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SUSTAINABLE DECISION-MAKING MODEL FOR MUNICIPAL SOLID-WASTE MANAGEMENT: BIFUZZY APPROACH

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Abstract: A sustainable model is observed as an important tool towards achieving the integrated municipal solid-waste (MSW) management decision. This paper proposes a new sustainable decision-making model to cope with this issue. The fuzzy analytic hierarchy process based on linguistics hedges combined with the fuzzy ideal solution was employed using the so-called conflicting bifuzzy-set approach. To ensure the model is well-suited with the local context, the input data was obtained entirely from the local stakeholders after attaining the consensus agreement among them. A case study in the state of Selangor and Kuala Lumpur Federal Territory was employed to demonstrate the feasibility of the proposed method. The model accommodates the integrated factors and is able to incorporate with the multiple stakeholders' so that the sustainable MSW management decision can be achieved successfully.

KEYWORDS: *Analytic hierarchy process (AHP), conflicting bifuzzy sets, fuzzy ideal solution (FIS), linguistic hedges, municipal solid waste (MSW), sustainable decision-making model*

Introduction

In recent decades, the municipal solid-waste (MSW) disposal decision option in Malaysia has been deeply debated. One of the main issues is how to develop the integrated approach to deal with the uncertainty factors arising in evaluation process, such as incomplete information, imprecision of input data, unobtainable information, partial ignorance, etc. The integrated concept in MSW management is actually synonymous with the sustainable approach that is practised to manage the materials as a daily procedure such as disposal, treatment, cleaning, collecting, etc. Generally, the integrated solid-waste management (ISWM) is defined as a system that takes an overall system approach and deals with all types of solid-waste materials and all sources of solid waste (McDougall & Hruska, 2000). The term of integration itself is very close related to sustainability. It means a variety of things in different societal contexts, all of which are components of a bigger, more complex picture and it requires an approach that integrates process in an effort to more towards sustainability. The approach should cover a range of collection and treatment to handle all materials in the waste stream in an environmentally-effective, economically-affordable and socially-acceptable way (Geng *et al.,* 2007). Thus, the sustainable management must encompass the framework in an integrated manner which enables waste generators to utilise their waste streams more efficiently than just the disposal option (Seadon, 2006).

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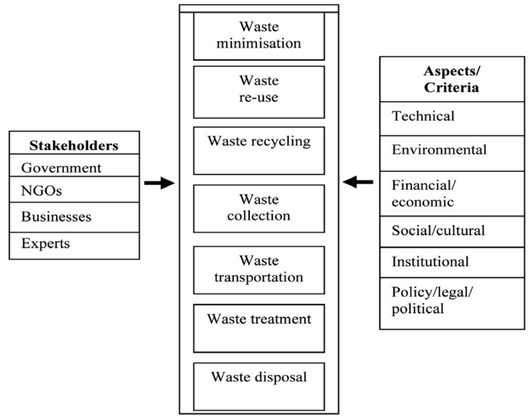
The definition of integrated waste management (IWM) strategies at a local scale also plays an important role in the achievement of the Kyoto's target and in the fulfillment of the new legislative requirement, both aimed to foster environmental protection and recovery (Cosmi *et al.,* 2000). Therefore, United Nations Environment Programme (UNEP) International Environmental Technology Centre describes the importance of viewing the solid-waste management in integrated manner (UNEP, 1996):

i. Some problems can be solved more easily in combination with other aspects of the waste system than individually;

ii. Integration allows for capacity or resources to be completely used;
iii. An IWM plan helps identify and select low-cost alternatives;
iv. Adjustments to one area of the waste system can disrupt existing practices in another area, unless the changes are made in a coordinated manner;
v. Public, private, and informal sectors can be included in the waste-management plan;
vi. Without an IWM plan, some revenue-producing activities are "skimmed off" and treated as profitable, while activities related to maintenance of public health and safety do not receive adequate funding and are managed insufficiently.

Numerous studies attempted to explain the concept of Integrated Waste Management (IWM) as shown in Figure 1. Klundert and Anschiitz (2000) for example, present the new concept of integrated sustainable waste management in the context of assessing the sustainability of waste-management alliances. It refers to a waste-management system that best suits the society, economy and environment including social-cultural, environmental, institutional and political aspects that influence the overall sustainability of waste management. The approach seeks stakeholder's participation, waste prevention and resource recovery, interactions with other urban systems and promoting an integration of different habitat scales (i.e., household, neighbourhood and city) with emphasis more on sustainable solutions of solid-waste problems as well. A more recent study discussed the IWM based on four categories; i) integration within a single medium (solid, aqueous, or atmospheric wastes) by considering alternatives waste-management options, ii) multi-media integration (solid aqueous, atmospheric and energy wastes) by considering waste-management options that can be applied to more than one medium, iii) tools (regulatory, economic, voluntary and information), and iv) agent (governmental bodies either local or national, businesses and the community). Thus, the study concludes that the IWM requires a broad participation and approach to arrive at an integrated process in an effort to move towards sustainability (Seadon, 2006).



Source: Modification from Kludert and Anschirtz (2000)

Figure 1: Integrated sustainable waste-management concept.

Some studies have looked more closely at the issue of integrated consideration towards the sustainable waste-management goal. Wilson *et al.,* (2001) survey the practical aspect of municipal waste management (i.e., transport, treatment and disposal) from waste-manager's perspective within the context of long-term planning in nine European countries. The factors including economic, social, political, environmental, legal and technical of their specific programmes were explored and analysed. They found that the transition of MSW management to urban-resource management was observed and 'key drivers' for more sustainable waste-management practices were identified. A similar study was also conducted by Geng *et al.,* (2007) to apply the integrated solid-waste management at industrial area near Tianjin Economic Development Area (TEDA), China. The study focuses on how to plan an integrated solid-waste management approach, that implements benefits as well as challenges faced during the implementation process.

As a consequence for above development, international research has focuses on the development of sustainable MSW model. Hung *et al.,* (2007) for instance, develop a sustainable MSW management decision model to overcome the conflicting arises from stakeholders and the feasibility of the decision. The study employs the combining between MCDM method and consensus analysis method (CAM). Analytic Hierarchy Process (AHP) uses to prioritising the alternatives and the CAM utilised to assess the degree of consensus between stakeholders for particular alternatives. Daskalopoulos *et al.,* (1998) developed an integrated MSW disposal model with focuses on economic and environmental sustainable aspects. Four main difference scenarios namely landfilling, incineration, composting and recycling, and another four combination options were involved in their study using simplex technique to derive the minimum total cost between the options. The indicator index also investigated by Krajnc & Glavic (2005) with emphasis on the monitoring of the sustainable development (SD) of an industrial company based on the integrated information on economic, environmental and social performance. Huhtala (1997) developed a control model to examine the optimal recycling rate for MSW. The model considers the physical costs of recycling, the social costs of landfilling, and consumers' environmental preferences.

