Available online at www.jlls.org

JOURNAL OF LANGUAGE AND LINGUISTIC STUDIES

ISSN: 1305-578X

Journal of Language and Linguistic Studies, 17(3), 1639-1650; 2021

Decision model using hierarchical fuzzy TOPSIS: Towards improving decision making in food waste management

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APA Citation:

Omar, M. F., Shukor, J. A., Kassim, M. M., Hussin, K. C. (2021). Decision model using hierarchical fuzzy TOPSIS: Towards improving decision making in food waste management. *Journal of Language and Linguistic Studies, 17*(3), 1639-1650. Doi: 10.52462/jlls.119

Submission Date:05/06/2021

Acceptance Date:01/09/2021

Abstract

Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) is based on decision model to measure alternative with shortest distance to positive ideal solution and the farthest distance from negative ideal solution. With growing complexity in decision making, vagueness and uncertainty often exist in human judgement. To manage conflicting criteria, a hierarchy structure in TOPSIS is proposed where the main criteria, sub-criteria, and alternatives are arranged in multi-level. To rate each alternatives, the weight of each criterion is evaluated using linguistic value before converted into fuzzy number as a way to measure the experts opinion. In this paper, we demonstrates our general framework for the development of hierarchal fuzzy TOPSIS. We also highlighted our initial finding on the criteria and alternatives in our case study i.e. selection of decomposition technology for food waste management. It is anticipates our work will contributes better decision making in the related area.

Keywords: Hierarchical Fuzzy TOPSIS; Linguistic Variable; Decomposition Technology; Food Waste

1. Introduction

TOPSIS is one of the conventional tools in Multi Criteria Decision Making (MCDM) has begun to be introduced by Hwang and Yoon (1981) as a method to find the right decision using the concepts of negotiation (Tzeng et al., 2011). This proposed method is widely used in decision assessment because it very simple MCDM method, easy to implement (Kabir et al., 2012), and most importantly the decision is rationale when it considering from the best till the worst alternative to measures each alternatives on attributes (Ataei & Branch, 2013). In the basic concept of TOPSIS, the chosen alternative should have the shortest distance from the Positive Ideal Solution (PIS) and the farthest distance from the Negative Ideal Solution (NIS) (Najafi et al., 2016; Chen, 2000).

In TOPSIS approach, the rating and the weight are mentioned precisely in numerical value and this provide an accurate decision data for decision making process. Since the concept of TOPSIS is quite

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practical in decision making process, it frequently applied to solve fuzzy-MCDM (FMCDM). The model of FMCDM is developed by integrating the concept of TOPSIS and fuzzy theory. This fuzzy TOPSIS enable decision makers the capability of handling uncertainties and complexity in decision making problems when considering a diversity of criterion. For this reason, linguistic value is used in fuzzy TOPSIS before converted into numerical data. The numerical value is then use to weights of all criteria and the rating of each alternatives with respect to each criterion (Chen, 2000). Since linguistic judgment can measure the uncertainty data in making the decision, therefore it has been applied by many researchers for making decision in different field. For example, this technique of fuzzy TOPSIS has been apply for the services quality (Kabir et al., 2012), selection of location (Ashrafzadeh et al., 2012), supplier selection (Sevkli et al., 2010), etc.

However, for decision-making process with multiplicity of decision elements, requires identification and data classification on decision options and decision criteria which is preferentially independent of each other. Therefore, to organize them in a decision-making problem, Hierarchical Fuzzy TOPSIS (HFTOPSIS) method is introduced. Hierarchical Fuzzy TOPSIS has simple procedure to implement the hierarchy structure where each sub-criteria, criteria and alternative are arranged in different level. Then sub-criteria is integrated to the main criteria using linguistic value to measure its weight for ranking the alternative (Ranjbar & Nekooie, 2018). The linguistic value is the information of uncertain variable that can be converted into fuzzy numbers before performing the arithmetic operation.

