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SUPPLIER SELECTION PROCESS IN DAIRY INDUSTRY USING FUZZY TOPSIS METHOD

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Research paper

Abstract: *Supplier selection is one of the most critical processes within the purchasing function. Choosing the right supplier makes a strategic difference to an organization's ability to reduce costs and improve the quality of products by helping to select the most suitable supplier. Sütaş Dairy Company, which is entered to Macedonia market in 2012. In the dairy company, there is only one purchasing manager who selects the farmers. Importance weights of criteria are determined using his reference, and also the alternatives are evaluated according to each criterion. The most important criteria are product and other costs, the price is also playing an important role, but due to the small marketplace of Macedonia, the prices are almost the same in every region. To select the dairy supplier in Macedonia, Fuzzy TOPSIS technique is used. The main goal of using fuzzy logic in this study is to help decision-makers for identifying the importance of selection criteria and rank possible suppliers easily. Since the supplier selection process is a Multi-Criteria Decision Making (MCDM) problem, after identify the weights and rankings in a fuzzy environment, TOPSIS algorithm has been used in the rest of the problem. Finally, fuzzy TOPSIS methodology has been implemented successfully, and its result pointed out the most suitable suppliers.*

Keywords: *Supplier selection, Fuzzy TOPSIS, Dairy industry*

1. Introduction

In today's competitive world, supply chain management has a significance role in the companies' plan due to survive and stay competitive. Supply chain management is a management process that consists of getting raw materials by selecting the best supplier into the organization, work on the raw materials to produce end products, and also supply chain management involves customer satisfaction. Since the procurement of raw material is the first and vital step of supply chain management, we may say that supplier selection has a numerous significant place in supply chain

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management. Also, organizations exist due to serve customers and satisfy their needs. Because if there is not any customer, the organizations can not survive anymore. Also, from another point of view, the businesses must stay competitive in the global marketing area not to lose their potential of consumers as well as their stakeholders. The common ground of all these goals of the organizations is passing through the select a suitable supplier. Because a well-selected supplier can affect all needs and objectives of any organization, accordingly this study focuses on the selecting the best supplier and represent the supplier selection process in the dairy industry.

Supplier selection is a cross-functional group decision-making problem where the decision-makers from different parts of an organization. It is providing a long-term decision process due to it affects firm's expectations from raw material to the end products and also regarding end products customers' satisfaction. The role of purchasing managers (buyers) has become very important because supplier selection is an essential task within the purchasing function. However, since the supplier selection is a cross-functional group decision-making process, it involves different company departments, not only purchasing manager. On the hand, the purchasing department is influenced by several sets of factors such as individual, interpersonal, organizational, and environmental. On the other, supplier selection is a complicated process that may involve several and different types of criteria, a combination of different decision models, group decision-making, and various forms of uncertainty. Therefore, the supplier selection process is one of multi-criteria decision making (MCDM) problems, and Techniques for order performance by similarity to ideal solution (TOPSIS), which is one of the known classical MCDM methods, may provide the basis for developing supplier selection models that can effectively overcome with these uncertainties. For this purpose, in this work TOPSIS method is applied with its fuzzy renewal.

Moreover, according to Benyoucef et al. (2003), there are two different aspects that characterize the supplier selection problem. The first aspect is the determination of a number of the suppliers by considering the characteristics of the company product and market and the second aspect is the selection of the best suppliers among existing alternatives. In this study, we consider the second aspect of the problem. Therefore, we assume that the number of suppliers to be selected are already given.

2. Literature review

According to Vinodh et al. (2011), supplier selection is a cross-functional group decision-making problem providing long-term decision for the company, and Mazaher et al. (2013) mentioned that objective of supplier selection is to identify suppliers with the highest potential for meeting a firm's needs consistently. Professionals believe that supplier selection is an essential task within the purchasing function. Therefore, the decision of supplier selection takes an essential place for the businesses. Supplier or vendor selection processes are complicated by reason of various criteria have to be taken into account while decision making. From the beginning of the 1960' s the analysis of criteria for the supplier selection and calculating their performance have been the focus of many academists, decision-makers, and purchasing managers.

Through define the selection criteria of suppliers, one of the most important study prepared by Dickson (1966). Dickson's studies has based on a questionnaire sent to 273 buying managers and directors who are members of the National Association of Purchasing Managers. As a result of this study, he identified 23 criteria that are still the main priorities of the supplier selection process and ranked concerning their importance. In the past, because cost reduction is the main priority for a decision-makers, the price was the key factor in choosing a supplier. However, the evolution of the industrial environment and hard competitive business world modified the degrees of the relative of these selection criteria and new criteria have to be taken into consideration by the decision-makers. For instance, Weber et al. (1991) examined 74 supplier selection articles, which were published from 1966 to 1990, and also covered the Dickson's study.

Literature is very rich about supplier selection. In the nineties, Ellram (1990) presented three principal criteria for supplier selection problem which are: 1) the financial statement of the supplier, 2) organizational culture and strategy of the supplier, and the last one 3) technological state of the supplier. Also, for each criterion, the author defined several sub-criteria. Like Ellram's principal criteria, Barbarosoglu and Yazgac (1997) proposed another three principal criteria: 1) the performance of the supplier, 2) technical capability and financial of the supplier, and 3) the quality system of the supplier, and each one have some sub-criteria.

Cherangi et al. (2004) conducted a cluster analysis of 110 research papers which are written in 1990-2001 regarding critical success factors. Cherangi et al. compared their literature review with the literature review of Weber et al. and updated the criteria. Ho et al. (2010) assessed the 78 articles which were published the international magazines in 2000-2008. Thiruchelvam and Tookey (2011) examined 46 new articles, articles were written for engineering and manufacturing departments and published in international scientific magazines from 2000 to 2011. From the recent studies, Johan and Jimmy (2011) presented a review that was structured by four main headings such as the supplier selection process, buying-specific factors, organizational factors, and inter-organizational factors, and each heading purposed sub-headings.