An integrated interval-parameter fuzzy-stochastic mixed-integer linear programming (IFSMILP) model also was developed by Huang *et al.,* (2001). The model incorporates within a general interval-parameter mixed-integer linear programming framework. Chung & Poon (1996), uses the multi-criteria analysis (MCA) to provide an accessible and transparent justification for waste management decision making. MCA approach was made to find out the most preferred waste management options; landfilling, waste to energy, composting and source separation of MSW in Hong Kong. Klang *et al.,* (2003) developed the model for evaluating waste management systems towards sustainable development. The model was tested to a case-study which considers from environmental, economic and social aspects. Su *et al.,* (2007) develop a decision-making model of MSW management to resolve the insufficiencies in policy impact analysis to predict the possible impacts as well as to form a novel decision-making model. They employ five main factors; environmental, economic, social; management; and technology to prioritise the alternatives and combine the AHP and the policy impact potential analysis (PIPA) to reach a compromise decision.

In spite of the significant developments which have taken place to deal with the sustainable model in MSW decision process, existing research very rarely explores analytic hierarchy process (Saaty, 1980) based on the power of *dilation* or *concentration* combining with fuzzy ideal solution (FIS) (Chen, 2000) as an integrated decision tool. The use of integrated factors such as economics, environment, social and technology aspects and involvement of the multiple stakeholders can derive an efficient judgement towards achieving an integrated and sustainable decision-making process. Moreover, the equilibrium approach that utilised both the positive and negative aspects using conflicting bifuzzy sets (CBFS) (Zamali *et al.,* 2008), also observed as a value added aspect towards achieving the comprehensible judgement in the decision-making process. Thus, this paper is divided into five sections. The basic theory of the proposed concept is briefly discussed in Section 2. In Section 3, the formulation of the proposed model is concentrated on. A case study to illustrate the application of the proposed model in Section 4 is provided, before short conclusions are made in Section 5.

Basic Theory: Preliminaries

For purpose of the references, the conflicting bifuzzy-set theory (Zamali *et al.,* 2008) and the linguistic hedges (Cox, 1994) are reviewed in sub-section 2.1 – 2.2, respectively. Then, the proposed conflicting bifuzzy-evaluation approach is briefly discussed in sub-section 2.3.

Conflicting bifuzzy-set theory

In general, the intuitionistic fuzzy-set (IFS) approach involves setting or fixing the limitation of membership degree and non-memberships degree for any event in the range of [0,1]. However, in reality, these limited conditions are clearly not always true and the idea of solutions is needed beyond these boundaries. For example, if the performance of a candidate is said to be '*good*' (m_A = 0.75), it does not mean that the '*poor*' performance was always, m^1_A = 1 - 0.75 = 0.25, but it can be more than 0.25. Based on this idea, the conditions 0 £ $m_z(x) + g_z(x)$ £ 1 in IFS could be modified to allow both summation membership values exceed beyond this boundaries. Thus, a new theory, namely a conflicting bifuzzy sets (Abu Osman, 2006; Zamali *et al.,* 2008), is proposed by utilising both the positive and negative aspects concurrently, given as the following definition (Zamali, 2010; Zamali *et al.,* 2011):

Definition 1 Let a set $\boldsymbol{X}$ be fixed. A *conflicting bifuzzy set (CBFS) A* of $\boldsymbol{X} \times \boldsymbol{X}$ is an object having the following form:

$$Z = \{\langle x, \mu_Z(x), \gamma_Z(x)\rangle \mid x \in \boldsymbol{X};\ 0 < \mu_Z(x) + \gamma_Z(x) \leq 1.5\}$$

where the functions $\mu_Z : \boldsymbol{X} \to [0,1]$ represent the *positive degree* of x with respect to Z and $x \in \boldsymbol{X}$ such that $\mu_Z(x) \in [0,1]$, and the functions $\gamma_Z : \boldsymbol{X} \to [0,1]$ represent the *negative degree* of x with respect to Z and $x \in \boldsymbol{X}$ such that $\gamma_Z(x) \in [0,1]$, and the $0 < \mu_Z(x) + \gamma_Z(x) \leq 1.5$.

In order to avoid illogical ranges occur in the judgemental process, the values of $m_z(x)$ and $g_z(x)$ both cannot be dominant and/or 0 and 1, concurrently. However, the intersection and union of two conflicting bifuzzy sets A and B in X are similar with the IFS. The only difference is that the sum of these two-grade degrees can exceed 1 (in a logical range based on the experts' experiences). Since the idea was very recently introduced, so many assumptions and theoretical perceptions can be derived and cultivated from this new concept.

The linguistic hedges

In general, decision-makers (DMs) find it very difficult to practise the quantitative judgement in the evaluation process. For this reason, the concept of fuzzy-set theory was employed specifically using fuzzy numbers and the direct assign was utilised to suit with the approach. Using this evaluation approach, it can be better represented by natural expressions such as *very good*, *somewhat good*, *poor*, etc. This is because the DMs find crisp values in pair-wise comparison process inconvenient due to too much ill-defined information or input data. Moreover, the desired value, and the importance of a criterion, is more practical to describe by using common language. In addition, each attribute can be further refined in a flexible and simple manner without concerning or worrying about the numeric values as usual.

With regard to the above problems, the linguistic hedge was utilised to derive the importance of the relative weights for each criterion in the decision process. In our daily life, more than one word is often used to describe a variable. For instance, after a car is test-driven and a rating given by linguistic variables, then its values might be 'very comfortable', 'slightly comfortable', 'more or less comfortable', etc. Thus, the words such as "very", 'slightly', "more or less" are called linguistic hedges.

Definition 2 A linguistic hedge or a modifier is an operation that modifies the meaning of a term more generally, of a fuzzy set. If $\widetilde{A}$ is a fuzzy set then the modifier k generates the (composite) term $\widetilde{B} = k\left(\widetilde{A}\right)$. The modifiers used frequently are:

Concentration

$$\mu_{con(\widetilde{A})}(x) = \left[\mu_{\widetilde{A}}(x)\right]^{w}, \text{ where } w > 1 \qquad (1)$$

Dilation

$$\mu_{dil(\widetilde{A})}(x) = \left[\mu_{\widetilde{A}}(x)\right]^{1/w}, \text{ where } w > 1 \qquad (2)$$

Definition 3 The linguistic hedges and their approximate meanings are specifically classified as shown in Table 1.