Thus, Hierarchical Fuzzy TOPSIS can manage the ambiguities in multi-criteria problem to yield precise, consistent, and reliable results. It has been applied in different application domains, such as supplier selection (Najafi et al., 2016; Roshandel et al., 2013), earthquake damage (Ranjbar & Nekooie, 2018), risk evaluation (Liu et al., 2018), location planning (Sopha et al., 2018), and road safety assessment (Bao et al., 2012).

2. Hierarchical Fuzzy TOPSIS

To construct the hierarchical structure, the objective/goal, main criterions, sub-criterions, and alternatives are separated and organized into four or more level ((Roshandel et al., 2013). Hierarchical Fuzzy TOSIS used linguistic variable similar to the model developed by Chen and Hwang (1992) in order to handle uncertainty or imprecise of information in a complex situations. The linguistic variables are converted into fuzzy number in crisp value ((Chen, 2000; Ashrafzadeh et al., 2012; Chu & Lin, 2009; Kahraman et al., 2015). Linguistic variable (or value) is a subjective judgement in quantitative expressions by decision maker where the values is mention in statement instead of number (Chen, 2000; Sopha et al., 2018; Zadeh, 1975). Fuzzy concept is used when assessment or decision usually mentioned with unclear and definite meaning. For example, *student height* is a linguistic variable if the value is in linguistic term or fuzzy variables i.e., *tall, not tall, very tall, quite tall, short, not very short and not very tall,* etc., rather than the numbers 1*20cm, 121cm, 122cm, 123cm,…..* etc (Chen, 2000; Zadeh, 1975).

In our study, we used triangular fuzzy number (TFN) to express linguistic variable to describe the quantitative judgement of decision maker. TFN is the most often used due to its simplicity to compute. A triangular fuzzy numbers consists of triplet $\breve{\alpha} = (a_{ij}, b_{ij}, \mathrm{c_{ij}})$ which is represented as the smallest possible value, the most promising value, and the largest possible value of the fuzzy number, respectively (Moayeri et al., 2015; Elomda et al., 2013). This value is then used to constitute hierarchical fuzzy decision-making matrix $\widetilde{D}$ to allow the arithmetic operation (Sopha et al., 2018; Kahraman et al., 2015; Ye & Li, 2014; Kahraman et al., 2007). Table 1 and 2, shows the positive TFN as representing the linguistic value to give a measurement in numerical value for weight the various criteria and the rating of alternative.

Table 1. Linguistic variables for the importance weight of each criterion and sub-criterion

Scale	Weight (Triangular FN)
Very Not Important (VNI)	(0, 0, 0.1)
Not Important (NI)	(0, 0.1, 0.3)
Medium Low Important (MLI)	(0.1, 0.3, 0.5)
Medium Important (MI)	(0.3, 0.5, 0.7)
Medium High Important (MHI)	(0.5, 0.7, 0.9)
High Important (HI)	(0.7, 0.9, 1.0)
Very High Important (VHI)	(0.9, 1.0, 1.0)

Table 2. Linguistic variable for rating alternative than sub-criteria

Scale	Rating (Triangular FN)
Very Low (VL)	(0, 0, 1)
Low (L)	(0, 1, 3)
Medium Low (ML)	(1, 3, 5)
Average (A)	(3, 5, 7)
Medium High (MH)	(5, 7, 9)
High (H)	(7, 9, 10)
Very High (VH)	(9, 10, 10)

The purpose of hierarchical fuzzy TOPSSIS is not only to overcome the fuzziness of information of decision maker but can also provide accurate criterion weight. Besides that, there are several advantages of Hierarchical Fuzzy TOPSIS against classical TOPSIS and fuzzy TOPSIS as highlighted by (Zarbini-Sydani et al., 2011) (Table 3). This comparison shows the Hierarchical Fuzzy TOPSIS offers a more systematic, effective, and accurate evaluation for uncertainty decision under fuzzy environment. The model of Hierarchical Fuzzy TOPSIS is illustrated in Figure 1, where the structure of model consists of the level of objective, main criterions, sub-criterions, and alternatives.

