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Application of the fuzzy TOPSIS method in management of food supply chain

Zastosowanie rozmytej metody TOPSIS w zarządzaniu łańcuchem dostaw żywności

Abstract. This paper presents a multi-criteria decision-making method: the fuzzy TOPSIS method. This approach is an alternative for AHP, TOPSIS, ELECTRE or PROMETHEE methods. The paper presents the possibility of using the fuzzy TOPSIS method in food supply chain management (SCM). For this purpose, a brief review of the literature is shown. Then the fuzzy TOPSIS method is presented. At the end of the article, a simple problem is shown.

Key words: food supply chain, fuzzy TOPSIS method, management

Synopsis. W pracy przedstawiono wielokryterialną metodę podejmowania decyzji: rozmytą metodę TOPSIS. Jest to alternatywa dla metod AHP, TOPSIS, ELECTRE lub PROMETHEE. W pracy przedstawiono możliwość zastosowania rozmytej metody TOPSIS w zarządzaniu łańcuchem dostaw żywności (FSCM). W tym celu przedstawiono krótki przegląd literatury. Następnie przedstawiono rozmytą metodę TOPSIS, na końcu artykułu pokazano możliwość zastosowania metody do rozwiązania problemu.

Słowa kluczowe: łańcuch dostaw żywności, rozmyta metoda TOPSIS, zarządzanie

Introduction

The agri-food supply chain (ASC) concept was first proposed by scholars in the agricultural economics and management discipline [Salin 1998, Mardsen et al. 2000]. The commonly used terms to describe this idea include agricultural supply chain, agricultural value chain, food supply chain, and food value chain. The food supply chain is composed of a wide diversity of products and companies which operate in different markets and sell a variety of food products. It combines activities whose primary purpose is to ensure buyer satisfaction and profit to enterprises participating in the flow of products and services from the sphere of primary agricultural production (farmer) to the consumer (Fig. 1). All sectors, which belongs and create the food supply chain, are important from the economically point of view. There is many interactions between this sectors, purchasers and suppliers appear in every link in the food supply chain [Bukeviciute et al. 2009].

The diversity of the modern food supply chain and its ever-changing dynamics creates many challenges for the food industry. Agri-food supply chain management (ASCM) was first defined by a group of Dutch scholars, mainly from Wageningen University, The Netherlands, whose studies were published as monographs and in journals. ASCM refers to the management of the relationship(s) among the raw material supply for agricultural production, production processing, and product logistics and distribution [Hobbs and Young 2000, Van der Vorst 2000, Apaiah and Hendrix 2005, Taylor and Fearne 2006, Van der Vorst et al. 2007, Ahumada and Villalobos 2009].

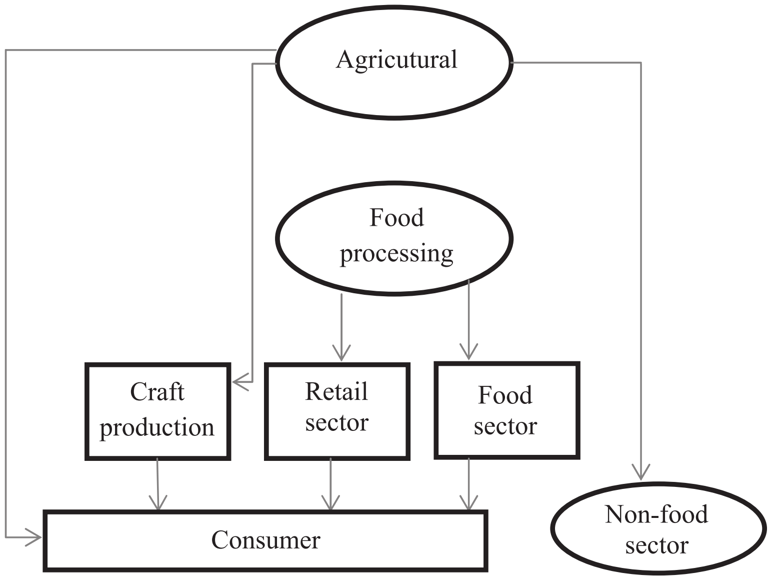

Figure 1. Schematic representation of the food supply chain
Rysunek 1. Schemat łańcucha dostaw żywności
Source: [Bukeviciute et al. 2009].

