An Integrated Decision Aid Framework for Fuel Provider Selection: A Case Study in Food Industry

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Abstract: - Lexical meaning of the word "fuel" is a material that can be made to react with other substances in order to release chemical or nuclear energy as heat or to be used for work. Down the ages, energy has been one of the most important part of the human life. From past to present, heating and cooking are used intensively and during the history, fuel has been used both for cooking and heating. This paper introduces an integrated multiple criteria decision making approach for fuel provider selection in food industry. Seven conflicting evaluation criteria namely lead time, reliability, sustainability, cost, service quality, location and warranties, are determined in this work. In order to illustrate the application, a numerical example is given by conducting a case study in Turkish food sector.

Key-Words: Fuel provider selection, decision support, multi-criteria decision making, 2-tuple linguistic representation, linguistic hierarchies, COPRAS, TOPSIS

1 Introduction

Food is vital requirement for people to continue their lives. The grand majority of staple foods, 95%, need cooking before they can be eaten and most people cook 2-3 times per day. 90% of household energy consumption is casued by cooking energy in developing countries. Nowadays, in the some parts of the world which are especially developed countries, electricity and gas are preferred as cooking fuel, biomass and biomass stoves are only used for recreational cooking. Frequently, biomass fuels are the only available energy source, particularly in rural areas. In most Sub-Saharan countries, more than 80% of the population uses biomass fuels for their daily cooking. Worldwide biomass fuels including firewood, charcoal, dung and agricultural residues are utilized by 2.9 billion people. In 2030, it is expected that 2.52 billion people will use biomass for cooking although use of electricity will be still increasing. Further, in the rural areas, cooking will dominate the aggregate consumption of energy [1].

This work aims to determine the most appropriate fuel provider alternative by employing linguistic hierarchies and COPRAS method. Over the last decade, researchers have contributed to the provider selection by developing multi-criteria decision making approaches. Wu and Chien [2] introduced a decision framework to evaluate outsourcing providers and solved order allocation problem. Büyüközkan et al. [3] proposed a 2-additive choquet integral method to fourth party logistics service provider selection problem. They conducted a case study in a logistic firm that performs in Turkey. Kahraman et al. [4] ranked IT service providers for a furniture company in Konya, Turkey. Wan et al. [5] determined the most suitable logistics outsourcing provider by employing an intuitionistic fuzzy linear programming methodology. Govindan et al. [6] identified 3PL provider selection factors to allow managers in automotive industry to achieve competitive advantages. Wang et al. [7] evaluated the contractors in logistics outsourcing. Rajaeian et al. [8] provided a literature survey on information technology (IT) outsourcing by applying MCDM, optimization and simulation methods that support IT outsourcing decision process.

The remaining parts of the work are organized as follows. Section 2 outlines materials and methods. The case study, which is conducted in food industry of Turkey, is presented in Section 3. Finally, concluding remarks and future research directions are delineated in the last section.

2 Materials and Methods

2.1 2-Tuple Linguistic Representation Model

The 2-tuple linguistic model that was introduced by Herrera and Martínez [9] is based on the concept of symbolic translation. It is utilized to represent the linguistic assessment information by means of a 2-tuple that is composed of a linguistic term and a number. It can be denoted as (s_i, α) where s_i denotes the linguistic label of the described linguistic term set S_T, and α is a numerical value indicating the symbolic translation.

Important definitions are given in the following to operate with the 2-tuples without loss of information.

Definition 1 [10]: Let $L = (\gamma_0, \gamma_1, ..., \gamma_g)$ be a fuzzy set described in S_T. A transformation function χ that transforms L into a numerical value in the interval of granularity of $S_T, [0, g]$ is given as

$$\chi : F(S_T) \rightarrow [0, g],$$
$$\chi(F(S_T)) = \chi(\{(s_j, \gamma_j), j = 0,1,\ldots,g\}) = \frac{\sum_{j=0}^{g} j\gamma_j}{\sum_{j=0}^{g} \gamma_j} = \beta. \quad (1)$$

where $F(S_T)$ is the set of fuzzy sets defined in S_T.

