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PRIMARY RESEARCH

Ranking of recycling technologies metal components of end of life vehicles by using modified electre

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Abstract

The evaluation and selection of recycling technologies presents one of the most important operational management problems. In this paper, a new fuzzy model to evaluate recycling technologies with respect to numerous criteria, simultaneously, taking into account the type of each criteria and its relative importance. The relative importance of criteria and their values are modelled by interval triangular fuzzy numbers type-2. Determining the criteria weights is stated as a fuzzy group decision making problem. The ranking of considered recycling technologies is obtained by applying modified ELECTRE. A case study with real-life data which come from reverse supply chain existing in the Republic Serbia is presented to illustrate the proposed method. The presented solution enables the ranking of recycling technologies and provides base for successful improvement of reverse supply chain management.

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I. INTRODUCTION

In the past decades, the reverse supply management is very relevant in research and practical domain. Many authors suggest that it is necessary to focus on End-Life-Vehicle (ELV) because ELVs are hi-tech products composed of different recyclable materials and used in numbers of industries as automobile industry, information technology industry, steel industry [1, 2, 3]. The evaluation and selecting of recycling technologies are one of significant operational management problem which is widely considered in the relevant literature [4, 5, 6, 7]. Determining personal capacity and quantity of recycling material, as well as necessary finances for supply of recycling equipment is based on selected recycling technologies [4, 8]. The problem of evaluating and ranking technological strategies to enhance the ELV recovery efficiency under uncertainties is treated in [5]. ELVs are described in terms of several sub-assembles which are expressed using six types of materials such as aluminum, ferrous and nonferrous material, plastics and other materials. By applying appropriate recycling technologies, the quality of recyclates can be increased, which leads to increased use of recycled material in production processes, or to decreasing of natural resources, and increasing environmental protection and at the same time increasing effectiveness of many industries and rise of sustainable development.

It can be said that evaluation and selecting of recycling technologies depends on many criteria. Determining of these evaluation criteria is based on literature data [9, 10] or the results of the best practice. Many authors suggest that these criteria have a different the relative importance and values at the level of each recycling technology. The relative importance and values it is almost impossible to determine the measurement. Therefore, their values are obtained accord-

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ing to the estimates of decision makers. Many authors suggest that decision makers could not, in a sufficiently effective way, make their assessments if they use numerical measurement scales. Therefore, it is more realistic to assume that they use linguistic terms which are defined as a linguistic variable, i.e., words or sentences and they are modeled by fuzzy sets [11]. In this research, all existing uncertainties are described by pre-defined linguistic expressions. Those are modeled by the interval type-2 trapezoidal fuzzy numbers [12, 13]. It can be concluded that type-2 fuzzy sets are more suitable to represent uncertainties than type-1 fuzzy sets. These fuzzy numbers are widely used to solve different decision-making problems [14, 15, 16].

The solution of the considered problem can be given by using the many multi-criteria optimization methods. [4] carried out research in domain evaluation and selecting of RTs under uncertainties. The determination of recycling technologies priorities under each considered criterion as well as the relative importance of criteria is stated as fuzzy group decision making problem. Fuzzy Analytic Hierarchy Process (AHP) [17] is used for ranking of recycling technologies. In [6], the relative importance of criteria at the level of each recycling technology is stated as fuzzy group decision making problem. Fuzzy rating of decision makers is modeled by triangular fuzzy numbers. The rank of recycling technologies is determined by applying the fuzzified TOPSIS method.

The main contribution of this paper is the introduction of the interval fuzzy sets for modeling of existing uncertainties for evaluation and ranking of recycling technologies which use for ELV recycling. The relative importance of criteria is stated as fuzzy group decision making problem. With respects to opinion, the authors of this paper suggested fuzzification of conventional ELECTRE [18]. It may be considered that this method is useful for assessment and selection of recycling technologies taking into account the numerous criteria and its relative importance.

The rest of the paper is organized as follows: The proposed model is presented in Section 2. The proposed Algorithm based o fuzzy group decision making approach and fuzzy ELECTRE model is given in Section 3. The proposed model is illustrated by an example with real-life data in Section 4. Discussion and Conclusions are presented in Section 5.