Supplier selection criteria for the identification of solution to problems to select the best supplier is the first and important step. However, after determining criteria, solution of the problem, in another word the process which leads to the best supplier, is important as much as criteria definition. Therefore, another literature review was prepared with respect to used methods in supplier selection. There has been wide labor to develop decision techniques and methods for supplier selection. Some previous reviews of these decision techniques have been prepared by Holt (1998), Ho et al. (2010), and Agarwal et al. (2011).

Holt (1998) presented an article about the contractor evaluation and selection modeling methodologies. Some of these methodologies are multiple regression, fuzzy set theory, multi-attribute analysis, and cluster analysis. The merits/demerits and previous/possible future applications of each methodology were also discussed. Ho et al. (2010) examined 78 articles in 2000-2008. In this study, several individual and integrated approaches are proposed to solve supplier selection problems. According to its result, the most common of the integrated approach is analytic hierarchy process- hierarchy process (AHP), and the most commons of the individual approach are data envelopment analysis (DEA), mathematical programming, and AHP. Agarwal et al. (2011) have prepared a literature review which involves 68 articles written from 2000 to 2011 which were about multiple-criteria decision making methods. As the result of Ho et al.'s study, this work also gave similar results and showed that the most commons of applied processes were DEA, mathematical programming, and AHP. Pearn et al. (2004) made sound the selection power analysis of the method using simulation and process capability. The certainty analysis provides useful information related to the sample size necessary for specified selection power. To tailor this method for in-plant applications and to select the better supplier and calculate the size of the difference between the two suppliers Pearn et al. (2004) developed a two-phase selection procedure.

Because supplier selection abounds in the literature, only several methods mentioned above. However, the methods have been classified a little bit differently but mostly the same in the literature. One of the literature review on supplier selection was prepared by Junyi et al. (2012). By using a methodological decision analysis in four aspects, including decision problems, decision-makers, decision environments, and decision approaches, they selected and reviewed 123 articles published in 2008-2012. To examine the research trend on uncertain supplier selection, they classified the articles into seven categories according to different uncertainties and 26 decision making techniques identified from three perspectives: Firstly, MCDM techniques, secondly, mathematical programming (MP) techniques, and the last one artificial intelligence (AI) techniques. Jadidi et al. (2009) used the TOPSIS method and multi-objective mixed integer linear programming in order to solve the complicated problem, which is used to define the optimum quantities among the selected suppliers. Rouyendegh et al. (2014) mentioned that supplier selection is mostly a complex multi-criteria problem which consists of qualitative and quantitative factors. Therefore to deal with optimal decision making for selecting the best supplier and allocating order, applied the method of integrated fuzzy TOPSIS and Multi-Choice Goal Programing (MCGP). Firstly they used a Fuzzy TOPSIS to determine uncertain and imprecise judgment of decision-makers and, for the final supplier selection and order allocation, applied the MCGP model. Tayyar et al. (2013) utilized AHP and VIKOR models to solve the problem of determining the best sub-contractor among those which sew the orders of the worldwide known brands in the clothing sector through MCDM models. In addition, Sachin and Ravi, (2014) utilized a two-step method to identify and rank the solutions of knowledge management (KM) adoption in the supply chain (SC) and overcome its barriers. At the first step, AHP was used to determine the weights of the barriers as criteria. At the second step, TOPSIS was applied to obtain final ranking of the solutions of KM adoption in SC. Also, Nydic and Hill, (1992) and Narasimahn, (1983) used AHP, and Akman and Aklan, (2006), fuzzy AHP to determine the best suppliers.

A study published by Yue, (2014) which aims to develop a new methodology for group decision-making (GDM) problems in an intuitionistic fuzzy environment. The weights of decision-makers were determined by using an extended TOPSIS technique. The individual decisions of decision-makers were then converted into the group decision of alternatives. Then the preference of alternatives was ranked by using an extended TOPSIS technique. In order to show the major technical advances in the applied model, comparisons between the proposed method and other methods were studied. Besides these approaches, three injection timing and three injector protrusion settings were tested to study engine performance and exhaust emissions. The experimental results were evaluated using two multi-criteria decision-making techniques AHP and TOPSIS and the optimal fuel type-injection timing-injector protrusion configuration was selected.

Another study proposed by Izadikhah, (2009) by applying the TOPSIS method to deal with fuzzy data for determining the best choice among all possible alternatives. In his approach, one of the Yager indices, which were used for ordering fuzzy quantities in [0, 1], was applied to identify the fuzzy ideal solution and fuzzy negative ideal solution. The result of Yager's index gave a procedure for choosing fuzzy ideal and negative ideal solutions directly from the data for observed alternatives. Then, he proposed the Hamming distance for calculating the distance between two fuzzy triangular numbers.

Demiral, (2013) used fuzzy linear programming in production planning among several optimization opportunities in the dairy industry. Several reasons, such as an uncertain supply of milk and demand of dairy products and the results of the fuzzy linear programming model are more realistic than a linear programming model and more profitable in terms of the firm, made preferred the fuzzy linear programming. Also, Guan et al. took into account uncertain milk supply, price–demand curves and contracting, and applied multistage stochastic programming to a production planning problem for Fonterra, a leading company in the New Zealand dairy industry. They described a model for uncertain milk supply and a model for Fonterra's supply chain. Then presented a multistage stochastic quadratic programming model and a decomposition algorithm to compute an optimal sales policy, which is tested in simulation against a deterministic policy. Jouzdani et al. (2013) proposed another study based on minimizing the costs of facility location, traffic congestion and transportation of raw/processed milk and dairy products under demand uncertainty by dynamic dairy facility location, and supply chain planning. They proposed a model which was dynamically incorporated possible changes in the transportation network, facility investment costs, the monetary value of time, and changes in the production process.

