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THE SELECTION OF EQUIPMENT FOR RECYCLING BY USING FUZZY COPRAS METHOD

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Abstract. *The aim of this study is to propose a new fuzzy multi-criteria model to evaluate recycling equipment with respect to numerous criteria, simultaneously, taking into account the type of each criteria and its relative importance. The all existing uncertainties into the criteria weights and their values are described by pre-defined linguistic expressions which are modelled by fuzzy sets theory. Fuzzy assessments of the criteria weights are performed in direct way. Determining the criteria weights is based on method for comparison of fuzzy numbers. The rank of possible recycling equipment is obtained by applying modified Fuzzy COPRAS (Complex Proportional Assessment of alternatives) technique. The proposed model is illustrated by example with real-life data come from reverse supply chain existing in the Republic Serbia. The presented solution provides base for successful improvement of reverse supply chain management.*

Key words: *recycling equipment, fuzzy sets, fuzzy COPRAS, rank, degree of belief.*

1. INTRODUCTION

During the last few decades, management of sustainable development is getting a lot of attention in variety of disciplines. There are numbers of different engineering, business, environmental and social factors which impact sustainable development (Ziout et al., 2014). By respecting the results of the good practice in developed countries, it can be said that the solving of reverse logistic problems can lead to reducing the consumption of natural resources, reducing waste and increasing environmental protection. As a positive consequence, this may lead to increasing effectiveness of many industries and achieving sustainable development of national, regional and global economy.

The selection of recycling equipment may be stated as a strategic management task. The solution of this task depends on experts' knowledge in the field of recycling. Respecting the mentioned facts, it can be concluded that the selection of equipment for recycling represents one of burning issues in the field of recycling.

The selected recycling equipment has the highest impact to a successful ELV recycling. In the current literature, many research papers may be found in the field of reverse logistics such as selection of recycling technologies (Pavlović et al, 2016), determination of the optimal material flow from collecting centres to recycling centres (Diener and Tillman, 2015). For solving mentioned issues, different mathematical tools have been applied (Tadić et al., 2018).

In solving issues, such as selection of recycling equipment, the evaluation criteria can be given according to literature data or results good practice. In this paper, the evaluation criteria is selected in compliance with assessment of stakeholders and manufacturers of recycling equipment. The existing uncertainties in the relative importance of criteria for assessment of recycling equipment and criteria values are described by linguistic variables which are modelled by triangular fuzzy numbers (TFNs) (Dubois and Prade, 1980).

In this paper, all uncertainties are described by five linguistic variables. The domains of defined TFNs are defined on common measurement scale (Saaty, 1990). The fuzzy assessment is performed by decision makers and the determination of criteria weights is based on method of comparing fuzzy numbers (Bass, and Kwakernaak, (1977); Dubois and Prade, (1980). The ranking of recycling equipment is based on modified COPRAS method.

The paper is organized in the following way. The proposed model and the proposed Algorithm are presented in Section 2. In Section 3, the proposed model is illustrated by an example with a real-life data. Conclusion is set in Section 4.

2. METHODOLOGY

The selection of recycling equipment is a problem that can be set as a multi-criteria decision making task. Criteria for assessing recycling equipment are formally presented as set $\kappa = \{1,..., k,.., K\}$. The total number of criteria is denoted as K and k, k=1,..,K is index of criteria. As it is known, criteria can be benefit and cost type. Hence, set κ is composed of two sub sets, so $\kappa' = \{1,..., k,.., K'\}$ and $\kappa'' = \{K'+1,..., k,.., K\}$. Let the sub set $\kappa' = \{1,..., k,.., K'\}$ represents the set of benefit criteria which are employed for assessment of recycling equipment and K' is the total number of benefit criteria. Also, let the sub set $\kappa'' = \{K'+1,..., k,.., K\}$ represent set of cost criteria. the number and type of criteria is determined by the decision makers in compliance with their knowledge and evidence data. The total number of different recycling equipment is denoted as I. The set of recycling equipment which is treated is $\iota = \{1,..., i,.., I\}$ and i, i=1,..,I is index of recycling equipment. The assessment of criteria weight is based on subjective opinion of decision makers. They articulate their opinions by using pre-defined linguistic expressions which are modelled by triangular fuzzy numbers (TFNs). The domains of these TFNs are defined on the common measurement scale (Saaty, 1990) in the following way:

very low (VL) - $(x;1,1,5.5)$, low (L) - $(x;1,3,7)$, moderate (M) - $(x;1.5,5,8.5)$, high (H) - $(x;5,7,9)$, and very high (VH) - $(x;4.5,9,9)$.

It may be assumed that the decision makers form decision by consensus. The assessment of criteria weights and criteria values on the level of each type of recycling equipment is performed by decision makers who perform their decision in direct manner.

The proposed Algorithm

The proposed Algorithm is realized through the following steps:

Step 1. The weight of each criteria k, k=1,..,K , $\tilde{\theta}_k$ as well as the value of criterion k for each type of recycling equipment i, i=1,.,,I, $\tilde{\gamma}_{ik}$ is assessed by decision makers which use one of five pre-defined linguistic expressions.