Table 3. Advantages of HFTOPSIS

Feature	**TOPSIS**	**Fuzzy TOPSIS**	**Hierarchical Fuzzy TOPSIS**
Support of hierarchical structure			•
Support of fuzzy concept		•	•
Realistic weighting of criteria			•
Ranking ability	•	•	•
Easily Understandable	•	•	•

Comparability with the ideal solution	•	•	•

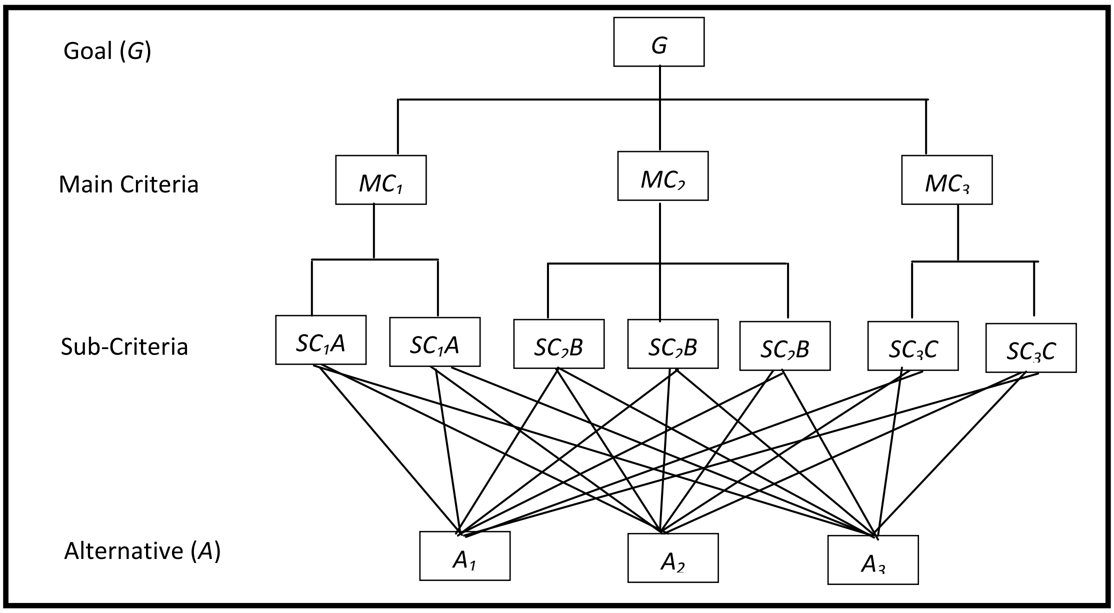

Figure 1. The hierarchical system proposed for HFTOPSIS model

3. The Framework of Hierarchical Fuzzy TOPSIS

The basic concept of TOPSIS is developed to solve ranking and the justification considering the maximum similarity to the positive ideal solution. This MCDM model concisely expressed in decision matrix (*D*) format in which the row list alternative (A_1, A_2, ... A_m) that are evaluated by criterion (C_1, C_2, ... C_n) in columns. However, there are some limitations on decision making techniques of conventional TOPSIS where the approach only applicable to one tier decision problem and does not consider a decision in hierarchy system or multi-tier decision between main criteria and sub-criteria (Taghavifard & Mirheydari, 2008; Wang & Chan, 2013). The drawback expose the lack of comparative analysis on different criteria. Therefore, for complex problem with multiple criteria analysis, Analytic Hierarchy Process (AHP) is widely used. AHP method is the only MCDM model considers the hierarchy system to assess the alternative between criteria and sub-criteria. The approach of AHP utilized pairwise comparisons between criteria and sub-criteria (Wang & Chan, 2013).