II. THE PROPOSED MODEL

It is assumed that many decision makers have got participation in evaluation of recycling technologies. They can be presented by sets indices $\varepsilon = \{1, \ldots, e, \ldots, E\}$. The index for a decision maker is denoted as e, and E is the total number of decision makers. Decision makers team consists of recycling expert from the national firm for recycling, member of the National Chamber of Commerce, financial expert, production manager from recycling center, and manufacturer of equipment for recycling.

The set of possible recycling technologies are defined according to assessment of decision makers and should be formally presented by set of indices $t = \{1, \ldots, i, \ldots, I\}$. The total number of treated recycling technologies is denoted as *I*. The index for a recycling technology is denoted as *i*, *i* = 1,.., *I*.

The selection of the evaluation criteria is performed by expert team and it is crucial and very essential for obtaining good, relevant and quality solution of the considered problem. It is common to selection criteria is based on results of the best practice. Identified criteria can be presented by the set of indices $K = \{1, \ldots, k, \ldots, K\}$. The index for an evaluation criterion is denoted as *k*, *k* = 1,..,*K* and *K* is the total number of considered evaluation criteria. In this paper, the rating of possible RTs is performed under criteria: investment in RT (*k* = 1), energy efficiency (*k* = 2), costs and availability of maintenance (*k* = 3), impact recycling technology on the environment (*k* = 4), safety in exploitation (*k* = 5).

Criteria do not have the same relative importance and they are unchangeable during a certain period. The relative importance of criteria at the level of each recycling technology is performed by decision maker. These assessments are described by five pre-defined linguistic expressions which are modeled by the interval type-2 trapezoidal fuzzy numbers. Their domains are defined as the interval [0-1]. The value 0 denotes that the relative importance of criteria at the recycling technologies is the lowest and the highest, respectively. They are presented as:

Low importance (LW)-
$(0, 0, 0.25, 0.6; 1, 1)(0, 0, 0.25, 0.5, 0.75, 0.75))$

Medium importance (MW)-
$((0.3, 0.5, 0.7, 0.9 \quad - \quad 1, 1), (0.35, 0.5, 0.7, 0.85, 0.75, 0.75))$

High importance (HW)-
$((0.4, 0.75, 1, 1, 1, 1), (0.5, 0.75, 1, 1, 0.75, 0.75))$

Determination of criteria weights are stated as fuzzy group decision making problem. The aggregation is performed by the fuzzy averaging method. The values of recycling technologies are not very suitable for description by precise numbers since decision makers base their estimates on literature data, experience and evidence data. In this case, the recycling technologies values are described by using linguistic terms. Those terms are modeled by the interval type-2 trapezoidal fuzzy numbers: Very Low (VL)-

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$((1,1,2,3;1,1),(1,1,2,2\cdot 5;0.8,0.8))$
Low (L)-
$(1,2,3,4;1,1),(1.5,2,3,3.5,0.8,0.8))$
Fairly Moderate (FM)-
$((2,3.5,4.5,6-1,1),(2.5,3.5,4.5,5.5;0.8,0.8))$
Moderate (M)-
$(2,3.5,4.5,6;1,1),(2.5,3.5,4.5,5.5;0.8,0.8))$
Fairly High (FH)-
$((4.5.5,6.5,8,1,1),(5,5.5,6.5,7.5;0.8,0.8)))$
High (H)-
$(6,7.8,9-1,1),(6.5,7,7.5,8.5,0.8,0.8))$
Very High (VH)-
$(7,8.9,99,1,1),(7.5,8,9,9;0.8,0.8))$
The domains of these the interval type-2 trapezoidal fuzzy numbers are defined on the Saaty scale [17].

The weighted fuzzy decision matrix is mapped into the fuzzy decision matrix which elements are described by precise numbers. The element of the decision matrix is given by using the defuzzification procedure proposed in [15]. The rank of the treated recycling technologies is given by the using conventional ELECTRE [18].

