Advance Journal of Food Science and Technology 11(10): 675-679, 2016
DOI:10.19026/ajfst.11.2762
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: September 7, 2015 Accepted: September 25, 2015 Published: August 05, 2016

Research Article

Food Safety Management Performance Evaluation Based on Fuzzy TOPSIS Method

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Abstract: The food safety management evaluation problem owns many evaluation indices and some of the indices are quality indices. Then with the complexity and uncertainty of quality indices and the ambiguity of human thinking, the crisp number cannot work well in food safety management evaluation problem. Interval numbers can well depict the uncertainty and fuzzy information. Thus for the food safety management evaluation problem, we build a Multi-Attribute Group Decision Making (MAGDM) model and then we develop a fuzzy TOPSIS method for the food safety management evaluation. An application example shows that the proposed model is reasonable and efficient and can be easily extended to the applications of similar decision problems.

Keywords: Food safety management evaluation, interval number, multi-attribute group decision, TOPSIS

INTRODUCTION

With the improvement of living standard and the increasing demand for more food varieties, the uncertainty and risk of food safety are also increasing at the same time (Ropkins and Beck, 2000). Many food safety issues, such as food contamination, food quality incidents and animal diseases are frequently reported and have been spreading significant concerns among consumers (Wang *et al*., 2012). Food safety is important not only for the people's general health and daily life, economic development and social stability, but also for the government's and country's image (Röhr *et al*., 2005; Liu *et al*., 2013). However, many food safety incidents have frequently occurred in China in the recent years, occur in China, such as SanLu milk powder melamine events, Salted duck eggs contain Sudan red, Beverages contain plasticizing agent, Sterilization cucumber, Dyeing steamed bread, Lean lean fine, Soya-bean milk powder with wash adjust. These incidents are a threat to the life of the people and safety of the society, which has caused concern and the worry of the society to the food safety. The Chinese government has set up a special agency named China National Center for Food Safety Risk Assessment (CFSA) as a technical authority of food safety risk assessment in 2011. Food safety assessment system is an important part of food safety research, which includes food safety management, food safety assessment and so on. Although a number of food companies have controlled some potential hazards in the food chain by implementing GAP and HACCP, there is still lack of accurate evaluation system for food safety in measuring the work effectiveness and level of customer satisfaction on food safety (Zhu and Liu, 2009). Many scholars have devoted into the study of food safety problems (Lahou *et al*., 2015; Charalambous *et al*., 2015; Hou *et al*., 2015).

Food safety management evaluation problem includes many qualified indices, which cannot or hardly depicted by crisp numbers because of uncertain or fuzzy information of these indices. In the evaluation process, many evaluation indices need to be simultaneously considered and thus the problem of food safety performance evaluation is also a fuzzy Multi-Attribute Decision Making (MADM) problem. With the complexity of the uncertainty and fuzziness of human cognition, the MADM problem which the attribute values expressed with interval number has aroused great attention of people (Jahan and Edwards, 2013; Cao and Wu, 2011; Sayadi *et al*., 2009). In order to make the decision-making process and the evaluation results are closer to the reality and reduce the decision bias of individual subjective factors, group decision making methods are often used to make the decision making process more scientific and democratic (Boran *et al*., 2009).

TOPSIS is one of the important techniques in dealing with Multi-Attribute Decision Making (MADM) problems. It simultaneously considers both the shortest distance from a Positive Ideal Solution (PIS) and the farthest distance from a Negative Ideal Solution (NIS) and the order of the alternatives is ranked according to relative closeness coefficients (Hwang and Yoon, 1981; Jiang *et al*., 2011). TOPSIS has been widely applied to the traditional crisp and fuzzy MADM problems (Krohling and Campanharo, 2011; Yue, 2011; Amiri, 2010; Li and Ren, 2015).