Zavadkas et al. (2020) studied on MCDM techniques for improving the sustainability engineering process. Markovic et al. (2020) proposed a novel integrated subjective-objective MCDM model for alternative ranking in order to achieve business excellence and sustainability. Gegovska et al. (2020) used Fuzzy-MCDM technics and Artificial Neural Networks for the green supplier selection process. Matic et al. (2019) applied a new hybrid MCDM model: sustainable supplier selection in a construction company. Puska et al. (2018) proposed a new way of applying interval fuzzy logic in group decision making for supplier selection. Stevic et al. (2016) applied an integrated Fuzzy AHP and TOPSIS model for supplier evaluation. Sahin et al. (2020) applied Fuzzy TOPSIS method for Dry Bulk Carrier Selection. Jain et al. (2018) used Fuzzy TOPSIS and Fuzzy AHP to select suppliers in the Indian automotive industry.

This study fills a gap in the literature by choosing a supplier in the dairy industry with a large number of specified criteria. Although milk suppliers are similar due to their structure, there are differences among them, such as capacity, systematic work, technical structure, etc. Determining these different criteria made it easier for us to decide among suppliers. This study determines the suppliers by solving a very complex decision problem using the Fuzzy-TOPSIS method according to ten different criteria.

3. TOPSIS Method and Its Fuzzy Extension

In supplier selection problems, according to the characteristics of products, there can be differences between product types, which are procured by a supplier. For instance, some product types of a supplier can be more expensive when classed the products with similar types of product of other suppliers. If we give an example in the dairy industry, the supplied product is milk, and it can have more fat than other suppliers` milk. Thus worth of a supplier can change with reference to each product it supplies. Therefore, the significance worth of each supplier with regard to relevant product is determined via fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

The classical TOPSIS is developed by Hwang and Yoon in 1981 as an alternative method to the ELECTRE method. As mentioned previously, TOPSIS is one of the MCDM methods, and it is based on calculating the distance of alternatives from the positive ideal solution and the negative ideal solution by using Euclidean distance approach. Therefore in the TOPSIS method ideal solution should have shortest distance from the positive ideal solution and the farthest distance from the negative solution in the geometric sense. In this method, the alternatives are compared by identifying weights for each criterion, secondly normalizing scores for each criterion, and lastly, calculating the distance between each alternative and the ideal alternative, which is the best score in each criterion. The meaning of ideal alternative is related to criteria. For instance, considering the cost decision maker should take the lowest alternative whereas for profit, the decision-maker should choose the highest value as an ideal alternative. The terms used in the TOPSIS are briefly defined as follows:

Criteria: Criteria/Attributes $(C_j, j = 1, 2, \dots, n)$ should provide a means of evaluating the levels of an objective. Each alternative can be characterized by a number of criteria.

Alternatives: As mentioned in MCDM alternatives are synonymous with ‘options’ or ‘candidates’. Alternatives $(A_i, i = 1, \dots, m)$ are different from each other.

Criteria weights: Weight values (w_j) show the relative importance of each criterion to the others.

$$W = \{w_j \mid j = 1, 2, \dots, n\} \tag{1}$$

Normalization: The purpose of normalization is to gain comparable scales, which allows comparisons across criteria and it transforms various criterion dimensions into non-dimensional criteria. To calculate the normalized value of x_{ij}, the vector normalization approach divides the rating of each attribute by its norm. The equation of x_{ij}, is in below:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \quad i = 1,...,m; \quad j = 1,...,n. \tag{2}$$

TOPSIS method is consisting of six steps, and within the presented steps, it is benefited from the study of Hwang and Yoon (1981) and Yang and Hung (2007).

Step 1: Calculate normalized rating for each element in the decision matrix using the normalization the equation.

Step2: Construct the weighted normalized ratings. The weighted normalized value v_{ij} is calculated by equation below:

$$v_{ij} = w_{ij} r_{ij}, \; i = 1,...,m; \quad j = 1,...,n. \tag{3}$$

New matrix generated from the multiplication of the normalized decision matrix by its associated weight.

Step 3: Determine the positive ideal (A^*), and negative ideal (A^-) solutions.

The positive ideal solution equation is;

$$A^* = \{v_1^*, ..., v_n^*\}, \tag{4}$$

where

$$v_j^* = \left\{ (\max_i \; v_{ij} \mid j \in B), (\min_i \; v_{ij} \mid j \in C) i = 1,...,m \right\}. \tag{5}$$

The negative ideal solution equation is;

$$A^- = \{v_1^-, ..., v_n^-\}, \tag{6}$$

where

$$v_j^- = \left\{ (\min_i \; v_{ij} \mid j \in B), (\max_i \; v_{ij} \mid j \in C) i = 1,...,m \right\} \tag{7}$$

where B is a set of benefit attributes (larger-the-better type) and C is a set of cost attributes (smaller-the-better type).

Step 4: Calculate the distance measures for each alternative. The distance between alternatives can be measured by the n-dimensional Euclidean distance.

The separation from positive ideal solution, A^* is given by the equation as in follow,

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}, \; i = 1,...,m. \tag{8}$$

Similarly, the separation from the negative ideal solution, A^-, is given by the equation below,

$$S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2},\ i = 1,\dots,m. \tag{9}$$

Step 5: Calculate relative closeness to the ideal solution C_i^* ;

$$C_i^* = \frac{S_i^-}{S_i^* + S_i^-},\ \ i = 1,\dots,m. \tag{10}$$

In this step, the important point is that $0 \le C_i^* \le 1$ where C_i^* =0 when $A_i = A^-$, and C_i^* =1 when $A_i = A^*$

Step 6: Rank preference order and according to preference rank order of C_i^* the best satisfied alternative can be decided. Therefore, the best alternative is the one that has the closest distance to the ideal solution, which means the ideal solution is guaranteed to have the farthest distance to the negative ideal solution.

Further from the classical TOPSIS method, uncertainty of the decision making environment is regarded by the fuzzy evaluations included in the fuzzy TOPSIS process.

Similar to the TOPSIS approach, in the fuzzy TOPSIS, an optimal alternative that is nearest to the Fuzzy Positive Ideal Solution (FPIS) and farthest from the Fuzzy Negative Ideal Solution (FNIS). A detailed description and treatment of fuzzy TOPSIS are discussed by many academicians (for instance, see: Yang and Hung (2007), Govindan et al. (2013), Saghafian and Hejazi (2005), Kilic(2012, 2013) and etc.) and we have adapted from Dymova et al., (2013) and Kilic (2013) the relevant steps of fuzzy TOPSIS as presented below.