The conflicting bifuzzy evaluation approach

Suppose that $L = \{l_\alpha / \alpha = 1,2,3,\ldots,t\}$ is a finite and totally-ordered linguistic terms set, where l_α represents a possible value for a negative aspect of linguistic variable and satisfies the following properties as

i. The set is ordered: $l_\alpha > l_\beta$ if and only if $\alpha > \beta$
ii. There is the negation operator: $Neg\,(l_\alpha) = l_\beta$, such that $\beta = t + 1 - \alpha$

In the evaluation process, the linguistic terms of a label system were employed. Hence, the transformation is needed from the linguistic scales into the triangular fuzzy numbers (TFNs) (see Table 2). The set on corresponding transformation of seven linguistic labels is given by

L = {l_1 = *Very low (VL)*, l_2 = *Low (L)*,
l_3 = *Medium low (ML)*, l_4 = *Medium (M)*,

$$l_5 = \textit{Medium high (MH)},\ l_6 = \textit{High (H)},\ l_7 = \textit{Very high (VH)}\}. \tag{3}$$

For example, if one attribute originally assessed as (L,MH) namely 'linguistic conflicting preference relations' (i.e., 'positive aspect', 'negative aspect'), it should be transformed into (L,ML) (henceforth called linguistic bifuzzy preference relations), where ML is 'non-negative aspect' derived from the negation operator (i.e., $Neg(l_{MH}) = Neg\ (l_5) = l_{7+1-5} = l_3 = l_{ML}$). Thus, the linguistic conflicting bifuzzy preference relations can be represented in TFN as (0.1,0.2,0.3;0.2,0.3,0.4), and the combination operation for both aspects can be derived as (0.15,0.25,0.35) namely 'linguistic equilibrium judgement' by arithmetic-mean operator. Please note that the arithmetic-mean operator was employed due to two reasons; i) it is the simplest and most efficient technique, and ii) it represents more closely the representative values due to no extreme conflicting linguistic input data in judgemental process.

Model Formulation

Since the MSW decision problem is very complex and involves uncertainty factors as well as non-homogenous input data, a new sustainable model is needed and vital to cope with these issues. Thus, based on the basic theory from Section 2, the proposed model was briefly formulated in step 1 to step 10 as follows:

Step 1: The prospective disposal options and the criteria

It can be identified through four main decision criteria decomposed into fifteen sub-criteria at the lower level of the hierarchical structure as shown in Figure 2.

Step 2: Unifying process

The unifying process of the non-homogenous (i.e., different units) of quantitative input data is needed. Thus two methods were employed to derive the score values.

i) The original data were represented by crisp values. After consulting with the experts, the membership function was constructed to derive the membership value.

ii) The original data was represented by TFN, and the unifying process derived based on either cost-criteria or benefit-criteria which naturally represented each sub-criterion. Let $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ ($i = 1, 2, ..., n; j = 1, 2, \ldots, m$), thus the formula (Fenton & Wang, 2006) was employed as

$$\tilde{U} = \left(\tilde{u}_{ij}\right)_{m\times n} \tag{4}$$

where

$$\tilde{u}_{ij} = \left(\frac{a_{ij}}{M}, \frac{b_{ij}}{M}, \frac{c_{ij}}{M}\right) \quad ..,n; j \in \omega_1$$

$$\tilde{u}_{ij} = \left(\frac{N - c_{ij}}{N}, \frac{N - b_{ij}}{N}, \frac{N - a_{ij}}{N}\right); i = 1,2,\ldots,n; j \in \omega_2$$

$M = \max_j c_{ij}$, $j \in \omega_1$ (benefit-criteria), and $N = \max_i c_{ij}$, $j \in \omega_2$ (cost-criteria)

Step 3: Assigning the preference rating

Assigning the linguistic preference rating of alternatives versus various sub-criteria using AHP conflicting bifuzzy direct-assigned method. By using this method, both the positive and negative aspects were considered, simultaneously. Table 2 gives the fuzzy linguistic values and its labels, accordingly.

Step 4: The overall performance scores

Summing-up of all the sub-criteria performance scores corresponding to their criteria with respect to each of the stakeholders (S^i, $i = 1, 2, 3, \ldots, n$) to derive the overall performance score values denoted as

$$\begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \ldots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \ldots & \tilde{x}_{2n} \\ \ldots & .. & \ldots & \ldots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \ldots & \tilde{x}_{mn} \end{bmatrix}, \quad \text{where } \tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \text{ is a TFN} \tag{5}$$

Step 5: Normalisation

To avoid complexity, the linear scale transformation is used to deal with quantitative datasets into a comparable scale. Thus, the TFN

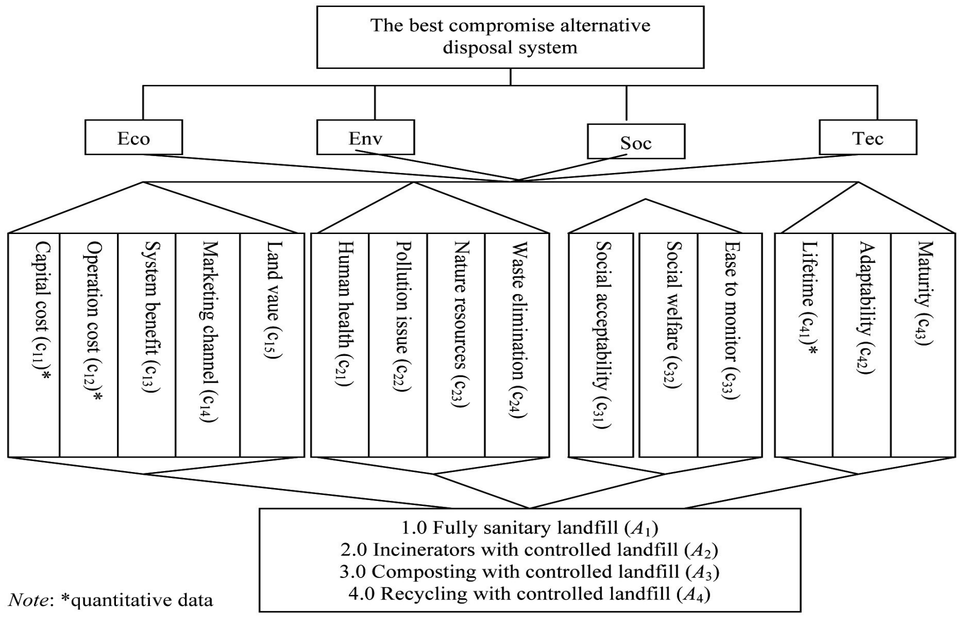


Figure 2: The hierarchical structure of MSW disposal alternatives.