Table 1: Evaluation indices of food safety management performance (Zhu and Liu, 2009)

Evaluation indices	Detail description of each index
Enterprise design and implementation	Mainly check the enterprise's environment, location and facilities, including layout of the factory, equipment, tooling and piping, architectural decoration, sanitary facilities.
Food enterprise management requirements	Contains two aspects: management responsibilities and enterprise management requirements. Management responsibilities is an important requirement of food safety and in ISO22000, it includes management commitment, food safety policy, food safety management system planning, responsibility and authority, communication, management review. Enterprise management requirements is to fully reflect the requirements of resource management, product realization, measurement analysis and improvement in ISO9000 quality standard and the nature of using process management to insure system implementation, including production equipment, staff requirements, technical standards, process documents and document management.
Food hygiene and quality control	Food hygiene and quality control is the requirement in the complete process of food production, which includes eleven third level indices: raw material procurement, production processes, product packaging and release inspection. It relates to procurement systems, procurement inspection, process management, quality control, product protection, testing equipment, test management, process inspection, normative use of food additives and recent three years' records of sample passing rate.

The aim of this study is to develop the traditional TOPSIS method to the food safety management performance problem, which involves many experts and the values with respect to the evaluation indices are modeled by interval numbers.

MATERIALS AND METHODS

Food enterprise safety performance evaluation problem contains many evaluation indices. Determining the reasonable evaluation index is the key to food safety performance evaluation problem. Zhu and Liu (2009) worked out an evaluation index framework for food Safety management performance and the detail information is shown in Table 1.

Suppose that $X = \{x_1, x_2,\ldots,x_m\}$ is a set of food companies. Now the local government department wants to inspect these food companies' safety performance. The evaluation index (attribute) set is $O = \{o_1, o_2,\ldots,o_n\}$. Considering the fuzziness and uncertainty of subjective judgment and the expert assessment information for alternatives to a single attribute expressed with interval numbers. Supposed that $D = \{D_1, D_2,\ldots,D_s\}$ is the expert set and the rating of alternative $x_i (i = 1, 2,\ldots,m)$ on index o_j $(j = 1, 2,\ldots,n)$ given by expert D_k $(k = 1, 2,\ldots s)$ is an interval number $\tilde{a}_{ij}^k = [\underline{a}_{ij}^k, \overline{a}_{ij}^k]$. Hence, the safety performance model is a MAGDM problem, which can be concisely expressed in matrix format as follows:

$$\tilde{D}^k = (\tilde{a}_{ij}^k)_{m\times n} = \begin{array}{c} \\ x_1 \\ x_2 \\ \vdots \\ x_m \end{array} \begin{array}{c} \begin{array}{cccc} o_1 & o_2 & \cdots & o_n \end{array} \\ \begin{pmatrix} \tilde{a}_{11}^k & \tilde{a}_{12}^k & \cdots & \tilde{a}_{1n}^k \\ \tilde{a}_{21}^k & \tilde{a}_{22}^k & \cdots & \tilde{a}_{2n}^k \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{a}_{m1}^k & \tilde{a}_{m2}^k & \cdots & \tilde{a}_{mn}^k \end{pmatrix} \end{array} \tag{1}$$

where, $k = 1, 2,\ldots,s$ and $w = (w_1, w_2,\ldots,w_n)$ is the index weight vector. Collect the index evaluation values of the fuzzy decision matrix $\tilde{D}^k = (\tilde{a}_{ij}^k)_{m\times n}$, $k = 1, 2,\ldots,s$ into final decision matrix $\tilde{D} = (\tilde{a}_{ij})_{m\times n}$,where:

$$\tilde{a}_{ij} = [a_{ij}^l, a_{ij}^u] = \frac{1}{s}(\tilde{a}_{ij}^1 + \tilde{a}_{ij}^2 + \cdots + \tilde{a}_{ij}^s) \tag{2}$$

In general, indices can be classified into two types: benefit indices and cost indices. In other words, the index set can be divided into two subsets: I_1 and I_2, where $I_k (k = 1,2)$ is the subset of benefit index set and cost index set, respectively.

The normalization method is to preserve the property that the range of a normalized interval number $\tilde{r}_{ij}^k$ belongs to the closed interval [0, 1]. Hence, the fuzzy decision matrix $\tilde{D} = (\tilde{a}_{ij})_{m\times n}$ are transformed into the normalized decision matrix $\tilde{R} = (\tilde{r}_{ij})_{m\times n}$, where $\tilde{r}_{ij} = [r_{ij}^l, r_{ij}^u]$ obtained by the following formula (Xu, 2004):

$$\begin{cases} r_{ij}^l = a_{ij}^l \Big/ \sqrt{\sum_{i=1}^m (a_{ij}^u)^2} \\ r_{ij}^u = a_{ij}^u \Big/ \sqrt{\sum_{i=1}^m (a_{ij}^l)^2} \end{cases}, i \in M,\ j \in I_1 \tag{3}$$

