0.955 -0.94	-0.94，-0.625，-0.31	-0.31，0.01，0.33

4. Construction of Early Warning System Based on Fuzzy Control

4.1 Mamdani fuzzy reasoning system

Mamdani fuzzy reasoning is a system that realizes the transparent identification of complex nonlinear problems on the premise of a series of inference rules. Expert experience mechanism gives more operability to the input data space. Its basic structure consists of 4 parts:

Fuzzy rule base. Several "if-then" rules with human intervention.

Blur generator. Use the membership function to map each input data space to an appropriate value interval.

Reasoning mechanism. Solve according to preset rules and objective facts.

Defuzzifier. Convert the membership function into an output value. The structure is shown in Fig.2.

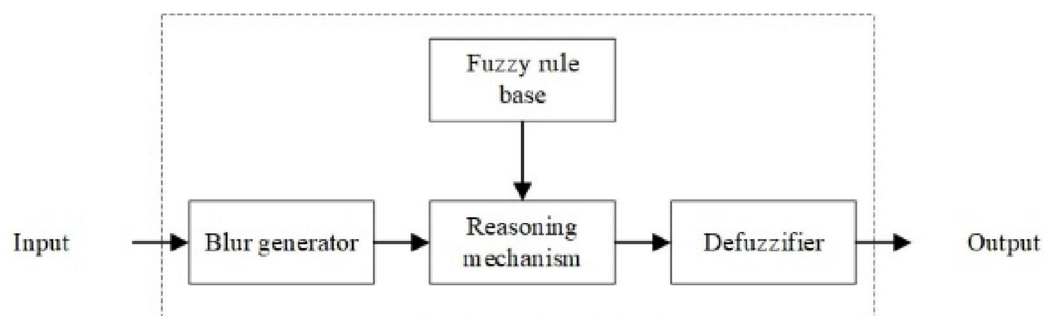

Fig.2. Fuzzy inference system

4.2 The fuzzification process

4.2.1 Fuzzy variables and membership functions

In the food security evaluation, the input variables {C1, C2, C3, C4, C5, C6, C7, C8, C9} and the output variable {F} are divided into four levels. The membership function takes a triangular shape to represent. Take the per capita arable land area C1 and output variable F as examples:

$$\mu_{e_j}(z) = T_{r_i}\left(z;\ a_{e_j};\ b_{e_j};\ C_{e_j}\right) = \begin{cases} 0 & z < a_{e_j} \\ \dfrac{z - a_{e_j}}{b_{e_j} - a_{e_j}} & a_{e_j} \le z \le b_{e_j} \\ \dfrac{C_{e_j} - z}{C_{e_j} - b_{e_j}} & b_{e_j} \le z \le c_{e_j} \\ 0 & c_{e_j} \le z \end{cases}$$

In the formula, is the j-th membership of the i-th index; z is the output variable; are the shapes of the membership of the output results Parameter; i=1,2,...9; j=1,2,3,4; e=1.

4.2.2 Fuzzy rule base

The fuzzy rule base consists of "if-then" rules. Since fuzzy inference classification must consider each input variable at the same time, the "and" operator is generally used. The input membership of the food security early warning model in this paper has rules:

$$if\left(C1 = \mu_{e_j}\right) and \left(C2 = \mu_{e_j}\right) and \left(C3 = \mu_{e_j}\right) and \left(C4 = \mu_{e_j}\right) and \left(C5 = \mu_{e_j}\right) and \left(C6 = \mu_{e_j}\right) and \left(C7 = \mu_{e_j}\right) and \left(C8 = \mu_{e_j}\right) and \left(C9 = \mu_{e_j}\right) then,\ R_k = \mu_{e_k}\left(z;\ a_{e_k};\ b_{e_k};\ C_{e_k}\right)$$

In the formula, is the result of the k-th rule; k = 1, 2, 3, 4.

4.3 Aggregation and defuzzification of membership functions

The aggregation process of membership function is based on truncation method weighting, combining the output functions corresponding to each rule into a single function to represent the final output variable. Use the "OR" operator to take the maximum:

=1,2,...,

In the formula, is the membership function after aggregation; is the membership function after weighting using truncation method; k is the number of rules.

