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Assessment of Grain Security in China by Using the AHP and DST Methods

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ABSTRACT

China is one of the largest grain producing and consuming nations in the world and the importance of grain security to the Chinese can never be overemphasized. In this paper, we present a comprehensive early-warning model for evaluating the status of grain security in China. The model is based on the analytic hierarchy process (AHP) method and the Dempster–Shafer theory (DST). We divided the risk assessment into four stages. First, we seek risk sources and identify the indices to be used in the model. Then, we preprocess the index data to obtain the index directions and risk bounds. After that, we assign index weights via AHP method. Finally, we evaluate risk of grain security via DST method and determine the overall risk degree. An empirical analysis is conducted to demonstrate the use of the model for evaluating the status of grain security in China. The result shows that the model which conforms to the reality of China is effective and can be used as a grain security pre-warning monitoring tool.

Keywords: Analytic hierarchy process, China, Dempster-Shafer theory, Grain security, Risk assessment.

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INTRODUCTION

Grain security has always been a concern for generations and continues to be high on the global policy agenda. Grain security is not only affecting the national political security, but also is affecting economic security and social stability (Lawrence, 1997; Stephen, 2004; Gudbrand *et al.,* 2007; Wright, 2011). Grain security is the prerequisite for food security. Internationally, food security, according to the United Nations' Food and Agricultural Organization (FAO), is defined as existing when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life. The term 'food' here should include not only grains, but also other agricultural products such as meat, milk, eggs, and fruits. However, since grain security represents the basic level of food security in China, food security is generally referred to as grain security as far as official policy is concerned. And according to China's first official grain security plan, grain security is mainly about boosting grain production. The main issues of grain security that should be addressed are producing factor, consuming factor and circulating factor. The grain system

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is a complicated system which includes both qualitative factors (such as the influence of policy support, agricultural knowledge *etc*.) and quantitative factors (such as the grain production, growth rate of grain price *etc*.) (Najafian *et al.,* 2010; Lee *et al.,* 2011). New challenges to food security are proposed by climate change and the morbidity and mortality of human immunodeficiency virus/acquired immunodeficiency syndrome. As a result of the disease, adult labor will have less capacity to produce or buy food and the agricultural knowledge base will deteriorate (Rosegrant and Cline, 2003). Early-warning system on grain security is a warning system for alarm and implementation, which can be used to help the government and related organizations to make policies. The basic role of grain security early-warning system is to realize the situation of grain security wholly and warn early. As the core of an early-warning system, risk assessment can provide basic information for grain-processing industry (Twala, 2010; Ebrahimnejad, 2010).

China is one of the largest grain producing and consuming nations in the world. The importance of grain to the Chinese can never be overemphasized. The grain supply chain in China is a network structure which consists of farmers, grain-purchasing enterprises, grain processing enterprises, grain distribution enterprises, consumers, *etc.* (Hu and Wu, 2010). Grain security for China faces many long-term challenges, such as loss of cultivated land from degradation and urbanization, limited water resources, frequent natural disasters, impacts of climate change, vulnerable ecosystems, increased demand from population growth and improved standard of living, a small-scale agricultural economy, and outdated aging agricultural infrastructure, among others (Wang *et al.,* 2009). In the forum of G8 in 2008, secretary-general Hu Jintao pointed, we China paid high attention to agriculture, especially the problem of grain. We stuck at the policy of grain security, which was based on ourselves, and we were self-supported (Men *et al.,* 2009). To meet the target of the policy, investment in agriculture research, especially in the risk assessment of grain is needed. The research on this system began in the 1990s. Though the study on grain security warning started relatively late in China, there are many domestic scholars engaged in early-warning research, they have made brilliant achievements, whose research combines international risk assessment theory with the reality of China (Lin *et al.,* 2010; Su *et al.,* 2011).