And:

$$\begin{cases} r_{ij}^l = (1/a_{ij}^u) \Big/ \sqrt{\sum_{i=1}^m (1/a_{ij}^l)^2} \\ r_{ij}^u = (1/a_{ij}^l) \Big/ \sqrt{\sum_{i=1}^m (1/a_{ij}^u)^2} \end{cases}, i \in M,\ j \in I_2 \tag{4}$$

where, $M = \{1,2,\ldots,m\}$.

FOOD SAFETY EVALUATION BASED ON TOPSIS METHOD

In this section, we will give the calculation steps of the TOPSIS method for the food safety management performance as follows:

Step 1: Calculate the normal food safety management performance decision matrix $\tilde{R}=(\tilde{r}_{ij})_{m\times n}$

Step 2: Calculate the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS):

The PIS is defined as $x^{*}=(x_1^{*},x_2^{*},\ldots,x_n^{*})$, where $x_j^{*}=[1,1]$;

And the NIS is defined as $x^{-}=(x_1^{-},x_2^{-},\ldots,x_n^{-})$, where $x_j^{-}=[0,0]$.

Step 3: Calculate the index weight vector by the following step:

- The final food safety management performance decision $\tilde{R}=(\tilde{r}_{ij})_{m\times n}$ is firstly transformed into a crisp number decision matrix $G=(g_{ij})_{m\times n}$ by the expectation method given as follows (Hu and Zhang, 2010):

$$g_{ij}=\frac{1}{2}(r_{ij}^{l}+r_{ij}^{u}) \tag{5}$$

- The coefficient of variation method proposed by Men and Liang (2005) and the calculation formula is:

$$w_j=\frac{\delta_j}{\sum_{j=1}^{n}\delta_j},\ j=1,2,\ldots,n, \tag{6}$$

where,

$$\delta_j=\frac{s_j}{\bar{x}_j},\ \bar{x}_j=\frac{1}{m}\sum_{i=1}^{m}x_{ij}\ \text{and}\ s_j=\sqrt{\frac{1}{m}\sum_{i=1}^{m}(x_{ij}-\bar{x}_j)^2}.$$

Step 4: Calculate the distances of alternative x_i with the PIS and NIS as follows:

$$d(x_i,x^{*})=\sqrt{\sum_{j=1}^{n}w_j^2 d^2(\tilde{r}_{ij},r_j^{*})}, \tag{7}$$

And:

$$d(x_i,x^{-})=\sqrt{\sum_{j=1}^{n}w_j^2 d^2(r_{ij},r_j^{-})} \tag{8}$$

where, the distance measures are:

$$d(\tilde{r}_{ij},r_j^{*})=\sqrt{(1-r_{ij}^{L})^2+(1-r_{ij}^{U})^2}$$

$$d(\tilde{r}_{ij},r_j^{*})=\sqrt{(r_{ij}^{L}-0)^2+(r_{ij}^{U}-0)^2}$$

Step 5: Calculate the closeness degree of the alternative:

$$C_i=\frac{d(x_i,x^{-})}{d(x_i,x^{-})+d(x_i,x^{*})},\ i=1,2,\ldots,m \tag{9}$$

Step 6: Rank all the alternatives according to C_i. The larger of C_i, the better of the alternative x_i.

CASE STUDY

Suppose that the local government department wants to inspect four food companies' safety performance. These four food companies (alternatives) are x_1, x_2, x_3, x_4 and the evaluation indices are o_1 (Enterprise design and implementation), o_2 (Food enterprise management requirements), o_3 (Food hygiene and quality control). These three indices are all benefit indices. The government department hires three experts D_1, D_2, D_3 to evaluate these four companies and the index evaluation values are shown in Table 2.

To sort the four food companies' safety performance using the proposed method, the steps are given as follows:

Step 1: According to the Eq. (1) and (2), the Fuzzy decision matrix $\tilde{D}=(\tilde{a}_{ij})_{m\times n}$ is obtained and shown in Table 3.

