Pathumwan Academic Journal, Vol. 10, No. 29, September - December 2020: 65 - 80

Selection of Suitable Rice Weevil Disinfestation Method Using Hybrid FAHP-FTOPSIS

Pariwat Nasawat[1], Sukangkana Talangkun[1,*], Sirawadee Arunyanart[1] and Narong Wichapa[2]

[1]Department of Industrial Engineering, Faculty of Engineering, Khon Kaen University, Thailand

[2]Department of Industrial Engineering, Faculty of Engineering and Industrial Technology, Kalasin University, Thailand

E-mail: sukangkana@kku.ac.th

Abstract

The objective of this article is to demonstrate how to choose a suitable rice weevil disinfestation method using hybrid FAHP-FTOPSIS. This problem is complicated, because there are both subjective and objective criterion involving total cost, rice quality, performance and environmental friendliness. Based on a case study, proposed technique was tested. The results show that an infrared-hot air system is the best alternative for rice weevil disinfestation, followed by the vacuum method and fumigation. The advantage of the proposed technique is simultaneous consideration of each criterion for solving this problem efficiently.

Keywords: Rice Weevil Disinfestation; FAHP; FTOPSIS; Multiple Attribute Decision Making

1. Introduction

One of the major crops in Thailand is rice, with 114,880 km^2 for rice cultivation and an output of 32.63 million tons per year. The average volume of mill rice exported from 2018 to 2019 was 7.56 million tons (102,308 million Baht) [1]. During storage in the warehouse before export, there are various rice insect pests, such as the Red flour beetle, Corn weevil and Rice weevil that cause damage to milled rice at about 5-10 % [2]. Since the government has a policy of promoting the cultivation of rice, mill companies need to build more warehouses for rice storage. Hence, the mill companies have come up with ways to prevent and eliminate the rice insect pests. For rice insect pest control, one of the most commonly used methods is fumigation. The implementation of this method is easy and cheap. However, this method may produce toxics that are harmful to the environment and the human body. Furthermore, Consumers lack confidence in products that are manufactured using this method, and the export of rice does not comply with agricultural standards [3]. The second method to eliminate the rice insect pest is vacuum seal packaging. The major advantage of this method is that it complies with agricultural standards for organic rice. However, this method has a relatively high cost and short shelf life, only 4 months. If the storage time exceeds that specified, it is not acceptable to consumers due to its bad odor [2]. A newly developed method to eliminate the rice insect pests is the infrared system. The major advantages are that it is cheap and environmental friendliness, and it does not affect the quality of the rice [4]. To choose the best method should consider both the advantages and disadvantages of each method. Therefore, the selection of the best method for rice insect pest control is a complex problem, because there are several conflicting decision factors such as cost, rice quality and

Research Paper **Received 7 June 2020**
***Corresponding author**
Revised 28 December 2020
Accepted 30 December 2020

being environmental friendliness.

The selection of rice weevil disinfestation is considered a multiple attribute decision making (MADM) problem, because there are many decision criterion involved, such as total cost, rice quality, performance and environmental friendliness, including both qualitative and quantitative criterion that should be simultaneously taken into consideration. Therefore, one of the most essential difficulties to address in this complicated problem is to choose an appropriate technique for solving the complex factors/criteria, because during the process of decision making the experts may be imprecise.

In order to aid decision maker to address the complicated problems, the Analytic hierarchy process (AHP) was introduced by Thomas Saaty in 1980. For addressing MADM problems. The pairwise comparisons between alternatives will be used to select the best possible alternative [5]. AHP is one of the flexible tools to solve the complex problems in literatures. However, AHP cannot deal with uncertainty and fuzziness in complex problems [6]. Hence, Fuzzy logic was taken into AHP, namely FAHP, to overcome the drawback. Nowadays FAHP is very common apply in various fields such as engineering and management decision making situations. For example, Othman et al. [7] have proposed using FAHP for evaluating the criteria contributing to the asymmetry of cargo flows in Malaysia large-scale minor ports. Li et al. [8] have proposed FAHP for evaluating eco-environmental vulnerability assessment for the danjiangkou reservoir area, China. Khamhong et al. [9] have proposed FAHP for based Criteria Analysis for 3D Printer Selection in Additive Manufacturing. Although the FAHP is a powerful technique to tackle real-world complex problems, there are many ways to convert fuzzy numbers to crisp numbers. Each way may not different ranking for a similar problem, but TOPSIS can be used to deal with this drawback. To rank uncertainty and fuzziness, Fuzzy TOPSIS (FTOSIS) can be used to rank alternatives instead of TOPSIS. Hence, in order to take advantage of each technique, while overcoming their drawbacks, selecting a hybrid FAHP-FTOPSIS will enhance the confidence of companies in choosing the best alternative for rice weevil disinfestation. In order to handle vague data involved in this problem, the integration of FAHP and FTOPSIS techniques is essential for solving the MADM problems in this case.