There is many methods supporting decision making in the field of efficiently management of food supply chain. To the group of decision support methods can be included multi-criteria decision making methods. These methods are used to support the decision-making process in situations where the choice is made between many variants. It is important, however, to properly select assessment criteria and to correctly assign weights. This means that depending on the issue, the criteria should reflect various aspects such as costs, time, requirements of the close and distant environment, implementation possibilities and others [Kukułka and Wirkus 2017]. In literature, the most frequently raised problems are those regarding location selection [Chu 2002, Martin et al. 2003, Farahani and Asgari 2007, Ertgrul et al. 2008; Tabari et al. 2008, Tzukaya et al. 2008, Avashti et al. 2011], choice of supplier [Chan and Kumar 2007; Onut et al. 2009], choice of strategy [Poh and Ang 1999, Wey and Wu 2007] or performance assessment (utility) [Chamodrakas et al. 2009, Bojkovic et al. 2010, Kannan et al. 2013]. The most commonly used methods to solve these problems are primarily: Analytic Hierarchy Process (AHP) [Poh and Ang 1999, Ertgrul et al. 2008], fuzzy AHP (fAHP) [Chan and Kumar 2007, Tabari et al. 2008], Analytic Network Process (ANP) [Wey and Wu 2007, Tzukaya et al. 2008], fuzzy ANP (fANP) [Onut et al. 2009], Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [Farahani and Asgari 2007], fuzzy TOPSIS (fTOPSIS) [Ertgrul et al. 2008, Chamodrakas et al. 2009, Onut et al. 2009 Kannan et al. 2013], ELimination and Choice Expressing REality (ELECTRE) [Bojkovic et al. 2010] and fuzzy Preference Ranking Organization Method for Enrichment Evaluations (fPROMETHEE) [Martin et al. 2003]. In the Polish literature on the subject, a description of multi-criteria methods and their application can be found in the work Sałabun [2015], Żak [2005], Żak and Sawicki [2000], Roszkowska [2009], Rudnik and Kacprzeak [2017].

Methodology

The TOPSIS method (Technique for Order Preference using Similarity to Ideal Solution) is a useful tool that is used to rank variants (alternatives, criteria) during the decision making process. The factor that distinguishes this method is the use of a measure of relative distance to the best solution, which is a model (ideal) and the worst solution, which is anti-ideal [Ertuđrul and Karakațođlu, 2008]. This method was extended by Chen in 2000 to fuzzy environments, which used a fuzzy linguistic value as a substitute for the directly given crisp value in the grade assessment. This method is used, among others, for the choice of supplier [Furnell 2001, Boran et al. 2008, Gupta and Gupta 2012], selection of projects and risk assessment [Boran et al. 2008], evaluation of websites [Kabir and Hasin 2013], selection of the object [Ertuđrul and Karakațođlu 2008], etc. It is also possible to find hybrid approaches. In 2012 Tansel proposed an integration of the Fuzzy TOPSIS method of linear programming for credit risk assessment [Tansel 2012]. Sun [2010] and others [Wang et al. 2009, Łuczak and Wysocki 2013] propose creating decision models and rankings based on integration of Fuzzy AHP and Fuzzy TOPSIS methods [Kauf and Tłuczak 2018].

In fuzzy TOPSIS method the decision matrix is defined by triangular fuzzy numbers. Decision matrix is made by fuzzy assessment of decision variants due to further criteria's. This assessments are given by formula [Boran et al. 2008, Kauf and Tłuczak 2018]:

$$\widetilde{f}_k(a^j) = (l_{jk}; m_{jk}; u_{jk})$$

and this are triangular positive fuzzy numbers where:
l_{jk} – pessimistic assessment of *j*-th variant based on the *k*-th criterion;
m_{jk} – most expected assessment of *j*-th variant based on the *k*-th criterion;
u_{jk} – optimistic assessment of *j*-th variant based on the *k*-th criterion;
$l_{jk} \geq 0$;
$m_{jk} \geq 0$;
$u_{jk} \geq 0$.