Definition 2 [9]**:** Let $S = \{s_0, s_1, ..., s_g\}$ be a linguistic term set and $\beta \in [0, g]$ a value supporting the result of a symbolic aggregation operation, then the 2-tuple that expresses the equivalent information to β is obtained with the following function:

$$\Delta : [0, g] \rightarrow S \times [-0.5, 0.5),$$
$$\Delta(\beta) = \begin{cases} s_i, & i = \text{round}(\beta) \\ \alpha = \beta - i, & \alpha \in [-0.5, 0.5), \end{cases} \quad (2)$$

where 'round' is the usual round operation, s_i has the closest index label to 'β' and 'α' is the value of the symbolic translation.

Proposition 1 [9]**:** Let $S = \{s_0, s_1, ..., s_g\}$ be a linguistic term set and (s_i, α) be a 2-tuple. There is a Δ^{-1} function, such that, from a 2-tuple it returns its equivalent numerical value $\beta \in [0, g] \subset \Re$. This function is defined as

$$\Delta^{-1} : S \times [-0.5, 0.5) \rightarrow [0, g],$$
$$\Delta^{-1}(s_i, \alpha) = i + \alpha = \beta. \quad (3)$$

2.2 Linguistic Hierarchies

The concept of linguistic hierarchies was proposed by Cordon et al. [11] to design hierarchical systems of linguistic rules, then it was utilized to enhance precision of computing with words in the multi-granular linguistic information contexts [10]. A linguistic hierarchy is a set of levels, where each level is a linguistic term set with different granularity to the rest of levels of the hierarchy. Each level belonging to a linguistic hierarchy is denoted as $l(t, n(t))$, where t indicates the level of the hierarchy, and $n(t)$ is the granularity of the linguistic term set of the level t [10]. A linguistic hierarchy, LH, can be defined as the union of all levels t as $LH = \bigcup_t l(t, n(t))$.

The linguistic term set of level t+1 is obtained from its predecessor as [10]

$$L(t, n(t)) \rightarrow L(t+1, 2.n(t) - 1) \quad (4)$$

Linguistic hierarchies are used to avoid the problem of loss of information that occurs in the unification phase of multigranular linguistic information. The transformation function between linguistic terms in any level of the hierarchy is defined as

$$TF_{t'}^{t} : l(t, n(t)) \rightarrow l(t', n(t'))$$
$$TF_{t'}^{t}(s_i^{n(t)}, \alpha^{n(t)}) = \Delta\left(\frac{\Delta^{-1}(s_i^{n(t)}, \alpha^{n(t)})(n(t') - 1)}{n(t) - 1}\right) \quad (5)$$

The transformation function is bijective, which guarantees the transformations are performed without loss of information [10].

2.3 COPRAS Method

The COPRAS (COmplex PRoportional ASsessment) method is an MCDM (multi-criteria decision making) method that identifies a solution relative to the ideal solution. It was introduced by Zavadskas and Kaklauskas [12].

The stepwise representation of the fuzzy COPRAS is given below.

***Step* 1.** Identify the alternatives A_i, $(i = 1,2,..., m)$, and required selection criteria C_j, $(j = 1,2,..., n)$.

***Step* 2.** Construct the decision matrices that denote the importance weight of criteria, and the ratings of alternatives with respect to criteria.
***Step* 3.** Normalize the decision matrix.
***Step* 4.** Calculate the weighted normalized decision matrix. The weighted normalized value $\tilde{v}_{ij}$ is calculated as

$$\tilde{v}_{ij} = w_j \tilde{r}_{ij},\ i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n \tag{6}$$

where $\tilde{r}_{ij}$ represents the normalized rating of the *i*th alternative regarding *j*th criterion and w_j is the weight of the *j*th criterion, and $\sum_{j=1}^{n} w_j = 1.$

