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An extension of MACBETH method for a fuzzy environment to analyze alternatives in reverse logistics for automobile tire wastes

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ABSTRACT

Waste tire related environmental problems and its recycling alternatives have been a major issue nowadays because of their complex combination of very different materials, which include several rubbers, carbon blacks, steel cord and other organic and inorganic minor components. The most important problem in the scrap tire recycling program is the type of product recovery option because there are few specific data available. Multi-criteria decision analysis (MCDA) was used to assess options in reverse logistics for waste tire. MCDA is a widely used decision methodology that considers conflicting systems of criteria. However, many real-world decision problems involve ambiguity and imprecise information. In this study, the analysis has been undertaken using an extended version of MACBETH methodology to take into account the imprecise and linguistic assessments provided by a decision-maker by integrating the 2-tuple model dealing with non-homogeneous information data. The proposed fuzzy MACBETH method has been applied to a real case related to the automobile tire waste to elucidate its details.

1. Introduction

With growing concern in environmental protection in recent years, a problem of tire wastes disposal has increased especially because they are virtually non-degradable and take up landfill spaces [1]. Discarded tires are useful in many recycling alternatives like recovering energy from waste tires by incineration/combustion [2], co-combustion with coal or other fuels [3], pyrolysis [4] and gasification [5]. In practice, waste tires can be used by the civil engineering applications or by marine applications, as a wave breaking material, ship/dock protective bumpers, or even to construct artificial reefs [6] in the ocean farming industry. Supplemental fuel for the cement kilns [7], roadway pavement material [8], refuse derived fuel [9] are different shapes of recycled waste tires. Waste tire can also contribute to build and construct materials [10], produce roadway guard rails, as engineered protective cushions or bumpers.

Thus, due to the diversity of recycling alternatives regarding waste tire, producers are looking for efficient ways to integrate reverse logistics into their supply chains to recover economic value from discarded tires. This paper aims to structure the problem related to the selection of an alternative for the reverse logistics option for waste tire and links the criteria with different alternatives. In the same context, Gomes et al., [23] have applied a multicriteria decision aiding hybrid algorithm (THOR) as a multicriteria decision support system that helps social agents to evaluate different disposal alternatives for plastic waste. Pati et al., [24] have developed a mixed integer goal programming (MIGP) model to assist in proper management of the paper recycling logistics system. Morais, Almeida [25] have focused on a group decision making procedure based on the analysis of individual rankings with the aim of choosing an appropriate alternative for a water resources problem.

This paper presents a multicriteria decision making model for decisions in reverse logistics practices based on MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) methodology. MACBETH methodology is an interactive approach that uses semantic judgments about the differences in attractiveness of several stimuli to help a decision maker quantify the relative attractiveness of each ([13]). The proposed method is designed for ranking problem. Our fuzzy MACBETH approach considers the fuzziness in the decision data. Therefore, the model relies not only on the quality of the process data but also on the imprecise assessment modeling by applying the 2-tuple model [16].

This paper is organized as follows: In Section 2, we review some of the basic definitions of the MACBETH method and the 2-tupple fuzzy linguistic model. In Section 3, we introduce our method. In Section 4, we present a real case to elucidate the details of the proposed method and in Section 5, we interpret our results. In Section 6, we present our conclusions and future research directions.

2. Preliminary definitions

In this section, some basic definitions of MACBETH method and the 2-tuple fuzzy linguistic model are reviewed.

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Definition 1. MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) is an interactive approach that allows a decision maker or a decision-advising group to evaluate alternatives by simply making qualitative comparisons regarding their differences of attractiveness in multiple criteria. Thus, what distinguishes MACBETH from the other multicriteria models is that it needs only qualitative judgments about the difference of attractiveness between two elements at a time, in order to generate numerical scores for the options in each criterion and to weight the criteria.

M-MACBETH software is offered in ([12]). It verifies automatically the consistency of the judgements expressed by the decision-maker and suggests to resolve inconsistencies if they arise. Using the functionalities offered by the software, criteria weights are provided from the decision-maker's semantic judgements. By taking all the criteria into consideration, the value scores of the options are, then, aggregated additively to generate the overall value scores that reflect their attractiveness. M-MACBETH software also gives extensive analysis of the sensitivity and robustness of the model's results.

Definition 2. The 2-tuple fuzzy linguistic representation model is one computational model in decision making that easily combines linguistic and numerical information. It deals with qualitative aspects that are presented in qualitative terms by means of linguistic variables, i.e., variables whose values are words or sentences in a natural or artificial language instead of numbers. Each linguistic value is characterized by a syntactic value or label and a semantic value or meaning. The label is a word or sentence belonging to a linguistic term set and the meaning is a fuzzy subset in a universe of discourse. For example, a set of seven terms *S*, could be given as follows:

$S=\{s_0=\text{none},\ s_1=\text{very low},\ s_2=\text{low},\ s_3=\text{medium},\ s_4=\text{high},\ s_5=\text{very high},\ s_6=\text{perfect}\}$. The semantics of the terms is given by fuzzy numbers defined in the [0, 1] interval. A way to characterize a fuzzy number is the use of a representation which is based on parameters of its membership function [18]. For example, we may assign the following semantics to the set of seven terms via triangular fuzzy numbers:

N= none= (0, 0, 0.17), VL= very low= (0, 0.17, 0.33), L= low= (0.17, 0.33, 0.5), M= medium= (0.33, 0.5, 0.67), H= high= (0.5, 0.67, 0.83), VH= very high= (0.67, 0.83, 1), P= perfect= (0.83, 1, 1).