The definitions of the related symbols used in the equations are as follows.

The definitions of the symbols

K: The number of decision-makers

i: Alternative

j: Criterion

$\tilde{x}_{ij}$: The rating of alternative "*i*" with respect to criterion j.

$\tilde{w}_j$: The importance of criterion *j.*

$\tilde{r}_{ij}$: Normalized triangular fuzzy number

$\tilde{R}_{ij}$: Matrix of normalized triangular fuzzy number

$\tilde{v}_{ij}$: Weighted normalized triangular fuzzy number

$\tilde{V}$: A matrix consisting of weighted normalized triangular fuzzy numbers

(a_{ij}, b_{ij}, c_{ij}): The lower, middle and upper values in the triangular fuzzy numbers indicating the rating of alternative "*i*" with respect to criterion "*j*"

(w_{ij}, w_{ij}, w_{ij}): The lower, middle, and upper values in the triangular fuzzy numbers indicating the importance of criterion *j*.

Step 1: In this step, the importance of criteria and the alternative ratings with respect to the criteria are evaluated by the decision-makers. Each criterion is evaluated according to linguistic variables as shown in Table 1, and each alternative is rated via Table 2.

Step 2: Table 1. shows Linguistic Variables and Fuzzy Triangular Numbers for Criteria Evaluation. Table 2. shows Linguistic Variables and Fuzzy Triangular Numbers for Criteria Evaluation. Alternative ratings $\tilde{x}_{ij}$ and criteria importance $\tilde{w}_j$ are computed by multiplying each data with their own weights.

Table 1. Linguistic variables for criteria evaluation

Linguistic variable	Fuzzy Numbers
Very Low(VL)	(0,0,0.1)
Low (L)	(0,0.1,0.3)
Medium low (ML)	(0.1,0.3,0.5)
Medium (M)	(0.3,0.5,0.7)
Medium high (MH)	(0.5,0.7,0.9)
High (H)	(0.7,0.9,1)
Very high (VH)	(0.9,1,1)

Table 2. Linguistic variables for alternative ratings

Linguistic variable	Fuzzy Numbers
Very Poor (VP)	(0,0,1)
Poor (P)	(0,1,3)
Medium Poor (MP)	(1,3,5)
Fair (F)	(3,5,7)
Medium Good (MG)	(5,7,9)
Good (G)	(7,9,10)
Very Good (VG)	(9,10,10)

Step 3: Normalizing the decision matrix.

An appropriate and method logically justified method for normalization of fuzzy decision matrices was developed in Chen (2000), and if $(\tilde{x}_{ij},\ i=1,2,\ldots,m,\ j=1,2,\ldots,\text{n},)$ are triangular fuzzy numbers, then the normalization process can be performed by:

$$\tilde{R}=[\tilde{r}_{ij}]_{mxn} \quad \Rightarrow \quad \tilde{r}_{ij}=(r_{ij}^{L},r_{ij}^{M},r_{ij}^{U})=\left(\frac{a_{ij}}{c_j^{+}},\frac{b_{ij}}{c_j^{+}},\frac{c_{ij}}{c_j^{+}}\right), \quad i=1,\ldots\text{m}; \quad j\in K_b \tag{11}$$

where

$$c_j^+ = \max_i(c_{ij}); \quad j \in K_{b,} \tag{12}$$

if the criterion is a cost, the following equation is taken into consideration:

$$\tilde{r}_{ij} = (r_{ij}^L, r_{ij}^M, r_{ij}^U) = \left(\frac{a_i^-}{c_{ij}}, \frac{a_i^-}{b_{ij}}, \frac{a_i^-}{a_{ij}}\right), \quad i = 1,\ldots \mathrm{m}; \quad j \in K_c \tag{13}$$

where

$$a_j^- = \min_i(a_{ij}); \quad j \in K_c. \tag{14}$$

Because fuzzy set is in [0,1] range, this normalization provides that $\tilde{r}_{ij} \subset [0,1]$ for all *i* and *j.*

Step 4: The weighted normalized the fuzzy decision matrix is obtained. The definitions of the related symbols used in the equations are as follows.

$$\tilde{V} = [\tilde{v}_{ij}]_{mxn} \qquad i = 1,2,\ldots,m, \quad j = 1,2,\ldots,\mathrm{n}, \tag{15}$$

$$\tilde{v}_{ij} = \tilde{r}_{ij}.\tilde{w}_j \tag{16}$$

Step 5: Definition of fuzzy positive ideal solution and fuzzy negative ideal solution values.

$$\tilde{A}^+ = \{\tilde{r}_1^+, \tilde{r}_2^+,\ldots,\tilde{r}_n^+\} = \{\max_i \{(r_{ij}^L, r_{ij}^M, r_{ij}^U)\} \mid j \in K_m, \min_i\{(r_{ij}^L, r_{ij}^M, r_{ij}^U)\} \mid j \in K_u\}, \tag{17}$$

$$\tilde{A}^- = \{\tilde{r}_1^-, \tilde{r}_2^-,\ldots,\tilde{r}_n^-\} = \{\min_i\{(r_{ij}^L, r_{ij}^M, r_{ij}^U)\} \mid j \in K_m , \max_i \{(r_{ij}^L, r_{ij}^M, r_{ij}^U)\} \mid j \in K_u \}. \tag{18}$$