Table 1: The hedge values of the specific dilation and concentration (Cox, 1994).

Linguistic hedges	*Meaning*	*Hedge type*	*Hedge values (w)*
Extremely A	Intensify a fuzzy region	*Concentration*	$[\mu_{extremely\ A}(x)]^3$
Very A	Contrast intensification	*Concentration*	$[\mu_{very\ A}(x)]^2$
A (i.e., no hedges)	-	-	$[\mu_A(x)]^1$
Usually A	Contrast diffusion	*Dilation*	$[\mu_{usually\ A}(x)]^{1/2}$
Somewhat A	Dilate a fuzzy region	*Dilation*	$[\mu_{somewhat\ A}(x)]^{1/4}$
Between above linguistic hedges	Intensify/contrast/dilate	*Concentration/dilation*	between above two hedges value range

was normalised (Chen, 2000), (i = 1, 2, ..., n; j =1, 2, …, m), denoted by $\tilde{S}^i_\bullet$

$$\tilde{S}^i_\bullet = \left(\tilde{k}_{ij}\right)_{m\times n} \tag{6}$$

where

$$\tilde{k}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right);\ j\in B \text{ and } c_j^* = \max_i c_{ij},\ if\ j\in B$$

$$\tilde{k}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right);\ j\in C \text{ and } a_j^- = \min_i a_{ij},\ if\ j\in C$$

B is a set of benefit-criteria, where the higher the value of $\tilde{k}_{ij}$ the better it is for the decision-maker, and C is a set of cost-criteria, where the lower the value of $\tilde{k}_{ij}$ the better it is for the decision-maker. Please note that this TFN normalisation method is to preserve the property in the range of [0,1].

Table 2: Linguistic variables for the ratings.

Linguistic variables	*TFN*	*label*
Very low (VL)	(0,0 0.1)	l_1
Low (L)	(0,0.1,0.3)	l_2
Medium low (ML)	(0.1,0.3,0.5)	l_3
Medium (M)	(0.3,0.5,0.7)	l_4
Medium high (MH)	(0.5,0.7,0.9)	l_5
High (H)	(0.7,0.9,1.0)	l_6
Very high (VH)	(0.9,1.0,1.0)	l_7

Step 6: The importance of each criterion

Stakeholders determined the importance of each criterion by assigning the input weights using linguistic hedges based on the power of *dilation* and *concentration* concepts using Definition 3 in Table 1. In general, the overall weighted performance matrix ($\tilde{D}$) can be derived for each of the stakeholder $[S^i_\bullet]^w$ (i = 1,2,3), and w is a power of *dilation* or *concentration* given by the stakeholders, respectively denoted as

$$\tilde{D} = \begin{bmatrix} (S_{\bullet}^{1})^{w} \\ (S_{\bullet}^{2})^{w} \\ (S_{\bullet}^{3})^{w} \end{bmatrix} = \begin{bmatrix} \tilde{b}_{ij}^{k} \\ \tilde{b}_{ij}^{k} \\ \tilde{b}_{ij}^{k} \end{bmatrix}_{m\times n} \quad ; \; i, j = 1,2,3, \ldots, n \text{ and } k \text{ is number of the stakeholders} \tag{7}$$

where

$$[S_{\bullet}^{1}]^{w} = \begin{pmatrix} a_{11}^{(w_1)} & a_{12}^{(w_2)} & \ldots & a_{1n}^{(w_n)} \\ a_{21}^{(w_1)} & a_{22}^{(w_2)} & \ldots & a_{2n}^{(w_n)} \\ \ldots & \ldots & \ldots & \ldots \\ a_{m1}^{(w_1)} & a_{42}^{(w_2)} & \ldots & a_{mn}^{(w_n)} \end{pmatrix}; [S_{\bullet}^{2}]^{w} = \begin{pmatrix} a_{11}^{(w_1)} & a_{12}^{(w_2)} & \ldots & a_{1n}^{(w_n)} \\ a_{21}^{(w_1)} & a_{22}^{(w_2)} & \ldots & a_{2n}^{(w_n)} \\ \ldots & \ldots & \ldots & \ldots \\ a_{m1}^{(w_1)} & a_{42}^{(w_2)} & \ldots & a_{mn}^{(w_n)} \end{pmatrix};$$

$$[S_{\bullet}^{3}]^{w} = \begin{pmatrix} a_{11}^{(w_1)} & a_{12}^{(w_2)} & \ldots & a_{1n}^{(w_n)} \\ a_{21}^{(w_1)} & a_{22}^{(w_2)} & \ldots & a_{2n}^{(w_n)} \\ \ldots & \ldots & \ldots & \ldots \\ a_{m1}^{(w_1)} & a_{42}^{(w_2)} & \ldots & a_{mn}^{(w_n)} \end{pmatrix}$$

***Step 7*: The importance of each of the stakeholders**

The weights for the stakeholders can be derived after consulting and sincerely discussing with all the stakeholders. Multiply the overall weight-normalised fuzzy performance matrix to the relative important weights for each of the stakeholders. Thus, the overall weight-normalised fuzzy performance matrix $\left(\tilde{P}_{ij}\right)$ is denoted as

$$\left(\tilde{P}_{ij}\right) = \begin{bmatrix} \tilde{p}_{11} & \tilde{p}_{12} & \tilde{\ldots} & \tilde{p}_{1n} \\ \tilde{p}_{21} & \tilde{p}_{22} & \tilde{\ldots} & \tilde{p}_{2n} \\ \tilde{\ldots} & \tilde{\ldots} & \tilde{\ldots} & \tilde{\ldots} \\ \tilde{p}_{m1} & \tilde{p}_{m2} & \tilde{\ldots} & \tilde{p}_{mn} \end{bmatrix}, \quad 1 \le i \le m \text{ and } 1 \le j \le n \tag{8}$$

where

$$\left(\tilde{p}_{ij}\right) = \left(w_{S^1} \otimes \tilde{b}_{ij}^{1}\right) \oplus \left(w_{S^2} \otimes \tilde{b}_{ij}^{2}\right) \oplus \left(w_{S^3} \otimes \tilde{b}_{ij}^{3}\right); \; i, j = 1,2,3,4$$

$\oplus$ and $\otimes$ are the TFN addition and multiplication operator, respectively.

***Step 8*: The fuzzy ideal solution**

Determining the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS), and calculate the distance of each alternative versus p^* and p^-, respectively. The FPIS (A^*) and FNIS (A^-) were defined as

$$A^* = \{p_1^*, \ldots, p_m^*\} = \{(\max_j c_{ij} / j \in B), (\min_j a_{ij} / j \in C)\}, \text{ and} \tag{9}$$

$$A^- = \{p_1^-, \ldots, p_m^-\} = \{(\min_j a_{ij} / j \in B), (\max_j c_{ij} / j \in C)\} \tag{10}$$

where $\tilde{P}_j^* = (1,1,1)$ and $\tilde{P}_j^- = (0,0,0)$, $j = 1, 2, \ldots, n$.