This assignment is depicted in Fig. 1.

The 2-tuple fuzzy linguistic representation model takes as a basis the symbolic aggregation model [20]. In addition, it defines the concept of Symbolic Translation. The latter is used to represent the linguistic information by means of a pair of values called linguistic 2-tuple, (s, α), where *s* is a linguistic term and α is a numeric value representing the symbolic translation.

Definition 3. Let $S=\{so,\ldots,sg\}$ be a linguistic term set and $\text{ʈ}(V)=\{(so,\omega_0),\ldots,sg,\omega_g)\}$ be a fuzzy set that represents a numerical value V $\in[0, 1]$ over the linguistic term set $S=\{so,\ldots,sg\}$.

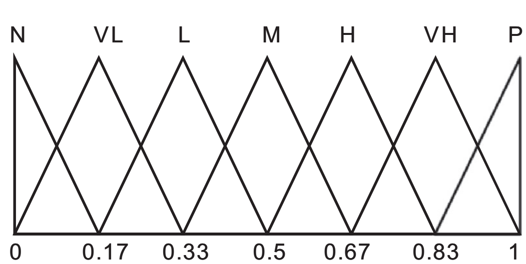

Fig. 1. A set seven terms with their semantics [19].

We obtain a numerical value β which is the result of a symbolic aggregation operation from the fuzzy set, assessed in the interval [0, *g*] by means of the function χ [16]

$$\chi : F(S_T)\rightarrow[0,g],$$

$$\chi(F(S_T))=\chi\left(\left\{(s_j,\gamma_j),j=0,\ldots,g\right\}\right)=\frac{\sum_{j=0}^{g} j\gamma_j}{\sum_{j=0}^{g}\gamma_j}=\beta \tag{1}$$

Definition 4. Herrera and Martinez [21] developed a linguistic representation model which represents the linguistic information by means of 2-tuples (s_k,α) where $s_k\in S$ is a linguistic term and $\alpha\in[-0.5,\ 0.5)$ is called a symbolic translation.

The 2-tuple expresses the equivalent information to β and it is obtained with the following function where *round* (.) is the usual round operation, s_k has the closest index label to "β " and "α" is the value of the symbolic translation

$$\Delta : [0,g]\rightarrow S\times[-0.5,0.5)$$

$$\Delta(\beta)=(s_k,\alpha),\ \text{with}\begin{cases} s_k & k=\text{round}(\beta)\\ \alpha=\beta-k & \alpha\in[-0.5,0.5)\end{cases} \tag{2}$$

Example. Let $S_T=\{s_0,\ s_1,\ s_2,\ s_3,\ s_4,\ s_5,\ s_6\}$ be a linguistic term and $\text{ʈ}(V)=\{(s_o,0),\ (s_1,0),\ (s_2,0),\ (s_3,0.75),\ (s_4,0.25),\ (s_5,0),\ (s_6,0),\}$ be the corresponding fuzzy set. By applying the function χ, $\beta=3.25$ is its result. Therefore, the representation of this quantity of information with the 2-tuples becomes Δ (3.25)=$(s_3,\ 0.25)$, as illustrated in Fig. 2.

3. Fuzzy MACBETH method

Multi-criteria decision analysis (MCDA) methods have become increasingly popular in decision-making for reverse logistic field because of the multi-dimensionality of the strategy goal and the complexity of environment policy [11]. MCDA includes various methods such as general utility analysis and outranking methodologies. This paper presents a multicriteria decision making model for policy decisions in reverse logistics using MACBETH (Measuring Attractiveness by a Categorical Based Evaluation TecHnique). The latter is an interactive approach that requires only qualitative judgements about differences to help a decision maker or a decision-advising group quantify the relative attractiveness of options. However, it is often difficult for a decision-maker (DM) to assign precise judgments. The merit of using a fuzzy approach such as the 2-tuple model is its contemplation of ambiguity and the imprecision in the decision making process. Similarly, integrating the 2-tuple model is very suitable for screening the qualitative deviations required by MACBETH method. In this section, we extend MACBETH method under a fuzzy environment for developing reverse manufacturing options.

Fig. 3 presents stepwise procedure to implement our methodology. The procedure is composed into four steps explained hereafter

3.1. *Step 1. identification of a MCDA problem with qualitative and quantitative assessments*

Most decision-making problems could be described by means of the following sets:

- A set of *n* actions called $A=\{A_1,\ A_2,\ldots,\ A_n\}$;
- A set of *m* criteria called $C=\{C_1,\ C_2,\ldots,\ C_m\}$;

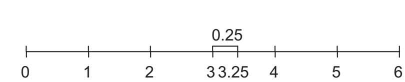

Fig. 2. Example of symbolic translation computing.