III. THE PROPOSED ALGORITHM

The proposed Algorithm can be realized into the following steps. Step 1. Fuzzy rating of the relative importance of criterion *k*, *k* = 1,..,*K* for recycling technology *i*, *i* = 1,..,*I* at the level the decision maker *e*, *e* = 1,..,*E* is denoted as:
$\overline{\overline{W}}_{\mathrm{ik}} = \Big(\big((1^{\mathrm{U}}_{\mathrm{ik}})^{\mathrm{e}}, (\mathrm{m}^{\mathrm{U}}_{\mathrm{ik}})^{\mathrm{e}}, (\mathrm{u}^{\mathrm{U}}_{\mathrm{ik}})^{\mathrm{e}}; \mathrm{H}_1\left((\mathrm{m}^{\mathrm{U}}_{\mathrm{ik}})^{\mathrm{e}}\right)\big), \Big((1^{\mathrm{L}}_{\mathrm{ik}})^{\mathrm{e}}, (\mathrm{m}^{\mathrm{L}}_{\mathrm{ik}})^{\mathrm{e}}$
$(\mathrm{u}^{\mathrm{L}}_{\mathrm{ik}})^{\mathrm{e}}; \mathrm{H}_2\left((\mathrm{m}^{\mathrm{L}}_{\mathrm{ik}})\right)\big)\Big), \mathrm{k}=1,\ldots,\mathrm{K}\cdot \mathrm{i}=1; \mathrm{e}=1,\ldots,\mathrm{E}$
Also, the fuzzy rating of the criteria values at the level of each recycling technology level are denoted as:
$\overline{\overline{v}}_{\mathrm{ik}} = \left(\left(\mathrm{L}^{\mathrm{U}}_{\mathrm{ik}}, \mathrm{M}^{\mathrm{U}}_{\mathrm{ik}}, \mathrm{U}^{\mathrm{U}}_{\mathrm{ik}}; \mathrm{H}_1\left(\mathrm{M}^{\mathrm{U}}_{\mathrm{ik}}\right)\right), \left(\mathrm{L}^{\mathrm{L}}_{\mathrm{ik}}, \mathrm{M}^{\mathrm{L}}_{\mathrm{ik}}\mathrm{U}^{\mathrm{L}}_{\mathrm{ik'}}\mathrm{H}_1\left(\mathrm{M}^{\mathrm{L}}_{\mathrm{ik}}\right)\right)\right),$
$\mathrm{k}=1,\ldots\mathrm{K}; \mathrm{i}=1,\ldots\mathrm{I}$
Step 2. Aggregated relative importance of criteria for each recycling technology.
$\overline{\overline{W}}_{\mathrm{ik}} = \left(\left(1^{\mathrm{U}}_{\mathrm{ik}}, \mathrm{m}^{\mathrm{U}}_{\mathrm{ik}}, \mathrm{u}^{\mathrm{U}}_{\mathrm{ik'}}; \mathrm{H}_1\left(\mathrm{m}^{\mathrm{U}}_{\mathrm{ik}}\right)\right), \left(\left(1^{\mathrm{L}}_{ik}, \mathrm{m}^{\mathrm{L}}_{\mathrm{ik}}, \mathrm{u}^{\mathrm{L}}_{\mathrm{ik}}; \mathrm{H}_2\left(\mathrm{m}^{\mathrm{L}}_{\mathrm{ik}}\right)\right)\right)\right)$
$\mathrm{k}=1,\ldots,\mathrm{K}; \mathrm{i}=1,\ldots\mathrm{I}$ is given using the fuzzy averaging method.
Step 3. The weighted fuzzy decision matrix is given as:
$[d^{\approx}_{ik} = W^{\approx}_{ik}.v^{\approx}_{ik}]$
The elements of the weighted fuzzy decision matrix are described by the interval type-2 trapezoidal fuzzy numbers according to fuzzy algebra rules [13].
Step 4. Defuzzification is performed by using the Defuzzied Type-2 Trapezoidal Fuzzy Sets (DTraT) which is proposed in [15].
Step 5. Determine concordance set $\mathrm{S}_{\mathrm{ii'}}$ and discordance set $\mathrm{NS}_{\mathrm{ii'}}, \mathrm{i}, \mathrm{i}' = 1,\ldots,\mathrm{I}; \mathrm{i} \neq \mathrm{i}'$
Step 6. Determine concordance matrix $\mathrm{C} = \lfloor \mathrm{c}_{\mathrm{ii'}} \rfloor_{\mathrm{IxI}}$ and the discordance matrix $\mathrm{N} = \lfloor \mathrm{n}_{\mathrm{ii'}} \rfloor_{\mathrm{IxI}}, i, i' = 1,.,\quad I; i \neq i$
Step 7. The average concordance index given $\bar{\mathrm{c}}$ and the average discordance index $\bar{\mathrm{n}}$ are calculated as: according to expression:
$\overline{c} = \frac{1}{I\cdot(I-1)}\sum_{i=1}^{I}\sum_{i=1}^{I} c_{ui'}, \overline{n} = \frac{1}{I\cdot(I-1)}\sum_{i=1}^{I}\sum_{i=1}^{I} n_{ii'}$
Step 8. Construct the concordance dominance matrix:
$\mathrm{M} = \lfloor \mathrm{m}_{\mathrm{ii'}} \rfloor_{\mathrm{IxI}}$ Where;
$\mathrm{m}_{\mathrm{ii'}} = 0$ if $\tilde{\mathrm{c}}_{\mathrm{it}} < \overline{\mathrm{c}} \vee \mathrm{n}_{\mathrm{it}} > \overline{\mathrm{n}}$
$m_{ii'} = 1$ if $\tilde{c}_{ii'} \geq \overline{c} \wedge n_{ii'} \leq \overline{n}$
Step 9. Rank of the recycling technologies is determined according to the value m_P. These values are sorted into the growing order. Recycling technology, which is associated with the lowest value M_p, is in the first place in the rank and the reverse is also true.
$\mathrm{M}_{\mathrm{i}} = \sum_{\mathrm{i}=1}^{\mathrm{I}} \mathrm{m}_{\mathrm{ii'}}$