***Step* 5.** Compute the sum of criteria value for benefit-related attributes for which the greater the performance value the more its preference as in Eq. (7)

$$\tilde{P}_i = \sum_j \tilde{v}_{ij} \tag{7}$$

Step 6. Compute the sum of criteria value for cost-related attributes for which the greater the performance value the less its preference as in Eq. (8)

$$\tilde{R}_i = \sum_j \tilde{v}_{ij} \tag{8}$$

Step 7. Compute the relative weight of alternatives as

$$\tilde{Q}_i = \tilde{P}_i + \frac{\tilde{R}_{\min} \sum_i \tilde{R}_i}{\tilde{R}_i \sum_i \frac{\tilde{R}_{\min}}{\tilde{R}_i}} \tag{9}$$

Step 8. $\tilde{Q}_i = (q_i^1, q_i^2, q_i^3)$ is transformed to non-fuzzy via Eq. (10)

$$Q_i = \frac{\left(q_i^3 - q_i^1\right) + \left(q_i^2 - q_i^1\right)}{3} + q_i^1 \tag{10}$$

Step 9. Determine the priority of the alternatives (N_i) using Eq. (11) and rank the alternatives.

$$N_i = \frac{Q_i}{Q_{\max}} 100\% \tag{11}$$

2.3 TOPSIS Method

The technique for order preference by similarity to ideal solution (TOPSIS) proposed Hwang and Yoon [13] is one of the well-known methods for classical multi-attribute decision making. TOPSIS is based upon the assumption that the chosen alternative should have the shortest distance from the ideal solution and the farthest from the anti-ideal solution.

The stepwise representation of the TOPSIS is given below.
***Step* 1.** Identify the alternatives A_i, $(i = 1,2,..., m)$, and required selection criteria C_j, $(j = 1,2,..., n)$.
***Step* 2.** Construct the decision matrices that denote the importance weight of criteria, and the ratings of alternatives with respect to criteria.
***Step* 3.** Normalize the decision matrix to obtain unit-free and comparable criteria values as

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n \tag{12}$$

where r_{ij} denotes the normalized value of x_{ij}, *m* is the number of alternatives, *n* is the number of criteria.
***Step* 4.** Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as

$$v_{ij} = w_j r_{ij},\ i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n \tag{13}$$

where w_j is the weight of the *j*th criterion, and $\sum_{j=1}^{n} w_j = 1.$

***Step* 5.** Define the ideal solution, A^*, and the anti-ideal solution, A^-. The A^* and A^- are defined in terms of the weighted normalized values as shown in Eqs. (8) and (9), respectively.

$$\begin{aligned} A^* &= \left\{v_1^*, v_2^*, ..., v_n^*\right\} \\ &= \left\{\left(\max_i v_{ij} \middle| j \in J_1\right), \left(\min_i v_{ij} \middle| j \in J_2\right)\right\}, \end{aligned} \tag{14}$$

$$\begin{aligned} A^- &= \left\{v_1^-, v_2^-, ..., v_n^-\right\} \\ &= \left\{\left(\min_i v_{ij} \middle| j \in J_1\right), \left(\max_i v_{ij} \middle| j \in J_2\right)\right\} \end{aligned} \tag{15}$$

where J_1 is the set of benefit-related criteria for which the greater the performance value the more its preference, J_2 is the set of cost-related criteria for which the greater the performance value the less its preference.

***Step* 6.** Calculate the separation measures using the *n*-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as

$$D_i^* = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^*\right)^2}, \quad i = 1,2,...,m \tag{16}$$

Similarly, the separation from the anti-ideal solution is given as

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2}, \quad i = 1,2,...,m \tag{17}$$

***Step* 7.** Calculate the relative closeness to the ideal solution as in Eq. (12).

$$C_i^* = \frac{D_i^-}{D_i^* + D_i^-}, \quad i = 1,2,...,m \tag{18}$$

***Step* 8.** Rank the alternatives according to C_i^* values in descending order. Identify the alternative with the highest C_i^* as the best alternative.