The outline of agriculture early-warning is edited by Tao and Chen (1994), which explains the theoretical foundation, basic principle and risk assessment method and the early-warning system. In the study of Verburg *et al.* (2000), various components of agricultural production in China were explored in a spatially explicit way. Xu *et al.* (2006) examined the conflict that may exist between conservation and grain security in China and found that Grain for Green Project which means return farmland to forests or grassland has only a small effect on China's grain production. Chen (2007) conducted a research on soil protection and food security in the context of rapid urbanization in China. A macro–micro analysis of the impact of policy reforms in China on agricultural production is presented by Nico *et al*. (2007). Efficiency and sustainability of grain production are analyzed and compared by means of using emergy method in the study of Liu and Chen (2007). Qiu *et al*. (2009) built up a model to analyze the impacts of soil organic carbon content of croplands on crop yields in China. Simelton (2011) examined the self-sufficiency of China's domestic harvests by using agricultural production (rice, wheat, maize, tubers, soybeans, and other grains) and natural disaster data (floods and droughts) for 31 provinces in China. Each of these methods puts emphasis on just a single angle and cannot make a concise and quantitative total evaluation. Men *et al*.'s research found this deficiency and tried to improve it. Men *et al*. adopted a comprehensive warning model of grain security using the AHP-GRA method (Men *et al*., 2009). However, Men *et al*.'s model is unreasonable and invalid in some situations. According to Men *et al*.'s model, the composite index of grain security should follow a normal distribution and lay out around the mean value. However, not every index of grain security follows a normal distribution. In fact, with the social development, indices like the proportion of agriculture increasing value in GDP are smaller. Therefore, we must develop a new grain security warning method that can deal with the situation where the distribution is non-normal and can overcome the drawback of Men *et al*.'s method (Men *et al*., 2009).

In this paper, we propose a comprehensive early-warning model of grain security in China by using the AHP and DST methods. The purpose of this research is to make a concise and quantitative total evaluation of grain security in China. The model can deal with the situation where the distribution is non-normal and can overcome the drawback of Men *et al*.'s method (Men *et al*., 2009). In this paper, we divided the risk assessment into four stages: seeking risk sources, preprocessing the data, determining weights of the indices and evaluating the risk degree. In the first stage, we seek the risk sources and adopt the warning index system as explained in Men *et al*. (2009). In the second stage, we preprocess the index data to obtain the warning bounds and index directions. After that, we assign index weights via AHP. In the last stage, we use the DS theory to evaluate the risk degree based on the results of the former stages.

MATERIALS AND METHODS

Mathematical Background

The AHP Method

AHP (analytic hierarchy process), developed by Saaty (1980), is a method to determine the relative importance of a set of activities in a multi-criteria decision problem. In the literature, AHP, has been widely used for solving many complicated decision-making problems (Ramanathan, 2001; Wang *et al*., 2008). For the sake of simplicity, we briefly introduce the main steps of AHP method as follows. More details are available in (Amiri, 2010).

Step 1: Build up a hierarchy structure of the complex decision problem. A hierarchy has at least three levels: overall goal of the problem at the top, multiple criteria that define alternatives in the middle and decision alternatives at the bottom (Albayrak, 2004).

Step 2: Set up a comparison matrix. The elements of the matrix are results of the pairwise comparison based on a standardized comparison scale of nine levels (see Table 1 (Amiri, 2010)).

Table 1. Nine-point intensity of importance scale.

Definition	Intensely of importance
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9
Intermediately more important	2, 4, 6, 8

Step 3: Normalize and find the relative weights for each matrix.

At the last step, the final consistency ratio (CR) should be mentioned. If *CR* of the matrix is higher, it means that the input judgments are not consistent, and hence are not reliable. In general, a consistency ratio of 0.10 or less is considered acceptable. If the value is higher, the judgments may not be reliable and have to be elicited again (Ramanathan, 2001).

The Dempster–Shafer Theory (DST)

Dempster–Shafer theory (DST) was originally introduced by Dempster (1967) and was later improved by Shafer (1976). As a powerful mathematical tool for modeling and fusing uncertain information, evidence theory is widely applied in target recognition (Deng *et al*., 2010) and information (data) fusion (Deng *et al*., 2011).