Step 6: The distances of each alternative from fuzzy positive and negative ideal solutions are calculated using the vertex method as follows:

$$S_i^* = \sum_{j\epsilon K_m}^n w_j(\tilde{r}_j^+ - \tilde{r}_{ij}) + \sum_{j\epsilon K_u}^n w_j(\tilde{r}_{ij} - \tilde{r}_j^-), \qquad 19)$$

$$S_i^- = \sum_{j\epsilon K_m}^n w_j(\tilde{r}_{ij} - r_j^-) + \sum_{j\epsilon K_u}^n w_j(\tilde{r}_{ij} - \tilde{r}_j^+) i = 1,2,\ldots,m, \;\; j = 1,2,\ldots,n. \tag{20}$$

$$S_i^* = \sqrt{\tfrac{1}{3}[(\tilde{r}_n^+ - \tilde{r}_{11})^2 + (\tilde{r}_n^+ - \tilde{r}_{21})^2 + (\tilde{r}_n^+ - \tilde{r}_{31})^2]} \qquad 21)$$

$$S_i^- = \sqrt{\tfrac{1}{3}[(\tilde{r}_{11} - \tilde{r}_n^-)^2 + (\tilde{r}_{21} - \tilde{r}_n^-)^2 + (\tilde{r}_{31} - \tilde{r}_n^-)^2]} \tag{22}$$

Step 7: The fuzzy closeness coefficient CC_i is computed as shown in the equation below, and the highest result is selected as the best alternative.

$$CC_i = \frac{S_i^-}{S_i^* + S_i^-} \quad i = 1,2,\ldots,m. \tag{23}$$

4. Application of Fuzzy-TOPSIS Method in Dairy Industry

In this section, we will apply fuzzy TOPSIS method in the supplier selection problem in the dairy industry. Sütaş dairy company is a newly built factory in Macedonia. The company produces packaged and pasteurized milk, yogurt, ayran (yogurt drink), and other milk products. Therefore there needs to be a daily milk supply, and to be competitive in the sector, and the company wants to choose the right suppliers and increase its efficiency. For this purpose, fuzzy TOPSIS method will be used for the selection of suppliers.

Firstly we defined criteria with purchasing manager of the company, who is an expert on purchasing function, and decide to select suppliers. Selection criteria have been determined by studying other similar supplier selection problems, and taking into account the specific structure of the dairy industry. The criteria are taken into consideration while supplier selection and they are as follows:

1. *Price:* The price of raw milk when buying from farmers, and each farmer gives different values due to their local costs. However, the prices in every region of Macedonia are almost the same.
2. *Product:* It is raw milk which is bought from suppliers. Also, it shows an alteration according to regions.
3. *On time delivery:* The delivered time of raw milk to the company from the first farmers.
4. *Capacity of supply:* The capacity of raw milk which suppliers daily produce.
5. *Performance history:* Performance history of suppliers.
6. *Conflict problem solving capacity:* It defines farmers' ability to solve problems such as the sickness of animals.
7. *Location:* The region where the suppliers are present. This criterion is considering to region of the supplier where the quality product can be supply. (i.e., air pollution, industrial area, capacity of farming and etc.)
8. *Transportation cost:* The company is buying raw milk from different cities. Therefore it causes costs, and we took into consideration.
9. *Technological capability:* It is the power of using technology.
10. *Other costs: All costs except transportation cost.*

Table 3. The evaluation for criterion importance weight

Criterion	Evaluation
Cr1 (Price)	MH
Cr2 (Product)	VH
Cr3 (On time delivery)	H
Cr4 (Capacity of supply)	MH
Cr5 (Performance history)	ML
Cr6 (Conflict problem solving capacity)	M
Cr7 (Location)	M
Cr8 (Transportation)	ML
Cr9 (Technological capability)	M
Cr10 (Other costs)	VH

After defining criteria, they are evaluated by using linguistic terms. Fuzzy linguistic terms of importance weight of the criteria are shown in Table 3. Alternative suppliers are determined as cities. There are six supplier cities, and their names as Skopje, Bitola, Kumanovo, Prilep, Kocani, and Tetovo-Gostivar. Tetovo and Gostivar are presumed as one supplier. The linguistic values of alternatives related to criteria are presented in Table 4.

Table 4. The evaluation of decision-makers for alternative ratings

Suppliers	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8	Cr9	Cr10
SKOPJE	MG	MG	G	G	MG	G	F	VG	F	MG
PRILEP	G	F	MG	MG	MG	MG	G	F	F	F
KUMONOVO	VG	MG	F	MG	F	MG	MG	G	F	F
BITOLA	MG	MG	MG	VG	G	G	MG	MP	MG	F
KOCANI	VG	MG	MG	F	F	MG	G	MG	F	F
TETOVA-GOSTIVAR	MG	G	VG	VG	VG	G	G	G	G	F

The linguistic terms of criteria are converted to triangular fuzzy numbers, and they will be used as weights in Fuzzy TOPSIS algorithm. Fuzzified criteria can be seen in Table 5.

Table 5. Fuzzy Weights of Criteria

Crıterıon	weıghts
Price	(0.5,0.7,0.9)
Product	(0.9,1.0,1.0)
On time delivery	(0.7,0.9,1.0)
Capacity of supply	(0.5,0.7,0.9)
Performance history	(0.1,0.3,0.5)
Conflict problem solving capacity	(0.3,0.5,0.7)
Location	(0.3,0.5,0.7)
Transportation	(0.1,0.3,0.5)
Technological capability	(0.3,0.5,0.7)
Other Costs	(0.9,1.0,1.0)

To prepare a decision matrix, the linguistic terms of alternatives are defined as triangular fuzzy numbers, which can be seen in Table 6. In the decision matrix, there are three cost criteria as well as seven benefit criteria, and they should be comparable values. For this purpose, each benefit criteria set, the highest value is taken, and all the other values are divided by this highest value.