Let $\tilde{a} = (a_1, b_2, c_3)$ and $\tilde{b} = (b_1, b_2, b_3)$ be two TFNs, then the vertex method (Chen, 2000) is defined to calculate the distance between $\tilde{a}$ and $\tilde{b}$ as

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}\left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2\right]} \tag{11}$$

The shortest distance from the positive ideal solution and the longest distance from the negative ideal solution is the most preferred alternative. Thus, the distance between each alternative and the FPIS and FNIS is calculated as

$$d_1^* = \sum_{j=1}^{n} d\left(\tilde{p}_{ij}, \tilde{p}_j^*\right) \tag{12}$$

$$d_1^- = \sum_{j=1}^{n} d\left(\tilde{p}_{ij}, \tilde{p}_j^-\right) \tag{13}$$

where $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$, and $d(\cdot, \cdot)$ is the distance measurement between two fuzzy numbers.

***Step 9*: The performance coefficients**

A performance coefficient (PC) is defined to determine the ranking order of all alternatives once the d_i^* and d_i^- of each alternative A_i ($i = 1, 2, \ldots, n$) has been calculated. The closer PC approached 1 the better the alternative's performance. Hence, the PC for each alternative (Hwang & Yoon, 1981) is given as

$$PC_i = \left[\frac{d_i^-}{d_i^- + d_i^*}\right], \; i = 1, 2, \ldots, n \tag{14}$$

***Step 10*: The ranking order**

Finally, the ranking order of the alternative can be identified based on the maximum relative value of performance coefficient. According to the closeness of performance coefficient from step 9, the ranking order of the n alternatives, $A_1, A_2, \ldots, A_n$ can be determined. For example, if the ranking of n alternatives as, $A_2 \rangle A_n \rangle \ldots \rangle A_{n-5}$, then it can be concluded that A_2 is the most preferred option followed by A_n and so on, and A_{n-5} is the last preferred option, where the symbol '$\rangle$' means 'is superior or preferred to'.

An Application of the Proposed Model: A Case Study

As a case study, the proposed method is applied to select the most suitable MSW disposal system among four different disposal options in the state of Selangor and KLFT (Zamali *et al.,* 2009). Four possible decision alternatives are identified and are given as follows: $A = \{A_i\}$, (i = 1, 2, 3, 4), where A_1 is fully sanitary landfill, A_2 is a incinerator equipped-to-energy with controlled landfill system, A_3 is a composting treatment with controlled landfill, and A_4 is recycling material with controlled landfill.

To ensure the proposed model is well-suited with the national sustainable MSW management vision, comprehensive observation, personal communication with more than a dozen of the practices personnel as well as consultation and discussion with the local stakeholders, local authorities (S^1), experts (S^2) and NGOs (S^3) was conducted and the decision criteria and sub-criteria were defined respectively, as follows: (C_i, i = 1,2,3,4) = {Eco = C_1, Env = C_2, Soc = C_3, and Tec = C_4}, where C_1 is economics factor, C_2 is environmental aspect, C_3 is social impacts, and C_4 is technological aspect, while the fifteen sub-criteria was employed as shown in Figure 3. From Section 3, the actual steps taken in this research can be summarised as follows:

Step 1**:** Identify the prospective MSW disposal options and the criteria through four main decision criteria which were decomposed into fifteen sub-criteria at the lower level of the hierarchical structure as shown in Figure 2.

Step 2**:** Unifying the non-homogenous (i.e., different units) of the quantitative input data

i) The membership function was constructed to derive the membership value of the sub-criteria (c_{12}) as shown in Table 7 and the unifying results shown in Table 3 – 6, respectively.

ii) The original data are represented by TFNs (i.e., c_{11} and c_{41}) derived using Eq.-(4) and the results are as shown in Table 3 - 6, respectively.

Step 3**:** Assign the linguistic preference rating of alternatives versus various sub-criteria using AHP conflicting bifuzzy direct-assigned method. Table 3 – 6 shows the linguistic equilibrium judgement of sub-criterion with respect to different alternative system.

Step 4**:** Compute the performance scores of the sub-criteria and sum up all the scores corresponding to its criteria with respect to each of the stakeholders (S^i, i = 1,2,3) using Eq. -(5) and summarised as

$$S^1 = \begin{bmatrix} (1.9308, 2.3462, 2.9038) & (1.3500, 2.1000, 2.8000) & (1.6000, 2.1500, 2.5500) & (2.1000, 2.3333, 2.4000) \\ (1.8750, 2.3635, 2.8519) & (2.2000, 2.8500, 3.3000) & (0.2500, 0.6000, 1.1000) & (2.0000, 2.4170, 2.7830) \\ (1.9279, 2.6125, 3.2817) & (1.5000, 2.2500, 2.9500) & (0.3500, 0.7500, 1.3000) & (0.7170, 1.1330, 1.6000) \\ (1.9625, 2.5702, 3.2087) & (2.5000, 3.2000, 3.6500) & (1.4500, 2.0000, 2.4500) & (0.9170, 1.4330, 2.0000) \end{bmatrix};$$

$$S^2 = \begin{bmatrix} (1.6808, 2.0462, 2.6038) & (0.3500, 0.8000, 1.5000) & (0.6000, 1.1000, 1.7000) & (1.7000, 2.0830, 2.3500) \\ (2.5750, 3.1635, 3.6019) & (2.5000, 3.1500, 3.6000) & (0.7500, 1.3000, 1.9000) & (2.0000, 2.4670, 2.8330) \\ (3.1279, 3.8125, 4.3317) & (1.2000, 2.0000, 2.8000) & (0.9000, 1.5000, 2.1000) & (0.2670, 0.4830, 0.9000) \\ (2.6625, 3.2202, 3.6587) & (1.6500, 2.3500, 3.0000) & (2.0000, 2.4000, 2.6000) & (1.5670, 2.1330, 2.6000) \end{bmatrix};$$

$$S^3 = \begin{bmatrix} (1.6308, 1.9462, 2.5038) & (0.3000, 0.6000, 1.2000) & (1.0000, 1.4000, 1.8500) & (0.6500, 1.0330, 1.5000) \\ (0.8250, 1.0635, 1.5519) & (0.7000, 1.0000, 1.5000) & (0.0000, 0.0500, 0.4000) & (1.4000, 1.6170, 1.9330) \\ (2.1279, 2.6625, 3.2317) & (1.3000, 1.9000, 2.5500) & (2.1000, 2.6500, 2.9500) & (0.9670, 1.2830, 1.6000) \\ (2.8625, 3.4202, 3.8087) & (1.9000, 2.6500, 3.2500) & (1.6000, 2.2000, 2.6500) & (1.2670, 1.8330, 2.4000) \end{bmatrix}$$