Let θ be the set of the probable result of an event *X*. The elements of θ are mutually exclusive and exhaustive hypotheses. The set θ

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is called the frame of discernment of *X*. The power set $P(\theta)$ of a set θ is the set containing all the possible subsets of θ. The subsets containing only one element are called singletons.

Definition: If the θ is the frame of discernment, we define a function m such that $m:\ 2^{\theta} \rightarrow [0,1]$ satisfying the following three conditions:

$$0 \le m(A) \le 1, \quad (1)$$

$$\sum_{A \subseteq \theta} m(A) = 1, \quad (2)$$

$$m(\phi) = 0. \quad (3)$$

The function $m(A)$ is called a basic probability assignment (BPA) of *X*, which represents the part of the belief exactly committed to the subset *A* of θ given a piece of evidence. If $m(A) > 0$, then *A* is called the focal element.

The Dempster Combination Rule:

Dempster's rule of combination (or orthogonal sum) $m = m_1 \oplus m_2$, is a classical rule of combination in evidence theory that combines two BPAs m_1 and m_2 to yield a new BPA:

$$m(A) = \frac{\sum_{B \cap C = A} m_1(B) m_2(C)}{1-k} \quad (1)$$

Where

$$k = \sum_{B \cap C = \phi} m_1(B) m_2(C) \quad (2)$$

The Proposed Model

The proposed model for evaluating the risk degree of grain security in China, composed of AHP and DST methods, consists of four basic stages as shown in Figure 1:

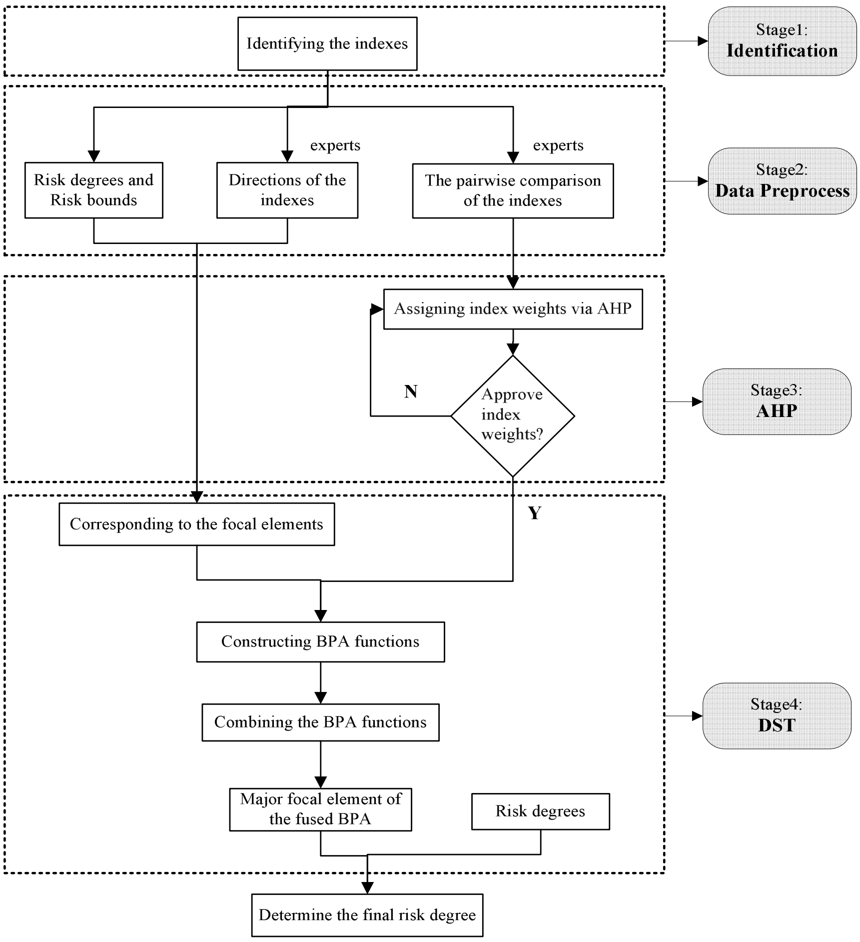

Figure 1. Schematic diagram of the proposed model.