The defuzzification of the membership function is to map the fuzzy set of the output space as a point. This study uses the method of center of gravity (COG). The membership function is weighted according to the phase method, and the formula for calculating the center of gravity of the coverage area is:

In the formula, is the center position of the total area, which determines the evaluation level of food security; is the truncated triangle area in the membership function; is the coordinate of the center on the x axis; n is the number of areas.

4.4 Judgment result

By analyzing the data in Table 1 and combining the corresponding relations of the various thresholds in Table 4, the alertness judgment results for 2009-2018 can be obtained, as shown in Table 5.

Table 5: Warning result

Years	Alertness determined by this method
2009	Moderate warning
2010	Light warning
2011	Light warning
2012	Light warning
2013	Safety
2014	Safety
2015	Safety
2016	Safety
2017	Safety
2018	Safety

4.5 Results analysis

The reality of China's food security situation from 2009 to 2018 is as follows: after the "food crisis" in 2008, the total annual food supply was lower than consumption, resulting in insufficient supply, which caused a long period of food price increases. Therefore, the food security level is moderate warning. In 2010, the total grain output reached 10928billion, but from the perspective of supply and demand, only a slight balance can be achieved in meeting the demand. However, in 2011, the worry of inflation followed, food prices rose again, and at the same time drove a large-scale rise in food prices. Therefore, the 2010-2011 food security level of light warning is in line with reality. As the economy continues to rise steadily, the gap between food supply and demand continues to increase, and China's food security level is gradually becoming safe and stable.

5. Conclusions

This study establishes a food security early warning system based on the idea of fuzzy control. The representation of uncertain information involved in this system, the synthesis of various parameter data, and decision-making methods in uncertain environments are all key technologies of decision science in common. Applying it to the establishment of agricultural early warning models shows a strong theoretical innovation. The system uses a combination of fuzzy theory and analytic hierarchy process. Firstly, the indicators that affect food security and their weights are determined, and then the data of each indicator is analyzed to determine the threshold. Secondly, the indicator data and the corresponding threshold are weighted to generate basic probability assignment function. Finally, the warning degree is obtained. On the basis, the 2009-2018 statistical yearbook data were used to conduct early warning analysis and alertness assessment of China's food security situation. The evaluation results were basically consistent with the actual situation, indicating the effectiveness of the early warning system.

The author believes that China's food security early warning system can be improved from the following three aspects.

5.1 Establish an independent early warning organization

At present, China has not yet established a unified national food security early-warning institution. At the same time, any system needs an organizational structure to play its basic role more effectively. Therefore, China urgently needs to establish an organization centered on the Development and Reform Commission, with the grain, agricultural and price departments as its backbone, and set up branches in provinces across the country to form a vertical leadership management. At the same time, equipped with corresponding early warning system experts at all levels of institutions, the system can timely reflect and report the local food security situation. This structure can not only help the country grasp the national food market, but also regulate and control the food in different regions.

5.2 The operating principles of the early warning mechanism

The operating principles of the system will guide the operation of the entire system, among which the system principles and qualitative and quantitative principles need to be followed. The principle of the system is that food security itself is a unified system. Ensuring food security requires solving food problems in various aspects through various means. With the combination of multiple tools, food production, transportation, and storage can be unified. The qualitative and quantitative principles mainly involve two aspects. On the one hand, qualitative is to make a qualitative assessment of national and regional food security issues-whether it is safe or not, and on the other hand, to make quantitative calculations on the food gap, based on the results to formulate corresponding solutions.

5.3 Formulate the operation mode of the early warning mechanism

After having the system structure and operating principles, we need to work out the operating model of the early warning mechanism, which is divided into a market-led model and a government-led model. The author believes that China needs to establish a government-led operation mode and a market-based operation mode. The government-led model can ensure that the country considers current food security issues from a more macro perspective. At the same time, the market can be supplemented by the government to provide necessary food price information and regional supply and demand conditions for the government to control food.

Although China's grain market has chosen to develop towards marketization, but the current China's grain market is not fully mature. Building a market-based system on this basis may cause the subject to be short-sighted. In addition, the state not only needs to ensure food security, but also needs to weigh the interests of both farmers and consumers. Therefore, it is necessary to establish a system operation mode supplemented by the state as the main government.

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