In the process of management of food supply chain, the following stages of calculation can be distinguished on the Fuzzy TOPSIS method [Boran et al. 2008, Ertuđrul and Karakațođlu 2008, Wang et al. 2009, Sun 2010, Łuczak et al. 2012, Wysocki 2013]:

1. Normalization of the fuzzy decision matrix $\widetilde{N} = \left[\tilde{z}_{jk}\right]$ where:

$$\tilde{z}_{jk} = \left(\frac{l_{jk}}{\max_j u_{jk}}; \frac{m_{jk}}{\max_j u_{jk}}; \frac{u_{jk}}{\max_j u_{jk}} \right)$$

– benefit criteria;

$$\tilde{z}_{jk} = \left(\frac{\min_j u_{jk}}{l_{jk}}; \frac{\min_j u_{jk}}{m_{jk}}; \frac{\min_j u_{jk}}{u_{jk}} \right)$$

– cost criteria.

2. Calculate the weighted normalized fuzzy decision matrix:

$$\widetilde{V} = \left[\tilde{r}_{jk} \right]$$

where:

$$\tilde{r}_{jk} = w_j \tilde{z}_{jk}$$

for $j = 1, \ldots, m$ and $k = 1, \ldots, n$, and $\sum_{k=1}^{n} w_k = 1$.

3. Identify the fuzzy positive ideal solution (FPIS)

$$\left(f_k(\tilde{a}^+) = \tilde{v}_k^+ = \max \tilde{r}_{jk} \right)$$

and fuzzy negative ideal solution (FNIS)

$$\left(f_k(\tilde{a}^-) = \tilde{v}_k^- = \min \tilde{r}_{jk} \right)$$

$j = 1, \ldots, m$ and $k = 1, \ldots, n$.

4. Calculate the distance of each alternative from ideal and negative ideal:

$$d_j^+ = \sum_{k=1}^{n} d\left(\tilde{r}_{jk}, \tilde{v}_k^+ \right)$$

and

$$d_j^- = \sum_{k=1}^{n} d\left(\tilde{r}_{jk}, \tilde{v}_k^- \right)$$

$j = 1, \ldots, m$ and $k = 1, \ldots, n$.

5. The closeness coefficient S_j represents the distances to fuzzy positive ideal solution and the fuzzy negative ideal solution:

$$s_j = \frac{d_j^-}{d_j^+ + d_j^-}$$

for $j = 1, \ldots, m$.

6. The alternative with highest closeness coefficient represents the best alternative and is closest to the Fuzzy Positive Ideal Solution and farthest from Fuzzy Negative Ideal Solution.

Example of use the fuzzy TOPSIS method

A discrete problem of multi-criteria decision making is considered. The decision problem is: how to choose a contractor/supplier which will deliver agricultural products to the processing plant. The three criteria which represents the possibility of risk: f_1 – cost / / price, f_2 – quality, f_3 – flexibility. And six of contractor will be assessed due to these criteria.

The profitable criteria will be considered, and each of them will be defined by a triangular fuzzy number. Assessment of decision variants against the criteria forming the decision making matrix is provided by the Table 1.

The next stage involves steps as outlined in section 2. Construct a normalized fuzzy decision matrix as shown in Table 2. The step of data normalization is necessary to overcome differences between the units. Normalization also enables valuation measure in the same range of values which is usually between zero and one. In the range system, 1 represents the highest value in upward movement where 0 represents the lowest value.

The next step is constructing a weighted normalized fuzzy decision matrix. For this purpose, the weight vector was as follow (0.45, 0.2, 0.35). To get multi criteria index, data from each of the criteria need to be aggregated. A lot of various methods can be implemented to do this. It this paper weighted mean was used, which can be calculated in two ways: by using arithmetic and geometric mean. Index based on arithmetic mean is generally more popular because of easily understood and implemented.

The next step is to get the fuzzy positive ideal solutions (FPIS) and fuzzy negative ideal solutions (FNIS). After getting the ideal solutions, the next step is to calculate the distance of the alternatives from (FPIS) and (FNIS) using equation (8) and (9), respectively (tab. 4). The last step was to find the closeness coefficient of each alternative, which is calculated according to formula (10): $a_1 = 0.46$, $a_2 = 0.45$, $a_3 = 0.71$, $a_4 = 0.48$, $a_5 = 0.40$, $a_6 = 0.53$.