The traditional tools, such as the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) [10]-[15], TOPSIS [16]-[22], have been proposed for solving complicated problems. However, AHP and TOPSIS are often suggested for addressing the complicated problems in literature, because they are two MADM techniques which are popular, flexible and powerful for evaluating both tangible criterion and intangible criterion [23]. However, these MADM techniques are difficult to reflect the opinion of decision makers as an exact value in a comparison of each alternative; they cannot reflect human thinking in the decision making process. Later, Zadeh [24] developed the fuzzy set theory to overcome this drawback. Nowadays this theory is widely used in combination with the traditional MADM techniques for handling complex problems, instead of traditional MADM techniques as reported in the literature [25]-[37]. The advantages and disadvantages of TOPSIS, AHP, FAHP and FTOPSIS are shown in Table 1.

For example, the FAHP is one of the powerful and popular techniques for solving MADM problems, and it can be used to choose the best alternative when the decision makers have multiple decision criteria [36, 42]. Its main advantages are addressing various criterion, being perspicuous, and effectively addressing both quantitative and qualitative data. However, the disadvantages of the FAHP are that consistency is hard to achieve when there are several alternatives and decision criterion to evaluate. The main advantages of the FTOPSIS technique are shown in Table 1. Because of the weakness of the FAHP technique, the ranking of this technique is rather imprecise. Recent researchers [43, 44] have proposed using a combination of FAHP, TOPSIS and FTOPSIS to solve the MADM problems. There are some papers (using FAHP-FTOPSIS) related to environmental or agricultural applications. For example, Dirwai et al. [45] have proposed FAHP-FTOPSIS to tackle the problem of water control infrastructure and water governance in KwaZulu-Natal, South Africa. Prakash [46] have proposed FAHP-FTOPSIS for selecting third-party reverse logistics partner under fuzzy uncertainty data.

Table 1 The advantage and disadvantage of TOPSIS, AHP, FAHP and FTOPSIS

MADM	Advantage	Limitation / Disadvantage	References
TOPSIS	- Simple to use. - Deals with subjective and objective criteria. - Rational and understandable. - The calculation steps are straightforward. - It can identify the best alternative rapidly.	- It cannot be manipulated with uncertain data. - It cannot verify the consistency of the data.	[16, 17, 18, 38, 39, 54]
AHP	- Flexible and powerful technique for addressing both tangible and intangible criteria.	- It cannot be manipulated with uncertain data.	[20, 21, 23, 38]
FAHP	- This technique is powerful to handle complicated problems. - Deals with uncertain data.	- The FAHP technique cannot rank candidate alternatives effectively.	[36, 37, 40, 53]
FTOPSIS	- Distance from the ideal solution for each alternative can be measured. - In general, the results will be close to the ideal solution.	- Cannot verify the consistency of the data.	[40, 41, 42, 43]

From the literature reviewed, the selection of a suitable rice weevil disinfestation method is an issue with many relevant factors, including factors that are difficult to interpret. In order to achieve the suitable method for rice weevil disinfestation, the FAHP and the FTOPSIS are suitable for solving multi-criteria decision making problems that are difficult to interpret. Hence, choosing integrated FAHP and FTOPSIS to solve the problem of selection of the suitable rice weevil disinfestation method, are reasonable for use in this case study. The FAHP-FTOPSIS proposed in this study is different from the traditional tools because it can overcome the weak points of each method. Unlike the traditional MADM tools based stand-alone method; this can help the problem solving to increase reliability and flexibility, and enhance the satisfaction level of stakeholders.

2. Methodology

The solution approach for the rice weevil disinfestation selection problem is as follows: (1) firstly, the main criteria in Level 1, sub-criteria in Level 2, and alternatives in Level 3 must be evaluated using the FAHP and (2) after that, FTOPSIS is used to rank the candidate alternatives of rice weevil disinfestation. The details of selecting the best alternative for rice weevil disinfestation using the hybrid MADM technique are shown in Fig. 1.

The first step of the framework for selecting the best method of rice weevil disinfestation is to determine and define a set of elements in the decision problem, including main criteria, sub-criteria and candidate alternatives, using previous research and experts' opinion. These elements must be decomposed into a hierarchy. The next step would be calculate the criteria weights using FAHP, and FTOPSIS would be used to calculate the clossness coefficient (cc_i) instead of common defuzzy formulas in FAHP for ranking the candidate alternatives. The final step is to select the best rice weevil disinfestation method using the hybrid MADM technique.