Table 6. Fuzzy decision matrix and fuzzy weights of criteria

	Cr1	Cr2	Cr3	Cr4	Cr5
SKOPJE	(5,7,9)	(5,7,9)	(7,9,10)	(7,9,10)	(5,7,9)
PRILEP	(7,9,10)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)
KUMONOVO	(9,10,10)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)
BITOLO	(5,7,9)	(5,7,9)	(5,7,9)	(9,10,10)	(7,9,10)
KOCANI	(9,10,10)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)
TETOVA-GV	(5,7,9)	(7,9,10)	(9,10,10)	(9,10,10)	(9,10,10)
Weight	(0.5,0.7,0.9)	(0.9,1.0,1.0)	(0.7,0.9,1.0)	(0.5,0.7,0.9)	(0.1,0.3,0.5)

	Cr6	Cr7	Cr8	Cr9	Cr10
SKOPJE	(7,9,10)	(3,5,7)	(9,10,10)	(3,5,7)	(5,7,9)
PRILEP	(5,7,9)	(7,9,10)	(3,5,7)	(3,5,7)	(3,5,7)
KUMONOVO	(5,7,9)	(5,7,9)	(7,9,10)	(3,5,7)	(3,5,7)
BITOLO	(7,9,10)	(5,7,9)	(1,3,5)	(5,7,9)	(3,5,7)
KOCANI	(5,7,9)	(7,9,10)	(5,7,9)	(3,5,7)	(3,5,7)
TETOVA-GV	(7,9,10)	(7,9,10)	(7,9,10)	(7,9,10)	(3,5,7)
Weight	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.9,1.0,1.0)

For the cost sets, the lowest value is selected, and it is divided by the rest values. As a result of those calculations, a normalized fuzzy decision matrix is obtained. It is shown in Table 7.

Table 7. Fuzzy normalized decision matrix

	Cr1	Cr2	Cr3	Cr4	Cr5
SKOPJE	(0.56,0,71,1)	(0.5,0.7,0.9)	(0.7,0.9,1.0)	(0.7,0.9,1.0)	(0.5,0.7,0.9)
PRILEP	(0.5,0,56,0,71)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.5,0.7,0.9)
KUMONOVO	(0.5,0.5,0.56)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.3,0.5,0.7)
BITOLO	(0.56,0,71,1)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.7,0.9,1.0)	(0.7,0.9,1.0)
KOCANI	(0.5,0.5,0.56)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.3,0.5,0.7)
TETOVA-GV	(0.56,0,71,1)	(0.7,0.9,1)	(0.9,1.0,1.0)	(0.9,1.0,1.0)	(0.9,1.0,1.0)
	Cr6	Cr7	Cr8	Cr9	Cr10
SKOPJE	(0.7,0.9,1.0)	(0.3,0.5,0.7)	(0.1,0.1,0.11,)	(0.3,0.5,0.7)	(0.33,0.429,0.6)
PRILEP	(0.5,0.7,0.9)	(0.7,0.9,1.0)	(0.143,0.2,0.33)	(0.3,0.5,0.7)	(0.429,0.6,1)
KUMONOVO	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.10,0.11,0.143)	(0.3,0.5,0.7)	(0.429,0.6,1)
BITOLO	(0.7,0.9,1.0)	(0.5,0.7,0.9)	(0.2,0.33,1)	(0.5,0.7,0.9)	(0.429,0.6,1)
KOCANI	(0.5,0.7,0.9)	(0.7,0.9,1.0)	(0.11,0.143,0.2)	(0.3,0.5,0.7)	(0.429,0.6,1)
TETOVA-GV	(0.7,0.9,1.0)	(0.7,0.9,1.0)	(0.10,0.11,0.143)	(0.7,0.9,1.0)	(0.429,0.6,1)

The next step is the fuzzy TOPSIS method is to determine the weighted normalized fuzzy decision matrix. In this step, the normalized decision matrix is multiplied by the importance weights of criteria, as shown in Table 8.

Table 8. Fuzzy weighted normalized decision matrix

	Cr1	Cr2	Cr3	Cr4	Cr5
SKOPJE	(0.28,0.497,0.9)	(0.45,0.7,0.9)	(0.49,0.81,1.0)	(0.35,0.63,0.9)	(0.05,0.21,0.45)
PRILEP	(0.25,0.392,0.639)	(0.27,0.5,0.7)	(0.35,0.63,0.9)	(0.25,0.49,0.81)	(0.05,0.21,0.45)
KUMONOVO	(0.25,0.35,0.504)	(0.45,0.7,0.9)	(0.21,0.45,0.7)	(0.25,0.49,0.81)	(0.03,0.15,0.35)
BITOLO	(0.28,0.497,0.9)	(0.45,0.7,0.9)	(0.35,0.63,0.9)	(0.35,0.63,0.9)	(0.07,0.27,0.5)
KOCANI	(0.25,0.35,0.504)	(0.45,0.7,0.9)	(0.35,0.63,0.9)	(0.15,0.35,0.63)	(0.03,0.15,0.35)
TETOVA-GV	(0.28,0.497,0.9)	(0.63.0.9,1.0)	(0.63,0.9,1.0)	(0.45,0.7,0.9)	(0.09,0.3,0.5)
	Cr6	Cr7	Cr8	Cr9	Cr10
SKOPJE	(0.21,0.45,0.7)	(0.09,0.25,0.49)	(0.01,0.03,0.055)	(0.09,0.25,0.49)	(0.297,0.429,0.6)
PRILEP	(0.15,0.35,0.63)	(0.21,0.45,0.7)	(0.0143,0.06,0.071)	(0.09,0.25,0.49)	(0.387,0.6,1)
KUMONOVO	(0.15,0.35,0.63)	(0.15,0.35,0.63)	(0.01,0.033,0.05)	(0.09,0.25,0.49)	(0.387,0.6,1)
BITOLO	(0.21,0.45,0.7)	(0.15,0.35,0.63)	(0.02,0.099,0.1)	(0.15,0.35,0.63)	(0.387,0.6,1)
KOCANI	(0.15,0.35,0.63)	(0.21,0.45,0.7)	(0.011,0.0429,0.055)	(0.09,0.25,0.49)	(0.387,0.6,1)
TETOVA-GV	(0.21,0.45,0.7)	(0.21,0.45,0.7)	(0.01,0.033,0.05)	(0.21,0.45,0.7)	(0.387,0.6,1)