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Stage 1: Identify the indices to be used in the model.

Stage 2: Preprocess the index data. For the data preprocessing stage, we should determine the risk degrees of the grain security and then calculate the risk bounds. Besides, we should determine the directions of the indices.

Stage 3: Assign index weights via AHP.

Stage 4: Evaluate the risk of grain security via DST and determine the final risk degree.

Identification of Indices

When selecting the indices of grain security, three principles should be followed: Representability Principle, Comprehensive Principle and Maneuverability Principle. In this paper, we adopt the warning index system in (Men *et al*., 2009). According to this system, there are eleven indices:

Productive indices mainly include: grain production x_1 (unit: 10^4 tons), grain seeding area x_2 (unit: 10^3 hectares), per capital seeding area x_3 (unit: square meters per person), effective irrigation area of cultivated land x_4 (unit: 10^3 hectares), the proportion of agriculture increasing value in GDP x_5 (unit: %); Consumptive indices mainly include: per capital occupation of grain x_6 (unit: kilograms), food imports accounted for the proportion of total agricultural imports x_7 (unit: %), food exports account for the proportion of total agricultural exports x_8 (unit: %), growth rate of Grain Price Index x_9 (unit: %); Disaster indices mainly include: disaster-affected area x_{10} (unit: 10^3 hectares), the proportion of disaster area in the disaster-affected area x_{11} (unit: %). Raw data of the indices from 1997 to 2007 are listed in Table 2 (Men *et al*., 2009).

Processing of Index Data

The Directions of the Index Data

When evaluating the risk of grain security, the directions of the indices should be taken into account. Index system to evaluate grain security includes positive indices, negative indices and non-directional indices. In normal circumstances, we believe that indices like “grain production” and “per capita occupation of grain” are positive, the more the better. On the contrary, indices like “disaster-affected area” and “proportion of disaster area in disaster-affected area” are negative. Some indices do not have any directions: “proportion of agriculture increasing value in GDP” is becoming smaller and smaller with the development of the society; “growth rate of Grain Price Index” is a cyclical variation, oversize fluctuation either in negative or in positive is bad. Thus, we define the directions of “proportion of agriculture increasing value in GDP” and “growth rate of Grain Price Index” as

Table 2. Grain Security Index Data in 1997-2007.

Year	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}
1997	49417.1	112912	910	51238.5	18.3	402	15.15	18.68	-0.08	53429	56.7
1998	51229.5	113787	910	52295.6	18.0	411	15	25.11	-0.03	50145	50.2
1999	50838.6	113161	900	53158.4	17.6	404	9.45	19.75	-0.04	49981	53.5
2000	46217.5	108463	860	53820.3	16.4	366	8.55	24.81	-0.10	54688	62.9
2001	45263.7	106080	830	54249.4	15.8	356	28.45	12.77	0.02	52215	60.9
2002	45705.8	103891	810	54354.8	15.3	357	29.97	18.16	-0.01	47119	58.0
2003	43069.5	99410	770	54014.2	14.6	334	31.98	22.99	0.02	54506	59.8
2004	46946.9	101606	780	54478.4	15.2	362	39.65	6.57	0.26	37106	43.9
2005	48402.2	104278	800	55029.3	12.5	371	35.39	10.98	0.29	38818	51.4
2006	49804.2	104958	800	56109.4	11.8	379	27.26	6.81	4.8	41091	59.9
2007	50160.3	105638	799	56518.3	9.9	380	29.84	10.13	6.6	48992	51.2

Table 3. Directions of the Grain Security Index.

Index	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}
Direction	(+)	(+)	(+)	(+)	(0)	(+)	(-)	(+)	(0)	(-)	(-)

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"0". Directions of the grain security index are shown in Table 3.