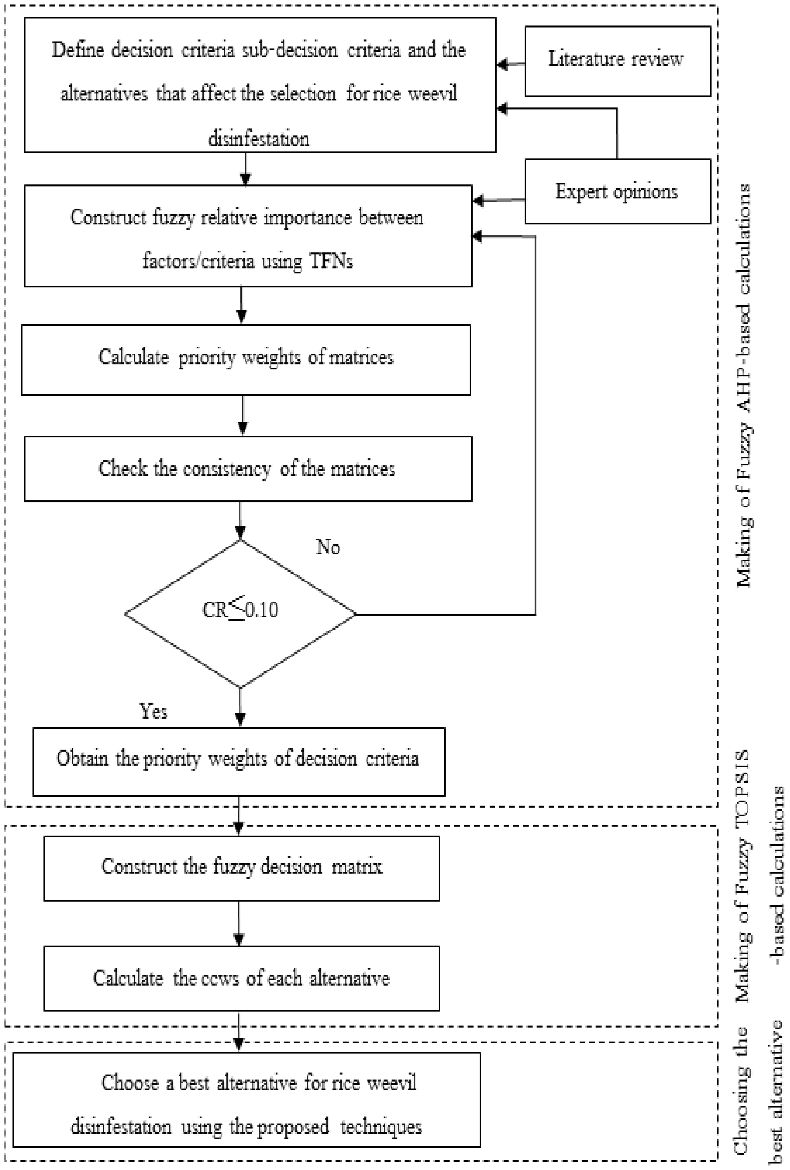

Fig. 1 The framework for selecting the best method of rice weevil disinfestation

2.1 The FAHP

In this study, the scale for choosing preferences is based on triangular fuzzy numbers (TFNs) as shown in Table 2 [37, 40, 47], based on the geometric means method of Buckley [48] and Buckley et al. [49].

Table 2 The comparison scale of TFNs

Fuzzy Numbers	TFNs	Definition
$\tilde{1}$	(1, 1, 1)	Equal
$\tilde{3}$	(2, 3, 4)	Moderate
$\tilde{5}$	(4, 5, 6)	Strong
$\tilde{7}$	(6, 7, 8)	Very strong
$\tilde{9}$	(8, 9, 9)	Extreme
	$\tilde{2}, \tilde{4}, \tilde{6}, \tilde{8}$	Intermediate values between the two adjacent judgments

The steps of the FAHP for solving the MADM problems are as follows.

2.1.1 Construction of the hierarchy

The criteria, sub-criteria and candidate alternatives for selecting the best rice weevil disinfestation method can be defined by reviewing the related literature and asking questions for experts. After that, all elements are decomposed into a hierarchy for selecting the best rice weevil disinfestation, as shown in Fig. 2. The goal, Level 0, would be to select the best rice weevil disinfestation method. The main criteria, in Level 1, are C_1, C_2, C_3 and C4. The sub- criteria, Level 2, are C_{21}, C_{22}, C_{23}, C_{24}, C_{31} and $C_{32.}$ The candidate alternatives, Level 3, are A_1, A_2 and A_3.

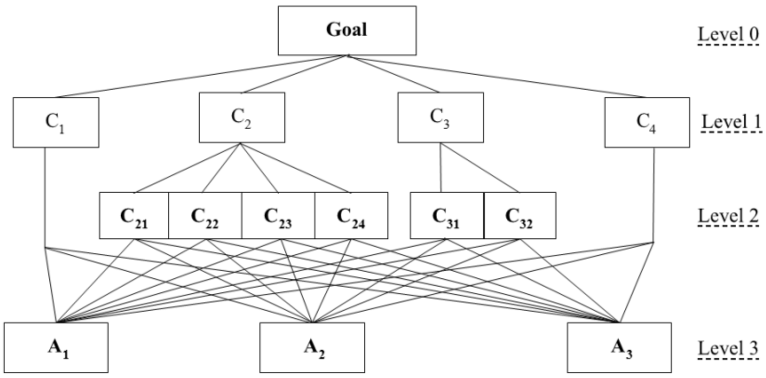

Fig. 2 A hierarchy for selecting the best rice weevil disinfestation

2.1.2 Construction of the comparison matrices

The fuzzy comparison matrices for all decision makers *(k)* can be constructed based on triangular fuzzy numbers shown in literatures [37, 40, 47]. After that, the aggregated comparison matrix from all decision makers is constructed, using the same method from the literatures [37, 50, 51] which is as shown in equation (1).