After calculation of weighted normalized decision matrix, fuzzy positive ideal solution ($\tilde{A}^{+}$) and fuzzy negative ideal solution ($\tilde{A}^{-}$) are determined. For fuzzy positive ideal solution the highest value of each benefit criteria column and the lowest value of each cost criteria column are taken into consideration. The determination of fuzzy negative ideal solution has a reverse situation and the values shown as follows:

$$\tilde{A}^* = [(0.25,0.25,0.25),(1.0,1.0,1.0),(1.0,1.0,1.0),(0.9,0.9,0.9),(0.5,0.5,0.5),$$
$$(0.7,0.7,0.7),(0.7,0.7,0.7),(0.01,0.01,0.01),(0.7,0.7,0.7),(0.297,0.297,0.297)]$$
$$\tilde{A}^- = [(0.9,0.9,0.9),(0.27,0.27,0.27),(0.21,0.21,0.21).(0.15,0.15,0.15),(0.03,0.03,0.03),$$
$$(0.15,0.15,0.15,),(0.09,0.09,0.09),(0.1,0.1,0.1),(0.09,0.09,0.09),(1.0,1.0,1.0)]$$

To calculate each alternative's distance from fuzzy positive ideal solution and fuzzy negative ideal solution Vertex method is used. The results are shown in Table 9 and Table 10.

Table 9. The distances from positive ideal solutions

	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8	Cr9	Cr10
S^* (SKOPJE, A^*)	0.426	0.37	0.31	0.35	0.31	0.35	0.45	0.0284	0.45	0.191
S^* (PRILEP, A^*)	0.343	0.54	0.44	0.45	0.31	0.38	0.32	0.0456	0.45	0.445
S^* (KUMONOVO, A^*)	0.158	0.37	0.58	0.45	0.35	0.35	0.38	0.0266	0.45	0.445
S^* (BITOLO, A^*)	0.402	0.37	0.44	0.35	0.28	0.35	0.38	0.0733	0.38	0.445
S^* (KOCANI, A^*)	0.158	0.37	0.44	0.56	0.35	0.35	0.32	0.0322	0.45	0.445
S^* (TETOVA-GV, A^*)	0.402	0.22	0.22	0.28	0.26	0.43	0.32	0.0266	0.32	0.445

Table 10. The distances from and negative ideal solutions

	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8	Cr9	Cr10
S^* (SKOPJE, A^*)	0.427	0.45	0.22	0.53	0.26	0.36	0.25	0.0284	0.25	0.191
S^* (PRILEP, A^*)	0.5	0.28	0.24	0.43	0.26	0.3	0.41	0.0456	0.25	0.445
S^* (KUMONOVO, A^*)	0.542	0.45	0.32	0.43	0.2	0.3	0.35	0.0266	0.25	0.445
S^* (BITOLO, A^*)	0.427	0.45	0.24	0.53	0.31	0.36	0.35	0.0733	0.35	0.445
S^* (KOCANI, A^*)	0.542	0.45	0.24	0.3	0.2	0.3	0.41	0.0322	0.25	0.445
S^* (TETOVA-GV, A^*)	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8	Cr9	Cr10

Using the total distance from fuzzy positive ideal solution and fuzzy negative ideal solution fuzzy closeness coefficient CC_i is computed as shown in below.

Table 11. Closeness coefficient and their rankings

	S^*	S^-	CC_i	Rankıng
SKOPJE	2.8094	2.963	0.5133	2
PRILEP	3.3806	2.65	0.4394	6
KUMONOVO	3.4016	2.794	0.4509	4
BITOLO	3.0683	3.059	0.4992	3
KOCANI	3.3172	2.639	0.4430	5
TETOVA-GOSTIVAR	2.5216	3.354	0.5708	1

After calculation of closeness coefficient, they are ranked from large to small values as in shown Table 11. Regarding the coefficient values, the best supplier is Tetova-Gostivar.

5. Conclusion

The supplier selection process is one of the most important activities in the supply chain management. In today's competitive world, a company or any organization should have right supplier selection methodology to provide a sustainable system. However, it is known that available information regarding supplier selection problems is often uncertain and changeable. Also, decision making for supplier selection becomes quite complicated because rather than the classical methods, which only focus on cost and profit, the supplier selection process is consisting of a wide range of factors such as product, quality, on time delivery time, etc. Moreover, the supplier selection process is a kind of multi-criteria decision making problem. Therefore, companies or organizations should have a strategic approach to choose the right suppliers considering all reasons that we mentioned. Using fuzzy logic may help to overcome these problems while facing in the decision making process and as an extension of multi-criteria decision making methodology, fuzzy TOPSIS is proposed in this study. The main purpose of the TOPSIS algorithm is to find the best solution; in other words, which solution is the closest to positive ideal solution at the same time the farthest from negative ideal solution. By combining these two methodologies the fuzzy TOPSIS is applied to the supplier selection process to determine the most preferable choice among all possible alternatives. In this research, the proposed method showed the best supplier is Tetova-Gostivar cities. According to this result, the company may pay more attention and invest to there for built new plantation or farms. In the future, A hybrid MCDM model can be used to select suppliers.

References

Agarwal, P.,S., Mishra M., Bag, V., M., and Singh, V. (2011), "A Review Of Multi-Criteria Decision Making Techniques For Supplier Evaluation and Selection", *International Journal of Industrial Engineering Computations*, 2:801–810.

Akman G. ve Aklan A. (2006), "Measurement of Supplier Performance at Supply Chain Management by Using Fuzzy AHP Method: a Study at Automotive Subcontractor Industry", *İstanbul Ticaret Üniversitesi Fen Bilimleri Dergisi,* 5(9), 23-46.

Benyoucef, L., Ding, H., Xie, X. (2003), "Supplier selection problem: Selection criteria and methods", *Theme 4- Simulation et optimisation de systemes complexes,* No: 4726, INRIA

Chen, C.T. (2000), Extensions of the TOPSIS for Group Decision Making under Fuzzy Environment, *Fuzzy Sets and Systems*, 114, 1-9.

Demiral, M., F. (2013), "A Case Study at Dairy Industry with Fuzzy Linear Programming". *Suleyman Demirel University Journal of Faculty of Economics & Administrative Sciences , Vol. 18 Issue 2,* 373-397.