IV. THE ILLUSTRATIVE EXAMPLE

The model which is proposed by this research is tested on recycling centers located in the Republic of Serbia. Recycling of the ferromagnetic materials is important task with respects to environmental protection and economic aspect. The ferromagnetic materials which are obtained into recycling processes may be used in the production processes. It is appraised that about 80000 ELV per year are recycled and about 4000 tons coming back into production processes. In this paper, the considered recycling technologies are: shredding technology (*i* = 1), baling technology (*i* = 2), shearing technology (*i* = 3), and car disassembly technology (*i* = 4). Shredding technology (*i* = 1) is very demanding in terms of maintenance activities, and energy consumption, still it is a high capacity process. After the separation process recyclers may obtain quality products, especially when ferrous metals are of the main interest. The not desirable remains of this process (Automotive Shredder Residue) may harm the environment if not treated correctly. Baling technology (*i* = 2) technology requires trained operators on balers and accompanying equipment. Shearing technology (*i* = 3) requires specially designed shears for cold cutting of automotive parts, primarily made of steel. The technology itself is a labor demanding one due to the high number of trained workers that operate on ELVs. Car disassembly technology (*i* = 4) requires high level of manual labor of skilled operators. The obtained car parts may be reused directly or after the reconditioning process. This process may be conducted both, using just manual work or using specially designed disassembly lines.

The assessment of the relative importance of criterion and its value at the level of each recycling technology is given by using questionnaire method and presented in Table 1 and Table 2, respectively. The decision matrix is presented in Table 3.