$$\tilde{D} = \left(\prod_{i=1}^{k} \tilde{d}_{ijk} \right)^{1/k} \tag{1}$$

Let $\tilde{d}_{ijk} = (l_{ijk}, m_{ijk}, u_{ijk})$ be TFNs, and $\tilde{D}$ be an aggregated comparison matrix from all decision makers.

2.1.3 Estimation of the priority weights

In the case, geometric means method of Buckley [48, 49], using equations (2) to (4), will be used to determine the priority weights of each element.

$$\tilde{r}_i = \left(\prod_{j=1}^{m} p_{ij} \right)^{1/n},\ i = 1,\ 2,\ 3, ..., n \tag{2}$$

where r_i and p_{ij} are the geometric mean of the fuzzy comparison values of criterion *i* to each criterion and aggregated fuzzy number respectively, and

$$\tilde{w}_i = \tilde{r}_i \otimes \left(\sum_{i=1}^{n} \tilde{r}_i \right)^{-1},\ i = 1,\ 2,\ 3, ..., n \tag{3}$$

where $\tilde{w}_i$ is fuzzy weight of each alternative.

The crisp weights for each alternative can be obtained using equation (4) [50, 52].

$$Df\tilde{d}_{ij} = \left(\frac{(u_{ij} - l_{ij}) + (m_{ij} - l_{ij})}{3}\right) + l_{ij},\ \forall i,\ \forall j \quad (4)$$

where $Df\tilde{d}_{ij}$ is defuzzy number for converting fuzzy number to crisp number.

2.1.4 Checking the cconsistency ratio (*CR*)

Consistency Ratio (*CR*) values can be checked using equations (5) to (7). Prof. Saaty proved that for consistent reciprocal matrix, the largest Eigen value is equal to the size of comparison matrix, or max λ = n. The λ^{max} is computed by Equation (5). The *CI* and *CR* are calculated as follows.

$$\lambda^{\max} = \frac{\sum_{i=1}^{n} \overline{w}_i}{n},\ i = 1,\ 2,\ 3, ..., n \quad (5)$$

$$CI = \left(\frac{\lambda^{\max} - n}{(n-1)}\right) \quad (6)$$

$$CR = \frac{CI}{RI} \leq 0.10 \quad (7)$$

If the value of *CR* is smaller or equal to 0.1, the inconsistency is acceptable. If the *CR* is greater than 0.1, we need to revise the subjective judgment.

2.2 The FAHP-FTOPSIS

After calculating the local priority weight of all decision criteria from FAHP, this step uses the FTOPSIS method for ranking. In this study, the calculation steps of the FTOPSIS for ranking are as follows.

2.2.1 Construction of the fuzzy decision matrix (FDM)

Details of the FDM are expressed in equation (8).

$$\tilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} C_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad C_{nm} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \tilde{x}_{13} & \cdots & \tilde{x}_{1m} \\ \tilde{x}_{21} & \tilde{x}_{22} & \tilde{x}_{23} & \cdots & \tilde{x}_{2m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \tilde{x}_{n3} & \cdots & \tilde{x}_{nm} \end{bmatrix} \end{array},\ \forall i,\ i = 1,2,3,...,n,\ \forall j = 1,2,3,...,m \quad (8)$$

Let $A_1, A_2, A_3 \ldots, A_n$ be the candidate alternatives for choosing sub criteria , C_{ij}. Let $\tilde{x}_{ij}$ be the fuzzy rating of alternative A_i with respect to sub criteria C_{ij}.

2.2.2 Normalization of the fuzzy decision matrix

The normalized FDM ($\tilde{R}$) can be expressed as

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{nxm} \quad i = 1,\ 2,\ 3,\ ...,n,\ j = 1,\ 2,\ 3,...,m \tag{9}$$

where $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$

$$\begin{aligned} &\tilde{r}_{ij} = \left(a_{ij} / c_j^+,\ b_{ij} / c_j^+, c_{ij} / c_j^+\right) \\ &and\ c_j^+ = \max(c_{ij}) \quad \text{(for benefit factors/ criteria)} \end{aligned} \tag{10}$$

$$\begin{aligned} &\tilde{r}_{ij} = \left(\ a_j^- / c_{ij},\ a_j^- / b_{ij},\ a_j^- / a_{ij}\ \right) \\ &and\ a_j^- = \min(a_{ij}) \text{ (for cost factors/ criteria)} \end{aligned} \tag{11}$$

2.2.3 Construction of the weighted normalized fuzzy decision matrix

The fuzzy weighted normalized FDM ($\tilde{V}$) is defined as

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{nxm} i = 1,\ 2,\ 3, ...,n,\ j = 1,\ 2,\ 3, ...,\ m \tag{12}$$

$$\tilde{v}_{ij} = \tilde{w}_j \otimes \tilde{r}_{ij} \tag{13}$$

Let $\tilde{w}_j$ be the fuzzy weights of criteria from using the FAHP technique.