Step 2. The degree of belief that a fuzzy number $\tilde{\theta}_k$ is bigger than/equal to K fuzzy numbers $\tilde{\theta}_1,..., \tilde{\theta}_k,..., \tilde{\theta}_K$, (Bass, and Kwakernaak, 1977) is determined:

$$\mathrm{Bel}\left(\tilde{\theta}_{k'} \geq \left(\tilde{\theta}_1,..., \tilde{\theta}_k,...., \tilde{\theta}_K\right)\right) =$$

$$\sup\min\left(\mu_{\tilde{\theta}_{k'}}, \mu_{\tilde{\theta}_1},..., \mu_{\tilde{\theta}_k},..., \mu_{\tilde{\theta}_K}\right) =$$

$$\mathrm{Bel}\left(\left(\tilde{\theta}_{k'} \geq \tilde{\theta}_1\right), \mathrm{and}\left(\tilde{\theta}_{k'} \geq \tilde{\theta}_2\right),...,\left(\tilde{\theta}_{k'} \geq \tilde{\theta}_k\right),...,\left(\tilde{\theta}_{k'} \geq \tilde{\theta}_K\right)\right) =$$

$$\min_{k', k=1,..,K;\, k' \neq k} \mathrm{Bel}\left(\tilde{\theta}_{k'} \geq \tilde{\theta}_k\right)$$

Weights vector is set as:

$$W_p = \left(\left(\mathrm{Bel}\left(\tilde{\theta}_1\right)\right),...,\left(\mathrm{Bel}\left(\tilde{\theta}_k\right)\right),...,\left(\mathrm{Bel}\left(\tilde{\theta}_K\right)\right)\right)$$

The normalized weights vector is:

$$\left(w_1,..., w_k,..., w_K\right)$$

is nonfuzzy number (Isiklar G. and Büyüközkan, 2007; Paksoy, 2012).

Step 3. Fuzzy rating of each type of recycling equipment i, $\tilde{\gamma}_{ik} = \left(l_{ik}, m_{ik}, u_{ik}\right)$, i=1,..,I, are normalized by using the linear normalization procedure (LIT):

$$\tilde{r}_{ik} = \left(\frac{l_{ik}}{u^*}, \frac{m_{ik}}{u^*}, \frac{u_{ik}}{u^*}\right) \text{ where } u^* = \max_{i=1,..,i}\left(u_{ik}\right)$$

Step 4. The weighted normalized fuzzy decision matrix $\left[\tilde{d}_{ik}\right]_{IxK}$, whose elements are calculated according to fuzzy algebra rules (Dubois and Prade, 1980), is calculated as:

$$\tilde{d}_{ik} = w_k \cdot \tilde{r}_{ik}$$

Step 5. The aggregated value of alternative i, i=1,..,I with respect to all benebit criteria by using fuzzy algebra rules (Dubois and Prade, 1980) is determined as: $\tilde{P}_i = \sum_{k=1}^{K'} w_k \cdot \tilde{r}_{ik}$

Step 6. The aggregated value of alternative i, i=1,..,I with respect to all cost criteria by using fuzzy algebra rules (Dubois and Prade, 1980) is calculated as:

$$\tilde{R}_i = \sum_{k=K'+1}^{K} w_k \cdot \tilde{r}_{ik}$$

Step 7. The relative value of each type of recycling equipment i, i=1,..,I is determined as:

$$\tilde{Q}_i = \tilde{P}_i + \frac{\sum_{i=1}^{I} \tilde{R}_i}{\tilde{R}_i \cdot \sum_{i=1}^{I} \frac{1}{\tilde{R}_i}}$$

According to fuzzy algebra rules (Dubois and Prade, 1980) the obtained value is not TFN. In the same time, an assumption that the value $\tilde{Q}_i, i = 1,..,I$ may be described as TFN (Dubois and Prade, (1980)) with enough preciseness.

Step 8. The maximum relative value $\tilde{Q}_{max}$ is determined by using the method for comparison fuzzy numbers (Dubois and Prade, (1980).

Step 9. The degree of efficiency of each type of recycling equipment is calculated:

$$\tilde{\varsigma}_i = \frac{\tilde{Q}_i}{\tilde{Q}_{max}}$$

The degree of belief that one type of recycling equipment is better than the rest with respects to treated criteria is calculated $Bel\left(\tilde{Q}_{i'} \geq (Q_i)\right), i, i' = 1,.., I; i \neq i'$ according to procedure which is proposed in Bass, and Kwakernaak, (1977) and Dubois and Prade, (1980).

Step 10. The rank of treated types of recycling equipment is determined according to the rank of TFNs, $\tilde{\varsigma}_i, i = 1,.., I$.

Step 11. The decision about the selection of recycling equipment is performed by management team of recycling centre by respecting the obtained rank as well as calculated degrees of belief.