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TABLE 1
FUZZY RATING OF THE CRITERIA RELATIVE IMPORTANCE

	k = 1	k = 2	k = 3	k = 4	k = 5
$i = 1$	$LW, MWx5$	$MWx2, HWs4$	LW, MW**x**5	LW, MWx2	$MWx6$
$i = 2$	MWx2, HWx4	MWx6	LW, MW_{X4}, HW	$MWx6$	$MWx3, HWx3$
$i = 3$	$LWx2, MW, HWx3$	$LW, MWx5$	$MWx6$	$MWx5,$	HW $MWx5, HW$
$i = 4$	$MWx6$	$LWx2, MWx4$	$MWx5, HW$	$LW, HWx5$	$MWx6$

TABLE 2
FUZZY RATING OF THE RTS VALUES

	k = 1	k = 2	k = 3	k = 4	k = 5
	(min)	(max)	(min)	(min)	(max)
i = 1	L	FM	FH	H	M
i = 2	FH	M	H	FM	VH
i = 3	M	VL	FH	VH	VH
i = 4	L	FH	M	H	VH

TABLE 3
DECISION MATRIX

	k = 1	k = 2	k = 3	k = 4	k = 5
	(min)	(max)	(min)	(min)	(max)
i = 1	1.43	3.01	4.31	3.9	2.97
i = 2	5.85	.2.97	4.15	2.52	5.61
i = 3	2.93	0.99	3.65	5.02	5.02
i = 4	1.61	2.87	3.2	5.14	4.82

Aggregated relative importance of criterion (k = 1) at the recycling technology (i = 3) is calculated by the proposed Algorithm (Step 1 to Step 2).

$$\overline{\mathrm{W}}_{31} = \frac{1}{6} \cdot \begin{cases} 2 \cdot ((0,0,0.25,0.6;1,1),(0,0,0.25,0.5;0.75,0.75))+ \\ ((0.3,0.5,0.7,0.9;1),(0.35,0.5,0.7,0.5;0.85,0.75)) \\ +3 \cdot ((0.4,0.75,1,1;1,1),(0.5,0.75,1,1;0.75,0.75) \end{cases}$$

$$\overline{\mathrm{W}}_{31} = \frac{1}{6} \cdot \begin{cases} ((0,0,0.5,1.2;1,1),(0,0,0.5,1;0.75,0.75))+ \\ (0.3,0.5,0.7,0.9;1,1),(0.35,0.5,0.7,0.5;0.85,0.75))+ \\ +((1.2,2.25,3,3;1,1),(1.5,2.725,3,3;0.75,0.75) \end{cases}$$

$$\overline{\mathrm{W}}_{31} = \frac{1}{6} \cdot \begin{pmatrix} (1.5,2.75,4.2,5.1;1,1) \\ (1.25,2.75,4.2,4 \cdot 8;0.75,0.75) \end{pmatrix}$$

$$= ((0.25,0.46,0.7,0.85;1,1)(0.31,0.46,0.7,0.81;1,1))$$

$$\bar{\mathrm{d}}_{31} = ((0.25,0.46,0.7,0.85;1,1),(0.31,0.46,0.7,0.81;0.75,)) \cdot ((2,3.5,4.5,6;1,1),(2.5,3.5,4.5,5.5;0.8,0.8))$$

$$\bar{\mathrm{d}}_{31} = \left((0.25,0.46,0.7,0.85;1,1),\begin{pmatrix} 0.31,0.46,0.7,0.81;0.75, \\ 0.75 \end{pmatrix}\right) \cdot ((2,3.5,4.5,6;1,1),(2.5,3.5,4.5,5.5;0.8,0.8))$$

$$\bar{\mathrm{d}}_{31} = ((0.5,1.61,3.15,5.1;1,1),(0.77,1.61,3.15,0.81,4.45;0.75\ \mathbf{0.75}))$$

The weighted value of criterion (i = 1) for the recycling technology (i = 3) is given according to the fuzzy rules algebra (Step 3 of the proposed Algorithm):

On the similarly way the values of the others elements of the weighted fuzzy decision matrixare obtained. The representative scalar of the interval type-2 trapezoidal fuzzy number d_{31}, d_{31} is given by using the (DTraT) (Step 4 of the proposed Algorithm):

$$c_{31} = \left\{ \frac{(5.1-0.5)+(1.61-0.5)+(3.15-0.5)}{4} + 0.5 + \left[\frac{(4.45-0.77)+(0.75.1.61-0.77)+}{4} + \frac{(0.75.3.15-0.77)+0.77}{4}\right] \right\}$$
$$= 2.93$$

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According to the procedure (Step 5 to Step 7 of the proposed Algorithm) are given:

The cordance matrix:

$$\begin{bmatrix} - & 0.6 & 0.4 & 0.4 \\ 0.4 & - & 0.4 & 0.4 \\ 0.6 & 0.6 & - & 0.6 \\ 0.6 & 0.6 & 0.4 & - \end{bmatrix}, \bar{c} = 0.5$$

The discordance matrix:

$$\begin{bmatrix} - & 1 & 0.984 & 0.670 \\ 0.597 & - & 0.850 & 0.615 \\ 1 & 1 & - & 0.106 \\ 1 & 1 & 1 & - \end{bmatrix}, \bar{\mathrm{n}} = 0.818$$

The concordance dominance matrix is constructed in compliance with the rules presented in step 8 of the proposed algorithm:

$$\begin{bmatrix} - & 0 & 0 & 0 \\ 0 & - & 0 & 0 \\ 0 & 0 & - & 1 \\ 0 & 0 & 0 & - \end{bmatrix}$$

Rank of the recycling technologies is determined according to the step 9 of the proposed Algorithm (Table 3). The decision matrix is presented in Table 4.

TABLE 4
DECISION MATRIX

	M_i	Rank
i = 1	0	2-4
i = 2	0	2-4
i = 3	1	1
i = 4	0	2-4

V. DISCUSSION AND CONCLUSION

If it is respected only economic aspect, the best recycling technology is the one which decrease the recycle materials numerous restrictions and embrace the lowest cost of the process. In practice, choosing of the recycling technologies depend on many criteria which are considered simultaneously. Usually, evaluation criteria are defined according to the results of developed countries good practice. Determining of the relative importance of criteria at the level of possible recycling technology is performed in direct way by each decision maker. They used pre-defined linguistic expressions. Those linguistic expressions are modeled by the interval type-2 trapezoidal fuzzy numbers. Aggregation of opinions of decision makers is given by using the fuzzy averaging method. Authors suggests that fuzzy rating of the relative importance of evaluation criteria at the level of each recycling technology a better express of the fuzzy rating of the decision makers compared to used AHP framework. The criteria values for the treated recycling technologies are assessed by decision makers. In this case, it is assumed that they decide by consensus. Hence, by applying fuzzy algebra rules, the elements of the weighted fuzzy decision matrix are calculated. The decision matrix is given by mapping the constructed the weighted fuzzy decision matrix. The elements of the decision matrix are given by using the defuzzification and they are described by precise values.

The final rank of the technologies recycling in can be obtained by applying the conventional ELECTRE method. The proposed model is presented and analyzed on the real-life data from recycling centers in Republic of Serbia. Analysis of the results obtained can provide the following information and suggestions to the management team of the recycling centers.

Choosing the best recycling technology should be performed according to the obtained results. The best recycling technology of the considered kind of waste is denoted as the shearing technology (*i* = 3). Using this recycling technology, the highest economic effect should be achieved. The others possible technologies, are placed in the second place in the rank. In order to apply these recycling technologies, it is essential that workers in recycling centers have greater knowledge, energy consumption is higher, etc.

The proposed model presents a suitable tool for decision making issues applicable to different tasks in recycling domain. As theoretical implications, the main contribution is handling all uncertain and vague input data by applying the interval type-2 fuzzy sets. The assessment of the relative importance and values of evaluation criteria at the level of recycling technologies is based on subjective assessment of decision makers. The decision makers form their opinion on their experience, knowledge and results of the best practice in developed countries. It may be considered that it is easier to form opinion by linguistic expression than express individual opinion by using precise numbers defined at any scale.

The proposed method is flexible: the changes related to the number of evaluation criteria or their relative importance/value can be easily incorporated into the proposed model. All these changes can be easily applied to the analysis of waste any types waste. The paper also suggests different managerial implications since it provides an adequate tool for overall recycling process improvement, which may be used by practitioners.

Besides the advantages, the proposed model has certain constraints, which are: the number of type of waste, rapid change of recycling technologies due to change political and economic environment, etc. For predefined time it could be considered that selected recycling technology has higher

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priority for metal waste.

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