Risk Degree and Risk Bound

Risk degree can be described in several grades, such as "no alarm", "light alarm", "middle alarm", "heavy alarm", "huge alarm" and so on. Risk bound is the key factor to confirm risk degree (Lin *et al*., 2010). In this paper, we divide risk degree into five grades: "no alarm", "light alarm", "middle alarm", "heavy alarm" and "huge alarm". Corresponding to the five grades, we need four risk bounds. Principles of determining risk bounds are mainly as follows: majority principle, half principle or principle of the median and average principle (Lin *et al*., 2010). This paper confirms risk bounds according to average principles. Firstly, we calculate the maximum value and the minimum value of each index. Secondly, we calculate the deviation and the average scale as shown in (3) and (4). Table 4 shows the risk bounds of the indices of grain security from 1997 to 2007:

$\Delta = \max - \min$ (3)

$p = \Delta/8$ (4)

The Weights of the Indices

After forming the grain security index system, the weights of the indices to be used in the evaluation process can be calculated by using AHP method. Experts are needed in this phase to form an individual pairwise comparison matrix by using the scale given in Table 1. The weights of the indices determined by AHP method are shown in Table 5 (Men *et al*., 2009).

Risk Evaluation *via* DST

Relation between Risk Degrees and Focal Elements

Risk degrees are divided into five grades: "no alarm", "light alarm", "middle alarm", "heavy alarm" and "huge alarm". In order to describe the five grades, we need at least three elements "a", "b" and "c" to construct the frame of discernment. Focal elements

Table 4. Risk Bounds of the Indices.

Index	Bounds	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}
max		51229.5	113787	910	56518.3	18.3	411	39.65	25.11	6.6	54688	62.9
min		43069.5	99410	770	51238.5	9.9	334	8.55	6.57	-0.1	37106	43.9
p		1020	1797.125	17.5	659.975	1.05	9.625	3.8875	2.3175	0.8375	2197.75	2.375
min+ p	Bound1	44089.5	101207.1	787.5	51898.48	10.95	343.625	12.4375	8.8875	0.7375	39303.75	46.275
min+3 p	Bound2	46129.5	104801.4	822.5	53218.43	13.05	362.875	20.2125	13.5225	2.4125	43699.25	51.025
min+5 p	Bound3	48169.5	108395.6	857.5	54538.38	15.15	382.125	27.9875	18.1575	4.0875	48094.75	55.775
min+7 p	Bound4	50209.5	111989.9	892.5	55858.33	17.25	401.375	35.7625	22.7925	5.7625	52490.25	60.525

Table 5. Weights of the Indices.

Index	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}
weight	0.14	0.08	0.11	0.1	0.03	0.17	0.04	0.04	0.09	0.1	0.1

"a", "ab", "b", "bc" and "c" correspond to "no alarm", "light alarm", "middle alarm", "heavy alarm" and "huge alarm", respectively. Table 6 shows the relation between risk degrees and focal elements.

Mapping Index Data into Focal Element

The mapping rules from index data to focal element depend on the directions of the indices. The mapping rules from index data to focal element are provided in Figure 2. Subgraph (i) shows the mapping rule for the indices whose directions are positive; Subgraph (ii) shows the mapping rule for the indices whose directions are negative. Subgraph (iii) shows the mapping rule for index "growth rate of Grain Price Index". As for the index "proportion of agriculture increasing value in GDP", the relation between its value and grain security has not been fully researched up to now. Thus in this paper, we think it is uncertain and map it to focal element "abc" which represents uncertain information.

According to Figure 2, Tables 2 and 3, mapping results from index data into the focal element are shown in Table 7.

Construction of Basic Probability Assignment (BPA) with Weighting Method

After mapping the index data into the focal elements, the basic probability assignment functions are synthesized in a weighting way. According to DS theory, if the frame of discernment is constructed with three elements "a", "b" and "c", then the focal element belongs to the set comprising "*a*", "*b*", "*c*", "*ab*", "*bc*", "*ac*" and "*abc*". Taking the year 1997 as an example, we explain the weighting method for constructing a BPA function. Calculate the weight distributed to each focal element based on Tables 5 and 7:

$m(a) = 0.08 + 0.11 + 0.17 = 0.36$;

Table 6. Relation between the Risk Degrees and the Focal Elements.