3 Case Study

To illustrate the application of the proposed decision making approach, which is illustrated in Figure 1, for fuel provider selection, a case study conducted in food industry of Turkey, is introduced. The case company performs in Turkish food sector, and wants to provide cooking fuel from a third party provider. Evaluation criteria are determined and assessed by literature survey and opinions of three employees who works in the case company for minimum four years. Seven criteria for fuel provider problem are defined as

C_1: Lead time
C_2: Reliability
C_3: Sustainability
C_4: Cost
C_5: Service quality
C_6: Location
C_7: Warranties

The evaluation is conducted by a committee of three decision-makers (DM_1, DM_2, DM_3). The linguistic hierarchy $LH = \bigcup_t l(1,3)$, shown in Table 1, is considered as multi-granular linguistic context, since the granularity of its linguistic term sets are very common in decision-making problems.

Table 1. Linguistic hierarchy $LH = \bigcup_t l(1,3)$

$l(1,3)$	(s_0^3, s_1^3, s_2^3)
$l(2,5)$	$(s_0^5, s_1^5, s_2^5, s_3^5, s_4^5)$
$l(3,9)$	$(s_0^9, s_1^9, s_2^9, s_3^9, s_4^9, s_5^9, s_6^9, s_7^9, s_8^9)$

The linguistic term set $l(2,5)$ is indicated as linguistic terms set to unify the multi-granular linguistic information given by the experts. In the decision process, equal weights are appointed to decision-makers. Hence, the unified evaluations of decision-makers are aggregated by incorporating 2-tuple mean operator, and the aggregated data related to agile supplier selection problem are given in Table 2.

Table 2. Aggregated data related to agile supplier selection problem

	A_1	A_2	A_3	A_4	Weight
C_1	$(s_4^5, -0.33)$	$(s_1^5, 0.33)$	$(s_2^5, -0.17)$	$(s_4^5, -0.17)$	$(s_1^5, -0.17)$
C_2	$(s_3^5, -0.5)$	$(s_4^5, -0.33)$	$(s_4^5, -0.33)$	$(s_1^5, -0.17)$	$(s_4^5, -0.33)$
C_3	$(s_3^5, -0.5)$	$(s_4^5, -0.5)$	$(s_4^5, -0.33)$	$(s_4^5, -0.33)$	$(s_3^5, 0.17)$
C_4	$(s_4^5, -0.5)$	$(s_1^5, 0.33)$	$(s_3^5, -0.33)$	$(s_3^5, 0.17)$	$(s_4^5, -0.5)$
C_5	$(s_4^5, -0.33)$	$(s_4^5, -0.17)$	$(s_2^5, 0.33)$	$(s_1^5, -0.17)$	$(s_1^5, -0.17)$
C_6	$(s_4^5, -0.33)$	$(s_1^5, -0.17)$	$(s_2^5, 0.33)$	$(s_4^5, -0.17)$	$(s_3^5, 0.17)$
C_7	$(s_2^5, 0.33)$	$(s_2^5, -0.17)$	$(s_4^5, -0.17)$	$(s_4^5, -0.17)$	$(s_4^5, -0.33)$

By employing COPRAS method, the final ranking of alternatives is obtained as in Table 3.

Table 3. Ranking of alternatives employing COPRAS method

	Q_i	N_i	Rank
A_1	0.135	87.26%	4
A_2	0.139	89.95%	3
A_3	0.155	100%	1
A_4	0.148	95.70%	2

In order to provide a comparative analysis, TOPSIS method is also employed. The final ranking of alternatives is obtained as in Table 4.