However, (Moayeri et al., 2015) indicated the decision results for math teacher selection using fuzzy AHP and fuzzy TOPSIS have same decision alternative. This study shown AHP and TOPSIS method can be used in fuzzy environment and evaluated using linguistic value. The final decision for both methods are approximately comparable. Fuzzy AHP used pair-wise comparisons for criteria, sub-criteria and alternatives, while fuzzy TOPSIS are based on the closeness coefficient of alternative with respect to each criteria and sub-criteria. In other study by Sun (2010) in the performance evaluation model and Ding (2011) for the best partner selection, fuzzy AHP can be integrated with fuzzy TOPSIS for more accurate assessment. Thus, fuzzy AHP was used to determine the preference weights of evaluation, while the fuzzy TOPSIS was used to improve the quality of decision-making for ranking alternative. These studies have brought opportunity to expose hierarchy system in TOPSIS model through inheriting the hierarchy mechanism of AHP. Interestingly, Hierarchical Fuzzy TOPSIS does not used pair-wise comparison technique and the decision results is more accurate to be used with relative distance (Moayeri et al., 2015; Kahraman et al., 2007; Baykasoğlu et al., 2013; Ateş et al., 2006). Hierarchical Fuzzy TOPSIS is also easy to implement and its calculations are less tedious and faster (Ateş et al., 2006). In our research work, the basic steps of the proposed hierarchy model to apply in TOPSIS can be describe below as shown in Fig 3.