Step 5**:** Normalise each of the stakeholders' fuzzy performance scores using Eq.-(6), where the environmental factor (C_2) is a cost-criteria, while the economical factor (C_1), social factor (C_3), and technological factor (C_4) are benefit-criterion. The normalised fuzzy performance scores ([$S^i\bullet$]; i = 1,2,3) results are obtained as

$$[S_{\bullet}^{1}] = \begin{bmatrix} (0.5884,0.7149,0.8848) & (0.4821,0.6429,1.0000) & (0.6275,0.8431,1.0000) & (0.7545,0.8383,0.8623) \\ (0.5714,0.7202,0.8690) & (0.4091,0.4737,0.6136) & (0.0980,0.2353,0.4314) & (0.7186,0.8683,1.0000) \\ (0.5875,0.7961,1.0000) & (0.4576,0.6000,0.9000) & (0.1373,0.2941,0.5098) & (0.2575,0.4072,0.5749) \\ (0.5980,0.7832,0.9778) & (0.3699,0.4219,0.5400) & (0.5686,0.7843,0.9608) & (0.3293,0.5150,0.7186) \end{bmatrix};$$

$$[S_{\bullet}^{2}] = \begin{bmatrix} (0.3880,0.4724,0.6011) & (0.2333,0.4375,1.0000) & (0.2308,0.4231,0.6538) & (0.6000,0.7353,0.8294) \\ (0.5945,0.7303,0.8315) & (0.0972,0.1111,0.1400) & (0.2885,0.5000,0.7308) & (0.7059,0.8706,1.0000) \\ (0.7221,0.8801,1.0000) & (0.1250,0.1750,0.2917) & (0.3462,0.5769,0.8077) & (0.0941,0.1706,0.3176) \\ (0.6147,0.7434,0.8446) & (0.1167,0.1489,0.2121) & (0.7692,0.9231,1.0000) & (0.5529,0.7529,0.9176) \end{bmatrix};$$

$$[S_{\bullet}^{3}] = \begin{bmatrix} (0.4282,0.5110,0.6574) & (0.2500,0.5000,1.0000) & (0.3390,0.4746,0.6271) & (0.2710,0.4310,0.6250) \\ (0.2166,0.2792,0.4075) & (0.2000,0.3000,0.4286) & (0.0000,0.0169,0.1356) & (0.5830,0.6740,0.8060) \\ (0.5587,0.6991,0.8485) & (0.1176,0.1579,0.2308) & (0.7119,0.8983,1.0000) & (0.4030,0.5350,0.6670) \\ (0.7516,0.8980,1.0000) & (0.0923,0.1132,0.1579) & (0.5424,0.7458,0.8983) & (0.5280,0.7640,1.0000) \end{bmatrix}$$

***Step 6*:** Stakeholders determined the importance of each criterion by assigning the input weights using linguistic hedges based on the power of *dilation* and *concentration* concepts, and the results are shown in Table 8 - 10, respectively. Thus, the overall weighted performance matrix ($\widetilde{D}$) can be derived for each of the stakeholder ($[S^{i}_{\bullet}]^{w}$; i = 1,2,3) using Eq.-(7) as

$$[S_{\bullet}^{1}]^{w} = \begin{bmatrix} (0.2037,0.3654,0.6928) & (0.4821,0.6429,1.0000) & (0.3937,0.7109,1.0000) & (0.8686,0.9156,0.9286) \\ (0.1865,0.3736,0.6563) & (0.4091,0.4737,0.6136) & (0.0096,0.0554,0.1861) & (0.8477,0.9318,1.0000) \\ (0.2027,0.5045,1.0000) & (0.4576,0.6000,0.9000) & (0.0188,0.0865,0.2599) & (0.5074,0.6381,0.7582) \\ (0.2139,0.4804,0.9347) & (0.3699,0.4219,0.5400) & (0.3233,0.6152,0.9231) & (0.5739,0.7176,0.8477) \end{bmatrix};$$

$$[S_{\bullet}^{2}]^{w} = \begin{bmatrix} (0.0584,0.1054,0.2172) & (0.0544,0.1914,1.0000) & (0.2308,0.4231,0.6538) & (0.2160,0.3975,0.5706) \\ (0.2101,0.3895,0.5749) & (0.0095,0.0123,0.0196) & (0.2885,0.5000,0.7308) & (0.3517,0.6598,1.0000) \\ (0.3765,0.6818,1.0000) & (0.0156,0.0306,0.0851) & (0.3462,0.5769,0.8077) & (0.0008,0.0050,0.0321) \\ (0.2322,0.4108,0.6026) & (0.0136,0.0222,0.0450) & (0.7692,0.9231,1.0000) & (0.1691,0.4269,0.7727) \end{bmatrix};$$

$$[S_{\bullet}^{3}]^{w} = \begin{bmatrix} (0.0785,0.1334,0.2841) & (0.0156,0.1250,1.0000) & (0.1149,0.2252,0.3933) & (0.5204,0.6562,0.7906) \\ (0.0102,0.0218,0.0676) & (0.0080,0.0270,0.0787) & (0.0000,0.0003,0.0184) & (0.7638,0.8207,0.8975) \\ (0.1744,0.3416,0.6109) & (0.0016,0.0039,0.0123) & (0.5068,0.8070,1.0000) & (0.6346,0.7312,0.8165) \\ (0.4245,0.7241,1.0000) & (0.0008,0.0015,0.0039) & (0.2942,0.5562,0.8070) & (0.7265,0.8740,1.0000) \end{bmatrix}$$

***Step 7*:** Assess the three stakeholders (S^{i} , i = 1,2,3) as having following weights: w_{S^1} = 1/2, w_{S^2} = 1/3, and w_{S^3} = 1/6, where $\sum^{3}_{i=1}$ = 1. Multiplying the overall weight-normalised fuzzy performance matrix to the relative important weights for each of the stakeholders. For instance, the first entry values of the weight-normalised fuzzy performance matrix $\left(\tilde{p}_{ij};\ i,j=1\right)$ can be calculated as

$$\left(\tilde{p}_{11}\right) = (w_{S^1} \otimes \tilde{b}^{1}_{11}) \oplus (w_{S^2} \otimes \tilde{b}^{2}_{11}) \oplus (w_{S^3} \otimes \tilde{b}^{3}_{11})$$

$$= \frac{1}{2}(0.2037, 0.3654, 0.6928) \oplus \frac{1}{3}(0.0584, 0.1054, 0.2172) \oplus \frac{1}{6}(0.0785, 0.1334, 0.2841)$$

$$= (0.1344,\ 0.2401,\ 0.4661)$$

Table 3: The linguistic equilibrium judgement of sub-criteria for fully sanitary landfill system from different stakeholders.