Dickson, W., G. (1966), "An Analysis of Vendor Selection Systems and Decisions", *Journal of Purchasing*, 2(1), 5-17

Dymova L., Sevastjanov P., Tikhonenko A. (2013), "An approach to generalization of fuzzy TOPSIS method". *Information Sciences* 238 149–162 pp. 151-152.

Gegovska, T,. Koker, R. And Cakar, T. (2020), "Green Supplier Selection Using Fuzzy Multiple-Criteria Decision Making Methods and Artificial Neural Networks", Computational Intelligence and Neuroscience, Vol 2020, Number: 8811834.

Guan Z., Philpott A., B. (2011), "A Multistage Stochastic Programming Model for the New Zealand Dairy Industry", *International Journal of Production Economics* Volume 134, Issue 2, 289–299

Ho, W., XU, X., and Dey, P. (2010), "Multi-Criteria Decision Making Approaches For Supplier Evaluation and Selection: A Literature Review", *European Journal of Operational Research,* 202:16–24.

Holt, G. D. (1998), "Which Contractor Selection Methodology?" *International Journal of Project Management,* 16(3), 153-164.

Izadikhah, M. (2009), "Using the Hamming Distance to Extend TOPSIS in a Fuzzy Environment." *Journal of Computational and Applied Mathematics* 231, 200-207

Jain, V., Sangaiah A.K., Sakhuja, S., Thoduka, N. And Aggarwal, R. (2018) "Supplier Selection Using Fuzzy AHP and TOPSIS: a Case Study in The Indian Automotive Industry", Vol.29, 555-564.

Jouzdani J., Sadjadi S. J., Fathian M. (2013), "Dynamic Dairy Facility Location and Supply Chain Planning Under Traffic Congestion and Demand Uncertainty: A Case Study of Tehran", *Applied Mathematical Modelling* Volume 37, Issues 18–19, 8467–8483

Kilic, H., S. (2012), "Supplier Selection Application Based on a Fuzzy Multiple Criteria Decision Making Methodology". *Online Academic Journal of Information Technology Summer Vol: 3 Num: 8*

Kilic, H., S. (2013), "An integrated approach for supplier selection in multi-item/multi-supplier environment". *Applied Mathematical Modelling* 37 7752–7763

Markovic, V., Stajic L., Stevic, Z. et al. (2020), "A novel Integrated Subjective-Objective MCDM Model for Alternative Ranking in order to Achive Business Excellence and Sustainability", SYMMETRY-BASEL, Vol. 12, Issue 1.

Matic, B., Jovanovic, S., Dillip, K. et al. (2019), "A new Hybrid MCDM Model: Sustainable Supplier Selection in a Construction Company", SYMMETRY-BASEL, Vol. 11, Issue 3.

Narasimahn R. (1983), "An Analytical Approach to Supplier Selection", *Journal of Purchasing and Management,* 19(4), 27-32.

Pearn, W. L., Wu, C.W. and Lin, H. C. (2004), "Procedure for supplier selection based on Cpm applied to super twisted nematic liquid crystal display processes," *International Journal of Production Research*, vol. 42, no. 13, 2719–2734,

Puska, A., Kozarevic, S., Stevic Z. and Stovrag, J. (2018), "A New Way of Appliying Interval Fuzzy Logic in Group Decision Making for Supplier Selection", Economic Computation and Economic Cybernetics Studies and Research, Issue 2, Vol. 52.

Rouyendegh, D., Babak, S., Thomy, E. (2014), "Supplier Selectio Using Integrated TOPSIS and Multi-Choice Goal Programing: a Case Study" *Procedia - Social and Behavioral Sciences 116, 3957 – 3970*

Sachin K. P., and Kant, R. (2014). "A fuzzy AHP-TOPSIS framework for ranking the solutions of Knowledge Management adoption in Supply Chain to overcome its barriers", *Expert Systems with Applications* 41, 679–693.

Saghafian S. and Hejazi S.R., (2005). "Multi-criteria Group Decision Making Using A Modified Fuzzy TOPSIS Procedure", *International Conference on Computational Intelligence for Modelling, Control and Automation, and International Conference on Intelligent Agents, Web Technologies and Internet Commerce* 0-7695-2504-0/05

Sahin, B., Yip, T.L., Tseng, P-H., Kabak, M. And Soylu, A. (2020), "An Application of a Fuzzy TOPSIS Multi-Criteria Decision Analysis Algorithm for Dry Bulk Carrier Selection", Information, 11, 251.

Stevic, Z., Tanackov, I., Vasiljevic, M., Novarlic, B. and Stojic, G. (2016) "An Integrated Fuzzy AHP and TOPSIS Model for Supplier Evaluation", Serbian Journal of Management 11 (1), 15 – 27.

Tayyar N. and Arslan, P. (2013), "Selection of the Best Sub-Contractor in Clothing Sector Using AHP and VIKOR Methods", *CBU Sosyal Bilimler Dergisi* vol. 11, no. 1.

Thiruchelvam, S. and Tookey, J. (2011), "Evolving Trends of Supplier Selection Criteria and Methods", *International Journal of Automotive and Mechanical Engineering*, 4:437-454.

Vinodh, S., R. Anesh Ramiya, and S. G. Gautham, (2011), "Application of Fuzzy Analytic Network Process for Supplier Selection in a Manufacturing Organisation." *Expert Systems with Applications* 38: 272–280.

Weber, C. A., Current, J. R. and Benton, W. C., (1991), "Vendor Selection Criteria and Methods", *European Journal of Operational Research*, 50 (1):2-18.

Yang, T. C., Hung, C. (2007). "Multiple-attribute decision making methods for plant layout design problem" *Robotics and Computer-Integrated Manufacturing* 23 126–137

Yue, Z. (2014), "TOPSIS-based Group Decision-Making Methodology in Intuitionistic Fuzzy Setting", *Information Science*.

Zavadkas, E.K., Pamucar, D., Stevic, Z. et al. (2020), "Multi-Criteria Decision Making Techniques for Improvement Sustainability Engineering Process", Symmetry, Vol. 11, Issue 6.