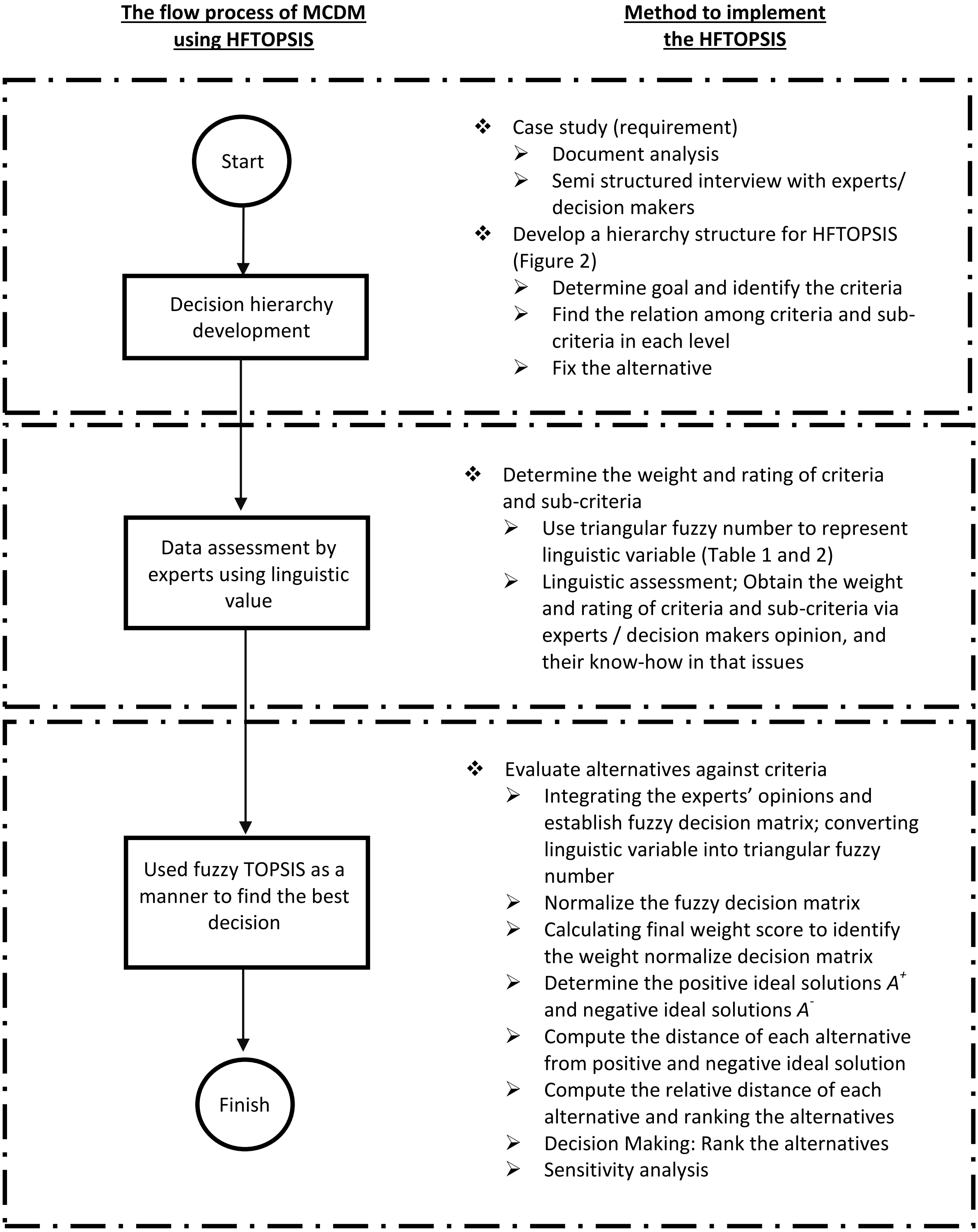

Figure 3. The flowchart of Hierarchical Fuzzy TOPSIS model for multi criteria decision making

4. Definition of Fuzzy TOPSIS

Based on Figure 3, to evaluate the alternative against criteria, the hierarchical system suggested to be used in fuzzy TOPSIS model and it can be constructed in details as follows;

Step 1: Develop fuzzy decision matrix.

$$\widetilde{D} = \begin{array}{c} \\ A_1 \\ . \\ . \\ A_i \\ . \\ . \\ A_m \end{array} \left| \begin{array}{ccccc} X_1 & \dots & X_j & \dots & X_n \\ \tilde{x}_{11} & \dots & \tilde{x}_{1j} & \dots & \tilde{x}_{1n} \\ . & \dots & . & \dots & . \\ . & \dots & . & \dots & . \\ \tilde{x}_{i1} & \dots & \tilde{x}_{ij} & \dots & \tilde{x}_{in} \\ . & \dots & . & \dots & . \\ . & \dots & . & \dots & . \\ \tilde{x}_{m1} & \dots & \tilde{x}_{mj} & \dots & \tilde{x}_{mn} \end{array} \right| \quad (1)$$

When $\tilde{x}_{ij}$ is fuzzy, it is represented by TFNs as $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ as shown in Figure 1. The rating value for each decision makers is calculated to form single decision matrix $\widetilde{D}_k$ as shown in equation below;

$$a_{ijk} = \min_K\{a_{ijk}^K\},\ b_{ijk} = \frac{1}{K}\sum_{K=1}^{K} b_{ijk}^K,\ c_{ijk} = \max_K\{c_{ijk}^K\} \quad (2)$$

Step 2: Normalize the Decision Matrix

In order to transform the various criteria dimension into non-dimensional criteria, decision matrix is normalized to make its elements unit free (Roshandel et al., 2013; Bao et al., 2012).

$$\tilde{r}_{ijk} = \tilde{X}_{ijk}(:)\tilde{X}_{jk}^{+} = \left(\frac{a_{ijk}}{c_{jk}^{+}}, \frac{b_{ijk}}{b_{jk}^{+}}, \frac{c_{ijk}}{a_{jk}^{+}}\right), \qquad \tilde{X}_{jk}^{+},\ j \text{ belongs to benefit criteria} \quad (3)$$

$$\tilde{r}_{ijk} = \tilde{X}_{jk}^{-}(:)\tilde{X}_{ijk} = \left(\frac{a_{jk}^{-}}{c_{ijk}}, \frac{b_{jk}^{-}}{b_{ijk}}, \frac{c_{jk}^{-}}{a_{ijk}}\right), \qquad \tilde{X}_{jk}^{-},\ j \text{ belongs to cost criteria} \quad (4)$$