	S^1	S^2	S^3
Economical (C_1)			
[1]Capital cost (c_{11})	(0.8308, 0.8462, 0.8538)	(0.8308, 0.8462, 0.8538)	(0.8308, 0.8462, 0.8538)
[1]Operating cost (c_{12})	(0.7500, 0.7500, 0.7500)	(0.7500, 0.7500, 0.7500)	(0.7500, 0.7500, 0.7500)
System benefit (c_{13})	(ML, L)	(ML, L)	(L, L)
Market channel (c_{14})	(M, M)	(ML, L)	(P, MP)
Land value (c_{15})	(VL, L)	(VL, L)	(L, VL)
Environmental (C_2)			
Human health (c_{21})	(ML, ML)	(M,M)	(VL, L)
Pollution issue (c_{22})	(ML, L)	(L, L)	(VL, L)
Nature resources (c_{23})	(H, H)	(L, VL)	(VP, VP)
Waste elimination (c_{24})	(MH, MH)	(ML, VL)	(M, M)
Social (C_3)			
Soc. acceptability (c_{31})	(H, VH)	(M, MH)	(MH, M)
Soc. welfare (c_{32})	(MH, H)	(M, ML)	(MH, H)
Ease to monitor (c_{33})	(ML, M)	(L, L)	(VL, VL)
Technological (C_4)			
[1]Lifetime (c_{41})	(0.3000, 0.3333, 0.4000)	(0.3000, 0.3333, 0.4000)	(0.3000, 0.3333, 0.4000)
Adaptability (c_{42})	(VH, VH)	(H, MH)	(M, M)
Maturity (c_{43})	(VH, VH)	(VH, H)	(ML, L)

Notes: [1]judgement in TFNs form, **(l^+, l^*)** = ('positive aspect', 'non-negative aspect')

Similarly, the full-entry values of overall weight-normalised performance matrix $\left(\tilde{p}_{ij}; i, j = 1,2,3,4\right)$ can be obtained as

$$\left(\tilde{P}_{ij}\right) =$$

$$\begin{bmatrix} (0.1344, 0.2401, 0.4661) & (0.2618, 0.4061, 1.0000) & (0.2929, 0.5340, 0.7835) & (0.5930, 0.6997, 0.7862) \\ (0.1650, 0.3203, 0.5311) & (0.2090, 0.2455, 0.3265) & (0.1010, 0.19441`, 0.3397) & (0.6684, 0.8226, 0.9829) \\ (0.2559, 0.5365, 0.9351) & (0.2343, 0.3109, 0.4804) & (0.2093, 0.3701, 0.5658) & (0.3598, 0.4426, 0.5259) \\ (0.2551, 0.4978, 0.8349) & (0.1896, 0.2186, 0.2857) & (0.4671, 0.7080, 0.9294) & (0.4644, 0.6468, 0.8481) \end{bmatrix}$$

Step 8**:** Determine the FPIS and FNIS, and calculate the distance of each alternative versus p^* and p^-, respectively. Thus, the FPIS distance ($d^*_i; i = 1,2,3,4$) and FNIS distance ($d^-_i; i = 1,2,3,4$) can be obtained and is shown in Table 10, respectively.

Step 9**:** Calculate the performance coefficients (PC_i , i = 1,2,3,4) of each alternative using Eq.-(14). For example, the first performance coefficient (PC_1) can be computed as

$$PC_1 = \frac{d_1^-}{(d_1^* + d_1^-)} = \frac{2.2242}{(2.1016 + 2.2242)} = 0.5142 = A_1$$

Similarly, the performance coefficients (PC_i ; i = 2,3,4) can be obtained as

$PC_2 = 0.4120 = A_2$; $PC_3 = 0.4388 = A_3$; and $PC_4 = 0.5214 = A_4$

Step 10**:** Finally, identify the ranking order of the alternative based on the maximum relative value of performance coefficient.

According to the performance coefficient from Step 9 above, the ranking order of the four systems is A_4, followed by A_1, A_3, and the last ranking is A_2 or symbolically it can be written as $A_4 \rangle\ A_1 \rangle\ A_3 \rangle\ A_2$, where the symbol '$\rangle$' means 'is preferred or superior to'. Obviously, the best option is system A_4.

Conclusions

In this paper we have proposed the decision-making model combining both the AHP and FIS with the new set theory namely conflicting bifuzzy-sets associated with the linguistic hedges concept. It provides efficiently in early stages

Table 4: The linguistic equilibrium judgement of sub-criteria for incinerator system with controlled landfill from different stakeholders.

	S^1	S^2	S^3
Economical (C_1)			
[1]Capital cost (c_{11})	(0.0000, 0.0385, 0.0769)	(0.0000, 0.0385, 0.0769)	(0.0000, 0.0385, 0.0769)
[1]Operating cost (c_{12})	(0.7750, 0.7750, 0.7750)	(0.7750, 0.7750, 0.7750)	(0.7750, 0.7750, 0.7750)
System benefit (c_{13})	(H, MH)	(H, VH)	(VL, VL)
Market channel (c_{14})	(H, M)	(H, MH)	(VL, L)
Land value (c_{15})	(VL, L)	(M, MH)	(ML, L)
Environmental (C_2)			
Human health (c_{21})	(M, ML)	(M, MH)	(VL, VL)
Pollution issue (c_{22})	(M, M)	(M, MH)	(VL, L)
Nature resources (c_{23})	(VH, VH)	(H, VH)	(VL, L)
Waste elimination (c_{24})	(H, VH)	(VH, VH)	(H, H)
Social (C_3)			
Soc. acceptability (c_{31})	(M, ML)	(M, M)	(VL, L)
Soc. welfare (c_{32})	(ML, VL)	(M, MH)	(VL, VL)
Ease to monitor (c_{33})	(L, VL)	(ML, L)	(VL, VL)
Technological (C_4)			
[1]Lifetime (c_{41})	(0.6000, 0.6667, 0.8333)	(0.6000, 0.6667, 0.8333)	(0.6000, 0.6667, 0.8333)
Adaptability (c_{42})	(H, VH)	(H, H)	(VH, H)
Maturity (c_{43})	(MH, H)	(H, H)	(VL, VL)

Notes: [1]judgement in TFNs form, (l^+, l^*) = ('positive aspect', 'non-negative aspect')

Table 5: The linguistic equilibrium judgement of sub-criteria for composting system with controlled landfill from different stakeholders.