2.2.4 Determination of the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS)

The *FPIS* (A^+) and *FNIS* (A^-) can be defined as

$$A^+ = \left(\tilde{v}_1^+,\ \tilde{v}_2^+,\ \tilde{v}_3^+,\ \ ...,\tilde{v}_m^+\right) \tag{14}$$

$$A^- = \left(\tilde{v}_1^-,\ \tilde{v}_2^-,\ \tilde{v}_3^-, ...,\tilde{v}_m^-\right) \tag{15}$$

Let $\tilde{v}_j^-\ be\ (0, 0, 0)$ and $\tilde{v}_j^+ be\ (\ 1, 1, 1\ )$

2.2.5 Evaluation of the distance d_i^+ and d_i^-

The d_i^+ and d_i^-, the distance of alternatives from FPIS and FNIS respectively, can be derived respectively as

$$d_i^+ = \sum_{j=1}^{n} dist(\tilde{v}_{ij}, \tilde{v}_j^+), \quad i = 1,\ 2,3...,n \tag{16}$$

$$d_i^- = \sum_{j=1}^{n} dist(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1,\ 2,3,...,n \tag{17}$$

Tsaur et al. [52] introduced a vertex method to calculate the distance between two TFNs. If $\tilde{x} = (l_1, m_1, n_1)$, $\tilde{y} = (l_2, m_2, n_2)$ and they are two TFNs then

$$dist\,(\tilde{x}, \tilde{y}) = \sqrt{\frac{[(l_2 - l_1)^2 + (m_2 - m_1)^2 + (n_2 - n_1)^2]}{3}} \tag{18}$$

2.2.6 Ranking of the candidate alternatives

Once the closeness coefficient (cc_i) of all alternative is calculated, the ranking order of each alternative can be obtained using equation (19).

$$cc_i = \frac{d_i^-}{d_i^+ + d_i^-}, \quad i = 1, 2, 3..., n \tag{19}$$

If index cc_i is larger, the alternative i is higher in the ranking order.

3. Application

To demonstrate the applicability of the hybrid MADM technique in solving MADM problems, a real case study is considered.

3.1 Evaluation of the priority vectors/weights for all elements using FAHP

This section presents the calculation steps for determining the priority vectors of all elements in all levels. Firstly, a decision hierarchy for the case study was constructed by consulting 5 decision makers and stakeholders. The criteria were chosen based on the company's requirements. We surveyed around 5 companies from 3 mills in Kalasin, Chachoengsao and Khon Kaen provinces, because they all face the problem of choosing the best alternative for rice weevil disinfestation. The survey was done by asking questions to 5 decision makers. The information on rice weevil disinfestation methods is shown in Table 3. In Fig. 2, level 0 includes the best alternatives for rice weevil disinfestation. Level 1 consists of four main criteria, total cost (C_1), rice quality (C_2), performance (C_3) and being environmental friendliness (C_4). In Level 2 there are six sub-criteria, Thai agriculture standards (C_{21}), the duration of the storage of rice (C_{22}), physical quality (C_{23}), chemical quality (C_{24}), capacity (C_{31}) and efficiency of rice weevil disinfestation (C_{32}). Level 3 had three candidate alternatives for rice weevil disinfestation including fumigation (A_1), the vacuum method (A_2) and the infrared-hot air system (A_3). Details of the hierarchy are shown in Fig. 2. Secondly, a fuzzy comparison matrix for all five decision makers was constructed, as shown in Table 4, using the 9-level scale of FAHP, a combined comparison matrix ($\tilde{D}$) was constructed from the fuzzy comparison matrices of all decision makers using equation (1), which is shown in Table 5. After that, the priority vectors/weights of all elements in level 1 were calculated by using equations (2) - (7), as shown in Table 6.