Step 3: Calculate the final weight score for each sub-criteria

The weight is represent in triangular fuzzy number where $\widetilde{w}_i = (\alpha_i, \beta_i, \delta_i)$ is the weight of the main criteria, and $\widetilde{w}_{ij} = (\alpha'_{ij}, \beta'_{ij}, \delta'_{ij})$ is the weight of sub-criteria (Chen, 2000; Taghavifard & Mirheydari, 2008; Kore et al., 2017). To measure the final weight score, the weight value from all decision maker are require to convert into a single weight for each sub-criteria as follow the equation below;

$$w_{ij1} = \min_K\{w_{ij}^K\},\ w_{ij2} = \frac{1}{K}\sum_{K=1}^{K} w_{ij}^K,\ w_{ij3} = \max_K\{w_{ij}^K\} \quad (5)$$

Then calculate the fuzzy number for the final weight score for each sub-criterion as follow (Bao et al., 2012; Taghavifard & Mirheydari, 2008).

$$\widetilde{W}_K = \widetilde{w}_i\,(.)\widetilde{w}_{ij} \quad (6)$$

$$\widetilde{W}_K = (\alpha_i, \beta_i, \delta_i).(\alpha'_{ij}, \beta'_{ij}, \delta'_{ij}) = (\alpha_i\alpha'_{ij}, \beta_i\beta'_{ij}, \delta_i\delta'_{ij}) \quad (7)$$

Step 4: Determine Weight Normalize Decision Matrix

The weight normalized fuzzy decision matrix is calculated as;

$$\tilde{V}_{ijk} = \tilde{r}_{ijk}\,(.)\widetilde{w}_{SCjk}, \quad (8)$$

$$\text{Where, } V = \left[\tilde{V}_{ijk}\right]_{kxm} \quad (9)$$

Step 5: Identify the fuzzy positive ideal solution (FPIS, A^+) and the fuzzy negative ideal solution (FNIS, A^-)

$$\tilde{A}^+ = [\tilde{V}_1^+, \cdots, \tilde{V}_n^+] \quad (10)$$
$$\tilde{A}^- = [\tilde{V}_1^-, \cdots, \tilde{V}_n^-] \quad (11)$$

Step 6: Calculate the distance $\tilde{d}_{ij}^+$ and $\tilde{d}_{ij}^-$ to define closeness coefficient CC_i

$$d_i^+ = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^+\right), \qquad i = 1, 2, \dots, m \quad (12)$$
$$d\left(\tilde{v}_{ij}, \tilde{v}_j^+\right) = \sqrt{\frac{1}{3}\left[(a-c^+)^2 + (b-c^+)^2 + (c-c^+)^2\right]} \quad (13)$$
$$d_i^- = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right), \qquad i = 1, 2, \dots, m \quad (14)$$
$$d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right) = \sqrt{\frac{1}{3}\left[(a-c^-)^2 + (b-c^-)^2 + (c-c^-)^2\right]} \quad (15)$$
$$CC_i = \frac{d_i^-}{(d_i^+ + \tilde{d}_i^-)} \quad (16)$$

Step 7: Ranking the alternative, *A*

The index value of CC_i can used to rank the set of alternative from the most preferred to the least preferred feasible solution (Roshandel et al., 2013; Taghavifard & Mirheydari, 2008).

5. Findings

The case of criteria and alternatives determination for Selection of Decomposition Technology for Food Waste Management

We applied the hierarchical Fuzzy TOPSIS framework for our problem i.e. Selection of Decomposition Technology for food Waste Management. The criteria were gathered from literature and validated from interview with experts in Malaysia. Table 4 list the criteria to be used in our case study. During the interview, the experts suggested *anerobic composting*, *vermicomposting* and *EM Composting* as alternatives for the decision model.