Step 2: The normalized food companies' safety performance decision matrix $\tilde{R}=(\tilde{r}_{ij})_{m\times n}$ is obtained and shown in Table 4.

Step 3: The ideal solution and negative ideal solution are respectively given as:

$$x^{*}=(x_1^{*},x_2^{*},x_3^{*})=([1,1],[1,1],[1,1])$$
$$x^{-}=(x_1^{-},x_2^{-},x_3^{-})=([0,0],[0,0],[0,0])$$

Step 4: Calculate the index weight vector:

- Calculate the crisp number decision matrix $G=(g_{ij})_{m\times n}$:

$$G=\begin{bmatrix}0.5056 & 0.5266 & 0.4920\\ 0.5288 & 0.5002 & 0.4827\\ 0.5002 & 0.4911 & 0.4942\\ 0.4718 & 0.4901 & 0.5372\end{bmatrix}$$

- Then the weight vector can be obtained by coefficient of variation method as:

$$w=(0.3620,0.2628,0.3753)$$

Step 5: Calculate the distance measure:

$$d(x_1,x^{*})=0.7015,d(x_2,x^{*})=0.7052,$$
$$d(x_3,x^{*})=0.7163,d(x_4,x^{*})=0.7097$$

Table 2: The index evaluation values of the four companies by experts

Evaluation index	Company	Expert D_1	D_2	D_3
o_1	x_1	(70,75)	(75,80)	(70,75)
	x_2	(75,85)	(65,75)	(80,85)
	x_3	(70,75)	(70,75)	(70,80)
	x_4	(68,75)	(65,72)	(65,70)
o_2	x_1	(71,77)	(76,81)	(80,85)
	x_2	(75,80)	(71,80)	(65,75)
	x_3	(63,75)	(70,75)	(75,80)
	x_4	(71,78)	(65,72)	(71,80)
o_3	x_1	(70,80)	(70,75)	(66,73)
	x_2	(65,71)	(65,70)	(75,80)
	x_3	(70,75)	(67,75)	(71,78)
	x_4	(80,85)	(70,80)	(77,82)

Table 3: Fuzzy decision matrix $\tilde{D} = (\tilde{a}_{ij})_{m \times n}$

Companies	Evaluation indices o_1	o_2	o_3
x_1	(71.6667, 76.6667)	(75.6667, 81.0000)	(68.6667, 76.0000)
x_2	(73.3333, 81.6667)	(70.3333, 78.3333)	(68.3333, 73.6667)
x_3	(70.0000, 76.6667)	(69.3333, 76.6667)	(69.3333, 76.0000)
x_4	(66.0000, 72.3333)	(69.0000, 76.6667)	(75.6667, 82.3333)

Table 4: Normalized decision matrix $\tilde{R} = (\tilde{r}_{ij})_{m \times n}$

Companies	Evaluation indices o_1	o_2	o_3
x_1	(0.4659, 0.5453)	(0.4839, 0.5693)	(0.4455, 0.5385)
x_2	(0.4768, 0.5808)	(0.4498, 0.5506)	(0.4433, 0.5220)
x_3	(0.4551, 0.5453)	(0.4434, 0.5389)	(0.4498, 0.5385)
x_4	(0.4291, 0.5144)	(0.4413, 0.5389)	(0.4909, 0.5834)

And:

$$d(x_1, x^-) = 0.7185, d(x_2, x^-) = 0.7164,$$
$$d(x_3, x^-) = 0.7038, d(x_4, x^-) = 0.7128$$

Step 6: The relative closeness degrees of all alternatives are obtained as:

$$C_1 = 0.5060, C_2 = 0.5039, C_3 = 0.4956, C_4 = 0.5011$$

Step 7: Obviously, $C_1 > C_2 > C_4 > C_3$, then the four food companies' safety performance order is $x_1 > x_2 > x_4 > x_3$.

CONCLUSION

This study is focus on food companies' safety performance problem. The evaluation model is constructed as the interval number MAGDM model and solved by an extension of TOPSIS method combining with variation coefficient method. In this study, the variation coefficient method can use the data information itself and thus it can overcome the artificial and uncertainty of subjective weight. In this study, the proposed method is simple, in line with the actual situation, the algorithm is easy to use Matlab and Excel software for modular operation, each department can use the method in the food companies' safety performance problem and other multi-attribute decision making model.

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