Table 3 The information on rice weevil disinfestation methods

Criteria	**Number of decision makers who select the criterion as their first choice**	**Fumigation (A_1)**	**Vacuum method (A_2)**	**Infrared-hot air system (A_3)**
Total cost (C_1)	1	1.44 Baht/kg.	2.22 Baht/kg.	1.65 Baht/kg.
Rice quality (C_2)	2	Little affected	Not affected	Not affected
Performance (C_3)	1	1,000 kg./ 7-10day	2,880 kg./8hr.	4,000 kg./ 8hr.
Environmental friendliness (C_4)	1	Little affected	Not affected	Not affected
Total	5			

Table 4 Fuzzy comparison matrices of 5 experts

Goal	C_1	C_2	C_3	C_4
C_1	(1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (0.25, 0.33, 0.50) (0.25, 0.33, 0.50) (0.25, 0.33, 0.50)	(0.33, 0.50, 1.00) (2.00, 3.00, 4.00) (0.25, 0.33, 0.50) (1.00, 1.00, 1.00) (0.25, 0.33, 0.50)	(1.00, 2.00, 3.00) (1.00, 2.00, 3.00) (0.25, 0.33, 0.50) (0.25, 0.33, 0.50) (0.20, 0.25, 0.33)
C_2	(1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (2.00, 3.00, 4.00) (2.00, 3.00, 4.00) (2.00, 3.00, 4.00)	(1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(1.00, 1.00, 1.00) (2.00, 3.00, 4.00) (0.33, 0.50, 1.00) (2.00, 3.00, 4.00) (1.00, 2.00, 3.00)	(1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (0.33, 0.50, 1.00) (1.00, 1.00, 1.00) (0.33, 0.50, 1.00)
C_3	(1.00, 2.00, 3.00) (0.25, 0.33, 0.50) (2.00,3.00, 4.00) (1.00, 1.00, 1.00) (2.00, 3.00, 4.00)	(1.00, 1.00, 1.00) (0.25, 0.33, 0.50) (1.00, 2.00, 3.00) (0.25, 0.33, 0.50) (0.33, 0.50, 1.00)	(1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)	(1.00, 1.00, 1.00) (0.33, 0.50, 1.00) (0.33, 0.50, 1.00) (0.25, 0.33, 0.50) (1.00, 1.00, 1.00)
C_4	(0.33, 0.50, 1.00) (0.33, 0.50, 1.00) (2.00, 3.00, 4.00) (2.00, 3.00, 4.00) (3.00, 4.00, 5.00)	(1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 2.00, 3.00) (1.00, 1.00, 1.00) (1.00, 2.00, 3.00)	(1.00, 1.00, 1.00) (1.00, 2.00, 3.00) (0.20, 0.25, 0.33) (1.00, 1.00, 1.00) (2.00, 3.00, 4.00)	(1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 1.00, 1.00) (1.00, 1.00, 1.00)

Table 5 The priority vectors/weights of main criterion

Goal	C_1	C_2	C_3	C_4	$\tilde{W}_i$	W_i	CR
C_1	(1.00, 1.00, 1.00)	(0.44, 0.52, 0.66)	(0.53, 0.70, 1.00)	(0.42, 0.64, 0.94)	(0.11, 0.17, 0.27)	0.171	0.047
C_2	(1.52, 1.93, 2.30)	(1.00, 1.00, 1.00)	(1.06, 1.55, 2.17)	(0.64, 0.76, 1.00)	(0.20, 0.30, 0.46)	0.299	
C_3	(1.00, 1.43, 1.89)	(0.46, 0.64, 0.94)	(1.00, 1.00, 1.00)	(0.76, 0.92, 1.20)	(0.15, 0.23, 0.36)	0.235	
C_4	(1.06, 1.55, 2.40)	(1.00, 1.32, 1.55)	(0.83, 1.08, 1.32)	(1.00, 1.00, 1.00)	(0.19, 0.30, 0.45)	0.295	

The priority weights of all levels were evaluated in the same way as level 1. Finally, the global priority vectors/weights for this case study are shown in Table 6.

Table 6 Global priority weights of candidates for rice weevil disinfestation using FAHP

Candidate for rice weevil disinfestation	Priority weights (w_i)
Fumigation	0.215
Vacuum method	0.332
Infrared-hot air system	0.454*

3.2 Estimation of the *cci* for alternatives using FAHP-FTOPSIS

3.2.1 Construction of the fuzzy decision making (FDM)

After obtaining the priority vectors/weights of each element in all levels, the fuzzy rating of each alternative i with respect to each criterion j is determined by adding the weights per alternative (using FAHP) multiplied by weights of the corresponding sub-criteria (using FAHP). These weights are taken into equation (8), and the fuzzy decision matrix based on FTOPSIS is shown in Table 7. For example, as seen in Fig. 3, A_1 respect to criterion C_2 = $((0.08,0.12,0.18)\otimes(0.20,0.30,0.46))\oplus((0.10,0.15,0.22)\otimes(0.22,0.34,0.50))\oplus((0.10,0.14,0.20)\otimes(0.16,0.22,0.31))\oplus((0.10,0.14,0.21)\otimes(0.09,0.14,0.23))=(0.07,0.14,0.31)$.