Table 1. Linguistic variables for the importance weight of each criterion and sub-criterion

Criteria	Sub Criteria	Description
Environmental Protecting public health, natural resources, and conserve environmental	Air Pollution / unwanted smell	Unpleasant odours release during waste handling or if composting process is not properly manage.
	Greenhouses gasses emission	The release of Carbon dioxide (CO_2), methane (CH_4), Nitrous Oxide (N_2O), along the treatment
	Water pollution	Leachate by-product; cannot evaporate as steam but will drain down towards the ground
	Expose to Pathogens	Pathogen possible to grow inside the waste if composting is not properly manage.
	Public Health	Health disruption toward works and nearby residents such as skin disease, respiratory symptoms etc.
Economic Aspects Cost and benefits	Implication on operational cost	Cost on technology usage, waste handling and ingredient for composting

obtain in using the technology	Marketability	market demand on compost product (humus/folior) compared to chemical fertilizer
	Energy Saving	Less energy consumption during the treatment
	Renewable Energy	The ability of technology to produce bio-gas as by-product
Social Aspects Contribution of technology to social	Benefit to society	Side income for nearby residents; through the purchase of their organic waste
	Usability and compatibility	Ability of technology to use in small scale such as at school, cafeteria, backyard etc.
Technical Aspect The ability of technology	Ability of Machinery/Equipment	capacity waste to decompose for one cycle
	Labour needs	Amount of workers to process the waste per machine
	Locality	Suppy chain
	Duration of processing time	time taken for one complete cycle of composting
	Free-chlorinated Water Supply	to control process condition

6. Discussion

Many methods in MCDM such as TOPSIS and AHP used fuzzy logic approaches to address conflicting criteria in order to select the appropriate alternative in decision making. In AHP method, a hierarchical system has shown to be useable in fuzzy TOPSIS method when the decision maker has a large, complex, uncertain and imprecise data for making the decision. Unlike AHP, the hierarchical system in fuzzy TOPSIS does not require to perform pairwise comparison. On the contrary, HFTOPSIS method is used for ranking the decision using relative distance (Moayeri et al., 2015; Kahraman et al., 2007; Masudin & Saputro, 2016; Paksoy et al., 2012) where the computation processes are straightforward and easy to determine the ideal solution

By using a simple mathematical definition, HFTOPSIS can be used to support a desired solution in decision making (Bao et al., 2012; Wang, & Chang, 2007). Previous studies shown the result from both fuzzy AHP and Hierarchical Fuzzy TOPSIS are comparable (Moayeri et al., 2015; Sun, 2010; Masudin, & Saputro, 2016; Paksoy et al., 2012). This prove the ability of HFTOPSIS approach for evaluating the problem by using hierarchical structure offers a more reliable and practical for multidimensional decision making problem.

7. Conclusion

Till date, many application has been applied in the area of MCDM (Nursal et al., 2016; Nursal et al., 2015; Sulaiman et al., 2015; Sulaiman et al., 2015; Omar et al., 2014; Nursal et al., 2014). To deal with complex and imprecise information, fuzzy approach is often being utilised in MCDM. TOPSIS is one of the popular MCDM technique and can be integrate with fuzzy number and hierarchy system in a complex and uncertain decision making environment. This is because numerical value or a discrete number is often difficult to evaluate imprecise data or human judgement. In contrast, the use of linguistic value which represented by a triangular fuzzy number can be determined the closeness of relationship in such data or criteria. Additionally, the criteria in the hierarchical structure can be arranged into main-criteria or sub-criteria for assessing the ranking of alternative.

In this paper, we presented to general framework of fuzzy TOPSIS with hierarchy system which is practical to evaluate criteria/alternatives. The approach is more practical, and easy to understand. In our future work, we consider to apply the above method in order to select the best decomposition technology for organic waste management (Shukor et al., 2018).

8. Future Work

We will continue to develop a decision model using hierarchical Fuzzy TOPSIS based on the criteria and alternatives gathered. In future, we also planned to further develop a computerised model to assist decision makers for selecting the best decomposition technology for food waste management.

Acknowledgement

The authors gratefully acknowledge the financial support from UUM Collaboration 1+3 Research Grant (S/O Code: 14036) for this research.

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