Risk degree	No alarm	Light alarm	Middle alarm	Heavy alarm	Huge alarm
Focal element	*A*	*ab*	*b*	*bc*	*c*

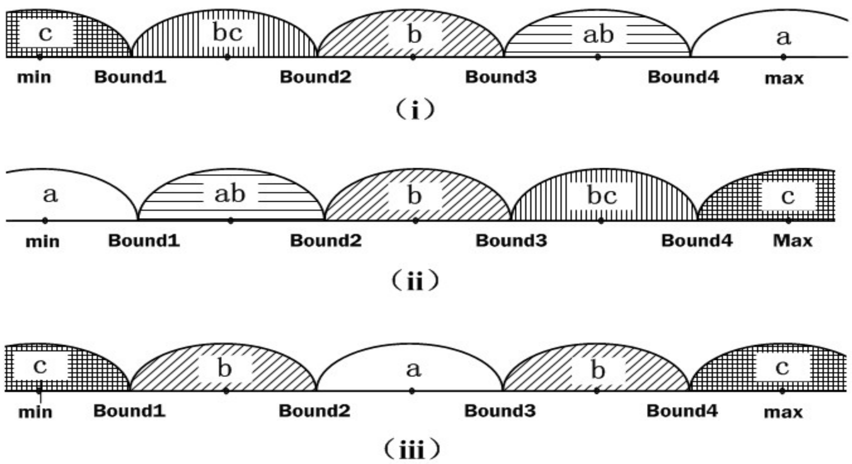

Figure 2. The mapping rules from index data to focal element.

$m(b) = 0$;

$m(c) = 0.1 + 0.09 + 0.1 = 0.29$;

$m(ab) = 0.14 + 0.04 + 0.04 = 0.22$;

$m(bc) = 0.1$;

$m(ac) = 0$;

$m(abc) = 0.03$.

Therefore, the BPA function of 1997 based on the index data is:

$m(a) = 0.36$; $m(c) = 0.29$; $m(ab) = 0.22$;
$m(bc) = 0.1$; $m(abc) = 0.03$

Similarly, the BPA functions of the years from 1998 to 2007 can be constructed. The results are shown in Table 8.

Combination of the Basic Probability Assignments (BPA)

The uncertainty of BPA function decreases after combination. It is easier for us to determine the risk degree of the grain security if the BPAs are combined into a fused BPA. At this stage, we obtain the fused BPA using the classical Dempster rule of combination. In the grain security warning system, there are eleven indices. Thus we use the Dempster rule of combination ten times to obtain a fused BPA (Deng *et al*., 2004). The results of combination of the basic probability assignments (BPA) are shown in Table 9.

Determining the Risk Degree

According to Table 9, we can obtain the major focal element of the fused BPAs. Therefore, using Table 6, the risk degrees will be determined. The grain security risk degrees are listed in the right column in Table 10 from 1997 to 2007.

RESULTS AND DISCUSSION

From 1996 to 1999, the grain production

Table 7. Mapping results from index data into focal element.

Year	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}
1997	*ab*	*A*	*a*	*c*	*abc*	*a*	*ab*	*ab*	*c*	*c*	*bc*
1998	*a*	*A*	*a*	*bc*	*abc*	*a*	*ab*	*a*	*c*	*bc*	*ab*
1999	*a*	*A*	*a*	*bc*	*abc*	*a*	*a*	*ab*	*c*	*bc*	*b*
2000	*b*	*ab*	*ab*	*b*	*abc*	*b*	*a*	*a*	*c*	*c*	*c*
2001	*bc*	*B*	*b*	*b*	*abc*	*bc*	*bc*	*bc*	*c*	*bc*	*c*
2002	*bc*	*bc*	*bc*	*b*	*abc*	*bc*	*bc*	*ab*	*c*	*b*	*bc*
2003	*c*	*C*	*c*	*b*	*abc*	*c*	*bc*	*a*	*c*	*c*	*bc*
2004	*b*	*bc*	*c*	*b*	*abc*	*bc*	*c*	*c*	*c*	*a*	*a*
2005	*ab*	*bc*	*bc*	*ab*	*abc*	*b*	*bc*	*bc*	*c*	*a*	*b*
2006	*ab*	*B*	*bc*	*a*	*abc*	*b*	*b*	*c*	*b*	*ab*	*bc*
2007	*ab*	*B*	*bc*	*a*	*abc*	*b*	*bc*	*bc*	*c*	*bc*	*b*

Table 8. BPA Functions of the Years from 1998 to 2007.