	S^1	S^2	S^3
Economical (C_1)			
[1]Capital cost (c_{11})	(0.6154, 0.7000, 0.7692)	(0.6154, 0.7000, 0.7692)	(0.6154, 0.7000, 0.7692)
[1]Operating cost (c_{12})	(0.7125, 0.7125, 0.7125)	(0.7125, 0.7125, 0.7125)	(0.7125, 0.7125, 0.7125)
System benefit (c_{13})	(M, M)	(H, MH)	(MH, H)
Market channel (c_{14})	(ML, M)	(H, H)	(M, ML)
Land value (c_{15})	(ML, ML)	(MH, MH)	(VL, L)
Environmental (C_2)			
Human health (c_{21})	(ML, M)	(M, MH)	(L, VL)
Pollution issue (c_{22})	(MH, VH)	(M, ML)	(M, MH)
Nature resources (c_{23})	(M, ML)	(M, MH)	(M, ML)
Waste elimination (c_{24})	(MH, M)	(M, ML)	(MH, VH)
Social (C_3)			
Soc. acceptability (c_{31})	(ML, L)	(M, M)	(H, H)
Soc. welfare (c_{32})	(L, VL)	(M, ML)	(H, MH)
Ease to monitor (c_{33})	(M, M)	(MH, M)	(H, VH)
Technological (C_4)			
[1]Lifetime (c_{41})	(0.2667, 0.3333, 0.4000)	(0.2667, 0.3333, 0.4000)	(0.2667, 0.3333, 0.4000)
Adaptability (c_{42})	(M, MH)	(L, VL)	(H, H)
Maturity (c_{43})	(ML, L)	(L, L)	(L, VL)

Notes: [1]judgement in TFNs form, (l^+, l^*) = ('positive aspect', 'non-negative aspect')

to assist the decision-makers to cope with the complexity of the real situation by its hierarchical structure and is successful in dealing with the non-homogeneousness of datasets in the evaluation process. Moreover, the power of *dilation* and/or *concentration* offers quantifying the imprecision of decision judgement directly among the DMs with respect to the each criterion. In addition, the model not only accommodates the integrated factors such as economic, environmental, society and technological factors but also incorporates the local multiple stakeholders, and therefore the sustainable MSW management decision can be achieved successfully. Although the model

Table 6: The linguistic equilibrium judgement of sub-criteria for material recycling system with controlled landfill from different stakeholders.

	S^1	S^2	S^3
Economical (C_1)			
[1]Capital cost (c_{11})	(0.8000, 0.8077, 0.8462)	(0.8000, 0.8077, 0.8462)	(0.8000, 0.8077, 0.8462)
[1]Operating cost (c_{12})	(0.1625, 0.1625, 0.1625)	(0.1625, 0.1625, 0.1625)	(0.1625, 0.1625, 0.1625)
System benefit (c_{13})	(M, MH)	(H, VH)	(H, H)
Market channel (c_{14})	(ML, ML)	(H, MH)	(M, MH)
Land value (c_{15})	(MH, MH)	(M, M)	(H, VH)
Environmental (C_2)			
Human health (c_{21})	(VH, H)	(MH, H)	(H, VH)
Pollution issue (c_{22})	(H, H)	(M, MH)	(M, MH)
Nature resources (c_{23})	(VH, MH)	(MH, H)	(MH, H)
Waste elimination (c_{24})	(M, M)	(ML, VL)	(ML, ML)
Social (C_3)			
Soc. acceptability (c_{31})	(H, MH)	(VH, VH)	(M, MH)
Soc. welfare (c_{32})	(M, L)	(VH, VH)	(M, H)
Ease to monitor (c_{33})	(H, H)	(M, ML)	(H, H)
Technological (C_4)			
[1]Lifetime (c_{41})	(0.6667, 0.8333, 1.0000)	(0.6667, 0.8333, 1.0000)	(0.6667, 0.8333, 1.0000)
Adaptability (c_{42})	(M, ML)	(H, MH)	(M, ML)
Maturity (c_{43})	(ML, L)	(H, M)	(M, MH)

Notes: [1]judgement in TFNs form, (l^+, l^*) = ('positive aspect', 'non-negative aspect')

Table 7: The crisp data of the operation cost (c12) for four disposal systems.

Item (c_{12})	A_1	A_2	A_3	A_4	Membership function
Operation cost (in RM/tonnes)	150	125	187.5	737.5	$\mu_{OC} = \begin{cases} (900-x)/1000, & 100 \le x \le 800 \\ 1, & x < 100 \end{cases}$

Notes: RM is Ringgit Malaysia; US$1= RM3.25 (approx.)

Table 8: The rating of the criteria from different stakeholders' perspectives.

Stakeholder	C_1	C_2	C_3	C_4
S^1	*EI*	*I*	*VI*	*SI*
S^2	*EI*	*VI*	*I*	*EI*
S^3	*EI*	*EI*	*VI*	*SI*

Notes:EI ~ Exteremely important; VI ~ Very important; I ~ Important; SI ~ Somewhat important

Table 9: The power of dilation and concentration derived from Table 8.

Stakeholder	C_1	C_2	C_3	C_4
S^1	$(\tilde{a}_{EI}(x))^3$	$(\tilde{a}_{I}(x))^1$	$(\tilde{a}_{VI}(x))^2$	$(\tilde{a}_{SI}(x))^{1/2}$
S^2	$(\tilde{a}_{EI}(x))^3$	$(\tilde{a}_{VI}(x))^2$	$(\tilde{a}_{I}(x))^1$	$(\tilde{a}_{EI}(x))^3$
S^3	$(\tilde{a}_{EI}(x))^3$	$(\tilde{a}_{EI}(x))^3$	$(\tilde{a}_{VI}(x))^2$	$(\tilde{a}_{SI}(x))^{1/2}$

Note: $\tilde{a}$ is a triangular fuzzy number denoted as $\tilde{a} = (x_1, x_2, x_3)$

Table 10: The distance measurement.

	A_1	A_2	A_3	A_4
d^*	2.1016	2.4311	2.3703	2.0310
d^-	2.2242	1.7034	1.8532	2.2130

proves efficient as a sustainable MSW decision tool in this case study, it is believed that the application can be extended to other similar management problems as well. Finally, possible future research proposals may include the effort to develop specific software which complies with the proposed method to assist the evaluators to reach judgement in a simple manner. Once this issue is well resolved, the proposed method would be one of the comprehensive evaluation methods available.

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