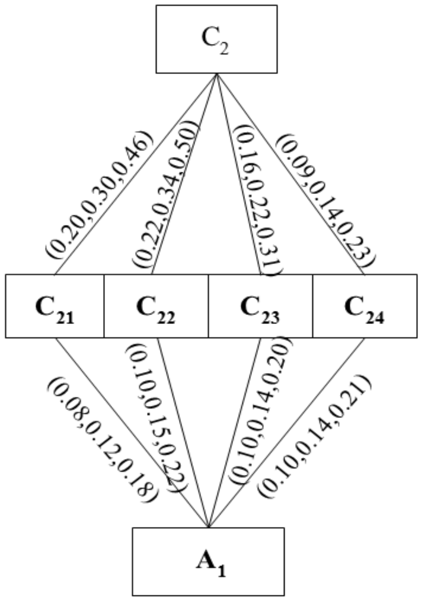

Fig. 3 The fuzzy weights for A_1 respect to C_2 from the FAHP

Table 7 The fuzzy decision matrix based on FTOPSIS

Candidate alternative	***C₁***			***C₂***			***C₃***			***C₄***		
A₁	0.45	0.47	**0.49**	0.07	0.14	0.31	0.16	0.27	0.46	0.07	0.10	0.14
A₂	0.05	0.05	0.06	0.18	0.12	0.28	0.19	0.29	0.45	0.35	0.46	**0.62**
A₃	0.45	0.47	0.49	0.21	0.47	**1.04**	0.28	0.45	**0.72**	0.33	0.44	0.58

Where the alternatives for rice weevil disinfestation to be chosen include fumigation (A_1), vacuum method (A_2) and infrared-hot air system (A_3). The main criteria are total cost (C_1), rice quality (C_2), performance (C_3) and being environmental friendliness (C_4).

3.2.2 Normalization of the fuzzy decision making

The data in Table 7 had their various attribute dimensions transformed into non-dimensional attributes using equations (9) to (11), as shown in Table 8.

Table 8 Normalized FDM

Candidate alternative	C_1			C_2			C_3			C_4		
A_1	0.92	0.96	1.00	0.06	0.13	0.30	0.22	0.37	0.64	0.12	0.16	0.22
A_2	0.11	0.11	0.12	0.17	0.12	0.27	0.26	0.40	0.63	0.57	0.75	1.00
A_3	0.92	0.96	1.00	0.21	0.45	1.00	0.39	0.62	1.00	0.53	0.71	0.94

3.2.3 Construction of the weighted normalized fuzzy decision making

The weighted normalized fuzzy decision making was evaluated by multiplying $\tilde{w}_j$ and $\tilde{r}_{ij}$ using equations (12) to (13), the results are shown in Table 9.

Table 9 The weighted normalized fuzzy decision making

Candidate alternative	C_1			C_2			C3			C4		
A_1	0.10	0.16	0.27	0.01	0.04	0.14	0.03	0.09	0.23	0.02	0.05	0.10
A_2	0.01	0.02	0.03	0.03	0.04	0.13	0.04	0.09	0.23	0.11	0.22	0.45
A_3	0.10	0.16	0.27	0.04	0.14	0.46	0.06	0.15	0.36	0.10	0.21	0.42

3.2.4 Determination of the FPIS and FNIS

The *FPIS* and the *FNIS* were defined as 0 and 1 respectively. After that, the d_i^+ and d_i^- were calculated using equations (14) to (15). Finally, the cc_i was calculated using equations (16) to (19), as shown in Table 10. The comparison of FAHP, FAHP-TOPSIS and FAHP-FTOPSIS is shown in Table 11.

Table 10 Ranking for candidate alternatives

Candidate alternative	d_i^+	d_i^-	cc_i	ranking
A_1	3.596	0.481	0.118	3
A_2	3.552	0.541	0.132	2
A_3	3.221	0.976	0.233	1

Table 11 Comparison of FAHP and FAHP-FTOPSIS

Candidate alternative	Based on cost		FAHP		FAHP-FTOPSIS	
	total cost	ranking	weight	ranking	weight	ranking
Fumigation	1.44 Baht/kg.	1	0.215	3	0.118	3
Vacuum method	2.22 Baht/kg.	3	0.332	2	0.132	2
Infrared-hot air system	1.65 Baht/kg.	2	0.454*	1	0.233*	1

As seen in Table 11, the best alternative for rice weevil disinfestation according to priority weights for each MADM method is the Infrared-hot air system (A_3) followed by the vacuum method (A_2) and fumigation (A_1). However, based on total cost, the ranking of alternatives is fumigation (A_1), Infrared-hot air system (A_3) and vacuum method (A_2) respectively. undoubtedly, (A_3) is the best alternative in this case.

The ranking of the alternatives using FAHP and FAHP-FTOPSIS is consistent in all two techniques. However, the weights of each method are different. There are many way to convert fuzzy numbers to crisp numbers. The fuzzy weights using FAHP were converted to crisp weights by one of common formula, for which the weights are vague estimates because the results using the formula are approximate. To overcome the drawback, FTOPSIS was used to calculate the cc_i instead of estimating by using defuzzy formulas in FAHP. Therefore, we believe that the proposed technique is reasonable, flexible and applicable for this case and other complex problems. The major advantage of the proposed approach is that relevant decision criteria under a fuzzy environment are focused on simultaneously. Also, different complex problems can be solved using our hybrid MADM technique.