Focal element	*a*	*b*	*c*	*ab*	*bc*	*ac*	*abc*
1997	0.36	0	0.29	0.22	0.1	0	0.03
1998	0.54	0	0.09	0.14	0.2	0	0.03
1999	0.54	0.1	0.09	0.04	0.2	0	0.03
2000	0.08	0.41	0.29	0.19	0	0	0.03
2001	0	0.29	0.19	0	0.49	0	0.03
2002	0	0.2	0.09	0.04	0.64	0	0.03
2003	0.04	0.1	0.69	0	0.14	0	0.03
2004	0.2	0.24	0.28	0	0.25	0	0.03
2005	0.1	0.27	0.09	0.24	0.27	0	0.03
2006	0.1	0.38	0.04	0.24	0.21	0	0.03
2007	0.1	0.35	0.09	0.14	0.29	0	0.03

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Table 9. Combination of the Basic Probability Assignments after 10 cycles.

Focal element	*a*	*b*	*c*	*ab*	*bc*	*ac*	*abc*
1997	0.9816	0.0021	0.0162	0.0001	0	0	0
1998	0.999	0.0008	0.0002	0	0	0	0
1999	0.9951	0.0041	0.0008	0	0	0	0
2000	0.0003	0.9991	0.0006	0	0	0	0
2001	0	0.8087	0.185	0	0.0063	0	0
2002	0	0.875	0.0937	0.0001	0.0312	0	0
2003	0	0	1	0	0	0	0
2004	0	0.3065	0.6932	0	0.0003	0	0
2005	0.0002	0.9995	0.0003	0	0	0	0
2006	0.0001	0.9999	0	0	0	0	0
2007	0	0.9994	0.0005	0	0.0001	0	0

was basically maintained around 0.5 billion tons in China reaching the global average level. In 1998, the grain production reached the highest level in the history of China. However, grain reduction became more and more serious in the next five years since 2000. In 2003, the grain production dropped to 0.43 billion tons. In 2004, the problem of "grain security" became a national obsession. With the effects of all kinds of factors, the grain production increased in 2005. From Table 10, we can see that the risk degree of the grain security in 1997 to 1999 is "no alarm" and the risk degree of the grain security in 2003, 2004 is "huge alarm". The risk degrees coincide with the facts well. Therefore, we assume that the model is effective.

Table 11 shows a comparison of the results between Men *et al.*'s method and the proposed method. From Table 11, we can see that the results obtained by these two methods are largely the same except for the results in 2004. According to the reality of China, the proposed method is more efficient. Compared with Men *et al.*'s Method, the proposed method has the following advantages: (1) the proposed method can be applied generally and can deal with the situation where the distribution is non-normal, which can overcome the drawback of Men *et al.*'s method; (2) the proposed method takes the directions of the indices into consideration, therefore it is more accurate; (3) the proposed method can deal with the uncertain information well based on the Dempster-Shafer theory.

Table 10. Risk Degrees of the Grain Security from 1997 to 2007.

Year	Major focal element	Risk degree
1997	*a*	No alarm
1998	*a*	No alarm
1999	*a*	No alarm
2000	*b*	Middle alarm
2001	*b*	Middle alarm
2002	*b*	Middle alarm
2003	*c*	Huge alarm
2004	*c*	Huge alarm
2005	*b*	Middle alarm
2006	*b*	Middle alarm
2007	*b*	Middle alarm

Table 11. Comparison of the Results between Men *et al.*'s Method and the Proposed Method.