3. ILLUSTRATIVE EXAMPLE

The wide literature review has included the guidelines suggested by different recycling equipment manufacturers (Marathon, WESSCO and Caterpillar) and relevant surveys so chosen set of criteria is: Size of Waste (k=1), Recyclables (k=2), Safety Standards (different) (k=3), Power Source (different) (k=4), Convenience (k=5), Available Space (different) (k=6).

The treated equipment is: mobile press (i=1), oil recycling device (i=2), the shredder for cables (i=3). Fuzzy rating of the relative importance of evaluation criteria (Table 1) are: M, VH, H, VL, L, and H, respectively (Step 1 of the proposed Algorithm).

Table 1 - Fuzzy rating of the relative importance of evaluation criteria

	K=1	K=2	K=3	K=4	K=5	K=6
i=1	L	L	M	L	H	VL
i=2	M	VL	L	L	M	M
i=3	H	VL	M	L	L	VH

By using the proposed Algorithm (Step 2 to Step 3), the weights vector is calculated and it can be presented as:

$$W_p = (0.062, 0.294, 0.500, 0.692, 1)$$

The normalized weights vector is:

$$(0.025, 0.115, 0.196, 0.272, 0.392)$$

The weighted normalized fuzzy decision matrix is presented in Table 2 (Step 3 to Step 4 of the proposed Algorithm).

Table 2 - The weighted normalized fuzzy decision matrix

	k=1 max	**k=2 max**
i=1	(0.022,0.065,0.152)	(0.044,0.131,0.305)
i=2	(0.033,0.109,0.185)	(0.044,0.065,0.218)
i=3	(0.109,0.152,0.196)	(0.044,0.065,0.218)
	k=3 max	**k=4 max**
i=1	(0.045,0.151,0.257)	(0.003,0.008,0.019)
i=2	(0.030,0.091,0.212)	(0.003,0.008,0.019)
i=3	(0.045,0.151,0.257)	(0.003,0.008,0.019)
	k=5 max	**k=6 min**
	(0.064,0.089,0.115)	(0.054,0.181,0.272)
	(0.019,0.064,0.109)	(0.032,0.054,0.181)
	(0.013,0.038,0.089)	(0.030,0.030,0.061)

The aggregated value of recycling equipment i, i=1,..,I with respect to all benefit criteria (Step 5 of the proposed Algorithm) is determined. The developed procedure is illustrated by example:

$$\tilde{P}_1 = (0.178, 0.444, 0.848)$$

$$\tilde{P}_2 = (0.129, 0.337, 0.819) \quad \tilde{P}_3 = (0.214, 0.414, 0.886)$$

The aggregated value of recycling equioment i, i=1,..,I with respect to all cost criteria are (Step 6 of the proposed Algorithm):

$$\tilde{R}_1 = (0.054, 0.181, 0.272) \qquad \tilde{R}_2 = (0.032, 0.054, 0.181)$$

$$\tilde{R}_3 = (0.030, 0.030, 0.061)$$

The relative value of the each recycling equipment i, i=1,..,I is calculated by using the proposed procedure (Step 7 of the proposed Algorithm):

$\tilde{Q}_1 = (0.189, 1.444, 2.218)$ $\tilde{Q}_2 = (0.135, 0.391, 1.843)$

$\tilde{Q}_3 = (0.229, 0.444, 1.010)$

The greatest relative value of recycling equipment $\tilde{Q}_{max}$ is obtained by using the proposed Algorithm (Step 8), so that: $\tilde{Q}_{max} = \tilde{Q}_1$

By using the proposed Algorithm (Step 9 to Step 11), the value of efficiency coefficient, degrees of belief and rank of the considered recycling equipment are given and presented in Table 3.

Table 3 - Efficiency coefficient, degree of belief and rank

	$\tilde{\varsigma}_i$	Degree of belief	Rank
i=1	(0.085,1.00,11.735)	1	1
i=2	(0.061, 0.271, 9.751)	0.929	2
i=3	(0.103,0.307,5.344)	0.884	3

On the basis of the obtained results it can be clearly concluded that the most suitable type of equipment is mobile press (i=1). At the second place in rank, there is oil recycling device (i=2). At the last place in rank, there is shredder for cables (i=3). Respecting the calculated value of degrees of belief measures, it can be said that it is impossible to make a clear difference which type of recycling equipment is dominantly better than others. From the perspective of decision-makers, this result shows that decision makers should purchase all three devices simultaneously or evaluate them according to additional criteria.

4. CONCLUSIONS

This paper investigates the issue of selection of appropriate equipment for recycling. This is one of the most significant issues in the activities of reverse logistics entities due to complex processes and a certain level of uncertainty associated with recycling centers and market demands.

The main contribution of this paper is represents the ranking of recycling equipment based on modified COPRAS method.

The main constraints of the proposed model are associated with the need of expert team and their relevant knowledge in recycling.

The future research should include testing of the model in different recycling centers and comparative analysis of obtained results so the proposed model could be verified.

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