Table 1. Fuzzy decision matrix

Tabela 1. Macierz wariantów decyzyjnych

			Offer of a logistics operator					
			a_1	a_2	a_3	a_4	a_5	a_6
criteria	f_1	l	2	3	5	1	1	5
		m	4	5	9	2	2	9
		u	6	7	11	7	5	10
	f_2	l	3	2	1	4	1	3
		m	5	3	3	6	5	5
		u	7	5	4	9	5	6
	f_3	*l*	5	4	4	3	5	2
		m	7	7	5	7	9	3
		u	9	9	12	10	12	4

Source: own study.

Table 2. Fuzzy normalized decision matrix for the selection

Tabela 2. Znormalizowana macierz rozmyta

			Offer of a logistics operator					
			a_1	a_2	a_3	a_4	a_5	a_6
criteria	f_1	l	0.18	0.27	0.45	0.09	0.09	0.45
		m	0.36	0.45	0.82	0.18	0.18	0.82
		u	0.55	0.64	1	0.64	0.45	0.91
	f_2	l	0.33	0.22	0.11	0.44	0.11	0.33
		m	0.56	0.33	0.33	0.67	0.56	0.56
		u	0.78	0.56	0.44	1	0.56	0.67
	f_3	l	0.42	0.33	0.33	0.25	0.42	0.17
		m	0.58	0.58	0.42	0.58	0.75	0.25
		u	0.75	0.75	1	0.83	1	0.33

Source: own study.

Based on table 6, it can be seen that the coefficients of the third alternative is the highest value followed by first and the fifth. Based on the coefficients, an alternative to selecting the firms listed on third should be the first choice, followed by selecting the firms listed first and the last one is to select a firm on the sixth.

Table 3. Weighted normalized fuzzy decision matrix
Tabela 3. Ważona znormalizowana rozmyta macierz decyzyjna

			Offer of a logistics operator					
			a_1	a_2	a_3	a_4	a_5	a_6
criteria	f_1	l	0.08	0.12	0.2	0.04	0.04	0.2
		m	0.16	0.2	0.37	0.08	0.08	0.37
		u	0.25	0.29	0.45	0.29	0.2	0.41
	f_2	l	0.07	0.04	0.02	0.09	0.02	0.07
		m	0.11	0.07	0.07	0.13	0.11	0.11
		u	0.16	0.11	0.09	0.2	0.11	0.13
	f_3	l	0.15	0.12	0.12	0.09	0.15	0.06
		m	0.2	0.2	0.15	0.2	0.26	0.09
		u	0.26	0.26	0.35	0.29	0.35	0.12

Source: own study.

In essence, the greater the value of the coefficient indicates the priorities of the decision to be made. This method not only allows the decision maker to provide the rank of each alternative, but also shows the degree of likelihood of alternative selection.

Table 4. Fuzzy positive ideal solutions (FPIS) and fuzzy negative ideal solutions (FNIS)
Tabela 4. Rozmyte pozytywne idealne rozwiązania (FPIS) i rozmyte negatywne idealne rozwiązania (FNIS)

	Criteria								
	f_1			f_2			f_3		
	l	m	u	l	m	u	l	m	u
FPS	0.20	0.37	0.45	0.09	0.13	0.20	0.15	0.26	0.35
FNS	0.04	0.08	0.20	0.02	0.07	0.09	0.06	0.09	0.12

Source: own study.

Summary

Supplier assessment is an extremely important issue for the effectiveness and efficiency of every enterprise. In the area of enterprise supply logistics it takes place twice: in the supplier selection phase (before cooperation with him) and in the phase (during) the cooperation itself. A very important element of functioning of food supply chain is its efficient management of entities operating in it. The right choice of agricultural product supplier can minimize the risk of incurring losses due to the short shelf life of these products. Multi-criteria decision-making methods can be helpful in choosing a supplier. Their scope of application in logistics and supply chain management is very wide.

The presented fuzzy TOPSIS method has a number of advantages and disadvantages that allow it to be used in logistics and supply chain management issues. The identified problem is unfortunately not immune to the rank reversal phenomenon. In this method expert decides about the weighting for individual criteria. The subject of the analysis was potential offers of suppliers evaluated in terms of the occurrence of risk in the implementation of projects.

The choice of supplier is often a strategic decision for the company, and especially applies to suppliers of the most important supply goods with whom long-term contracts are signed. This choice should take into account all the benefits and losses that the company incurs in connection with this choice, and not just one element (e.g. price).

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