Year	Men *et al.*'s method	The proposed method
1997	Quite safe	No alarm
1998	Quite safe	No alarm
1999	Quite safe	No alarm
2000	Safe	Middle alarm
2001	Safe	Middle alarm
2002	Safe	Middle alarm
2003	Unsafe	Huge alarm
2004	Safe	Huge alarm
2005	Safe	Middle alarm
2006	Safe	Middle alarm
2007	Safe	Middle alarm

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CONCLUSIONS

In this paper, we have presented a model for risk assessment of grain security in China based on the analytic hierarchy process (AHP) method and the Dempster–Shafer theory (DST). The AHP is used to set up the structure of the grain security system and to determine weights of the indices. The DST method is used to analyze the index data and obtain a final risk degree. The proposed model makes a concise and quantitative total evaluation and returns the overall risk degrees of grain security.

In this paper, we evaluated the level of China's grain security from 2001 to 2007 and the results are presented in Table 10. From Table 10, we can see that the proposed risk assessment method is effective, seeing that the results coincide with the facts well. The results are helpful for the Ministry of Agriculture and the Central Government to capture the overall food security situation and make proper decisions (such as agricultural policy-making and the annual financial budget planning). If there has been or potentially exist the risk, especially when the situation is "huge alarm", the relevant departments then should pay more attention to it and find alternative measures and policies to prevent risk and solve problems.

Furthermore, we also made a comparison of the results between the proposed method and those of Men *et al*.'s method (Men *et al*., 2009). The proposed risk assessment method overcomes the drawbacks of Men *et al*.'s method since the mentioned method cannot deal with the situation where the distribution is non-normal and cannot represent uncertain information reasonably.

In general, the proposed model in this paper is a comprehensive early-warning model which can help avoid evaluating grain security from only one perspective. It makes a total evaluation based on quantitative data and returns an overall risk degree on the whole. Relevant departments could benefit from the results when making decisions. A main shortcoming of this model is that it includes only quantitative factors according to Men *et al*.'s warning index system. As it is mentioned above, the grain system is a complicated system which includes both qualitative factors and quantitative factors. In this sense, some qualitative factors such as the influence of policy support, agricultural knowledge etc. should be added into the warning index system in future researches. Meanwhile, some proper methods that deal with the qualitative factors should be taken into consideration. Another area deserving future study is to build a nonlinear system such as a risk matrix highlighting measures which tells more details about the situation and is more enlightening to the managers that have to deal with the specific affairs of reducing risk.

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ارزیابی ریسک تامین غلات در چین با استفاده از روش‌های AHP و DST

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چکیده

چین یکی از بزرگترین تولید کنندگان و مصرف کنندگان غلات در جهان است و تامین غلات برای چینی‌ها از اهمیت بسیاری برخوردار است. در این مقاله، یک مدل جامع پیش‌هشدار برای ارزیابی تامین غلات در چین ارائه میشود. این مدل بر مبنای روش فرایند تحلیل سلسله مراتبی (AHP) ، تئوری دمپستر – شافر (DST) قرار دارد. ما ارزیابی ریسک را به چهار مرحله تقسیم می‌کنیم. ابتدا، منابع ریسک را پیدا کرده و شاخص‌های مورد استفاده در مدل را شناسایی می‌کنیم. سپس، داده‌های شاخص‌ها پیش پردازش شده تا جهت آنها و مرزهای ریسک را بیابیم. پس از آن، شاخص‌ها با استفاده از AHP وزن دهی میشوند. نهایتاً، ریسک تامین غلات با استفاده از DST ارزیابی شده و درجه ریسک کلی تعیین میشود. برای نشان دادن کاربرد مدل برای ارزیابی وضعیت تامین غلات در چین، یک تحلیل تجربی انجام شده است. نتیجه نشان داد که که این مدل که با واقعیت‌های چین تطابق دارد، موثر بوده و میتواند به عنوان یک ابزار پیش‌هشدار تامین غلات مورد استفاده قرار گیرد.

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