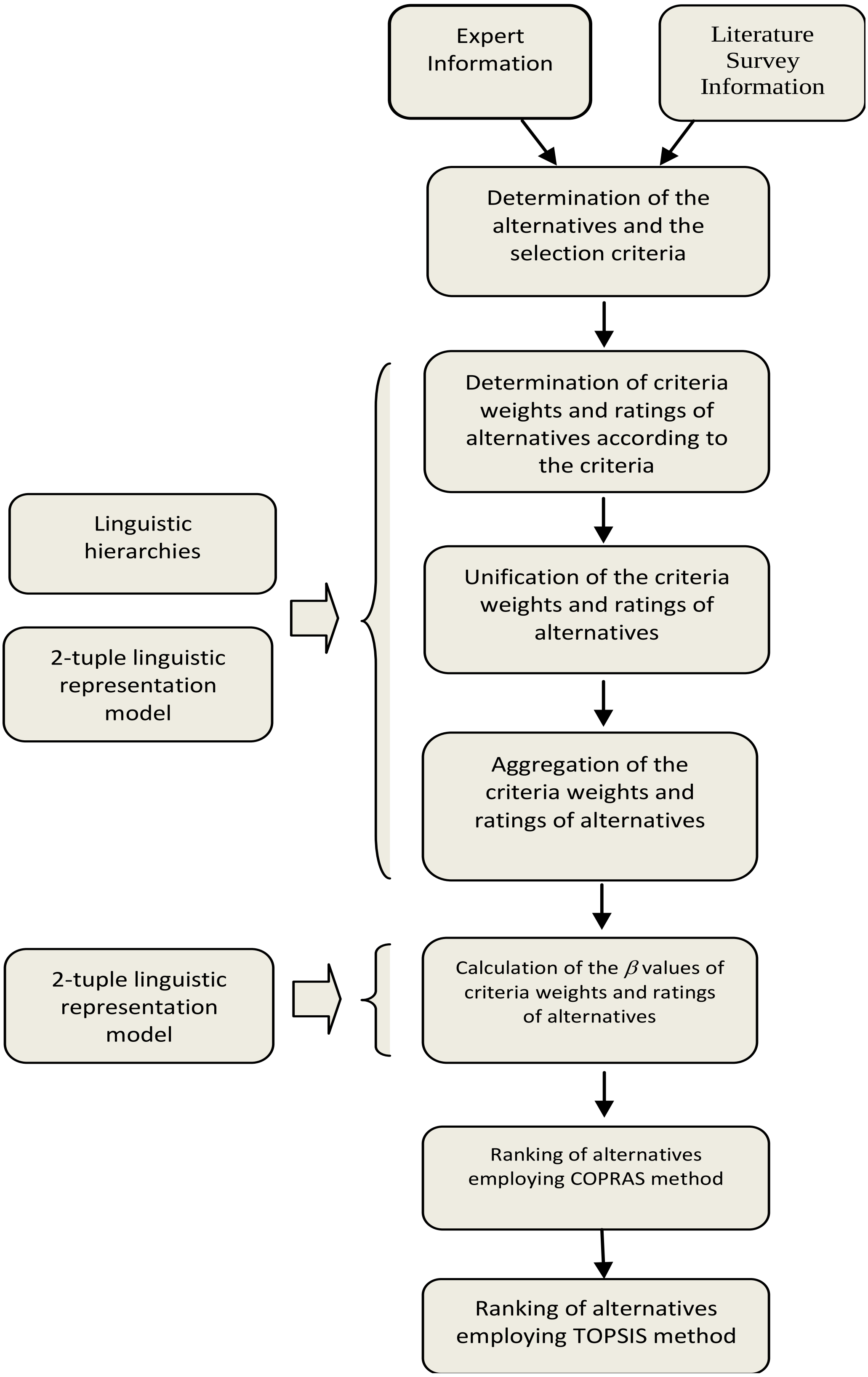

Fig. 1. Illustration of the proposed fuzzy decision making algorithm

Table 4. Ranking of alternatives employing TOPSIS method

	*D**	*D*-	*C**	Rank
A_1	5.317	0.786	0.128	4
A_2	5.368	0.980	0.154	1
A_3	5.218	0.857	0.141	2
A_4	5.272	0.841	0.137	3

4 Conclusions

Fuel provider selection problem, which contains several individual factors including vagueness and imprecision, may be thought as a highly important group decision-making problem. In this study, a fuzzy multi-criteria decision making approach which combines 2-tuple fuzzy linguistic modeling, linguistic hierarchies, and COPRAS method is introduced. The developed approach aims to manage multi-granular linguistic information, allows decision makers to use different semantic types, and copes with loss of information which may be occur due to the classical MCDM methods.

Lead time, reliability, sustainability, cost, service quality, location and warranties are considered as evaluation criteria. A numerical example, which illustrates the application, is provided by conducting a case study in food sector of Turkey. Future research may focus on multi-criteria decision problems with the presence of interdependence/interactions among criteria which influence the ranking process.

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