4. Conclusions

This paper presents the hybrid MADM techniques used in choosing a suitable rice weevil disinfestation method. Firstly, the most important criteria for selection of the best alternatives for rice weevil disinfestation are defined from the company's requirements. The 4 main decision criteria identified in this case study are total cost (C_1), rice quality (C_2), performance (C_3) and being environmental friendliness (C_4). There are sub-criteria under rice quality (C_2) including the Thai agriculture standard (C_{21}), the duration of the storage of rice (C_{22}), Physical quality (C_{23}), Chemical quality (C_{24}), and two sub-criteria under performance (C_3) that are Capacity (C_{31}) and efficiency of rice weevil disinfestation (C_{32}). The three candidate rice weevil disinfestation techniques are fumigation (A_1), vacuum method (A_2) and infrared-hot air system (A_3). Secondly, the priority vectors/weights for all elements in Level 1, Level 2 and Level 3 are evaluated using FAHP. Next, the alternatives were ranked using FAHP and FAHP-FTOPSIS. Finally, select the best alternative for rice weevil disinfestation according to the priority weights for each method. The results show that the infrared hot-air system becomes the best alternative for rice weevil disinfestation (cc_i = 0.233), followed by the vacuum method (cc_i = 0.132) and fumigation (cc_i = 0.118 respectively. The major advantages of the proposed hybrid techniques are that they can guide selection of a best alternative for rice weevil disinfestation by considering subjective criterion and objective criterion simultaneously. These proposed techniques are simple but powerful, and are flexible for decision makers to solve other complicated criteria in other real-world complex problems.

For the further research, more factors related to construction and implementation phases should be added into the study. In addition, the reliability of calculation can be improved if more experts are involved in the weighting system for each criterion during the selection process.

Acknowledgements

The authors are very grateful to the Department of Industrial Engineering, Faculty of Engineering, Khon Kaen University, Supply Chain and Logistics System Research Unit and Rajabhat Rajanagarindra University for supporting this research. Finally, the authors would like to thank the reviewers for their valuable comments and recommendations which enabled the improvement of the quality of this paper.

References

[1] Statistics, Principal rice exporting countries worldwide in 2018/2019 [Online], Available: https://www.statista.com/statistics/255947/top-rice-exporting-countries-worldwide-2011/ [May 1, 2020].

[2] Division of Rice Research and Development, Rice Knowledge Bank [Online], Available: http://www.ricethailand.go.th /rkb3/ [May 5, 2018].

[3] National Bureau of Agricultural Commodity and Food Standards, Thai Agricultural Standard TAS 4004-2017 [Online], Available: http://www.acfs.go.th/standard/download/ Thai-Rice_60.pdf [May 5, 2018].

[4] Z. Pan, R. Khir, L. D. Godfrey, R. Lewis, J. F. Thompson, and A. Salim, "Feasibility of simultaneous rough rice drying and disinfestations by infrared radiation heating and rice milling quality," Journal of Food Engineering, Vol. 84, No. 3, 2008, pp. 469-479.

[5] S. E. Alptekin, "A fuzzy decision support system for digital camera selection based on user preferences," Expert Systems with Applications, Vol. 39, No. 3, 2012, pp. 3037–3047.

[6] S. Kubler et al., "A state-of the-art survey & testbed of fuzzy AHP (FAHP) applications," Expert Systems with Applications, Vol. 65, 2016, pp. 398-422.

[7] M. K. Othman, N. S. F. Abdul Rahman, A. Ismail, and A. H. Saharuddin, "Factors contributing to the imbalances of cargo flows in Malaysia large-scale minor ports using a fuzzy analytical hierarchy process (FAHP) approach," The Asian Journal of Shipping and Logistics, Vol. 36, No. 3, 2020, pp. 113-126.

[8] L. Li et al., "A fuzzy analytic hierarchy process (FAHP) approach to eco-environmental vulnerability assessment for the danjiangkou reservoir area, China," Ecological Modelling, Vol. 220, No. 23, 2009, pp. 3439–3447.

[9] P. Khamhong, C. Yingviwatanapong and K. Ransikarbum, "Fuzzy Analytic Hierarchy Process (AHP)-based Criteria Analysis for 3D Printer Selection in Additive Manufacturing," Research Invention and Innovation Congress (RI2C), Bangkok, Thailand, 2019, pp. 1-5.

[10] R. Vetschera and A. T. de Almeida, "A PROMETHEE-based approach to portfolio selection problems," Computers & Operations Research, Vol. 39, No. 5, 2012, pp. 1010–1020.

[11] I. Veza, S. Celar, and I. Peronja, "Competences-based Comparison and Ranking of Industrial Enterprises Using PROMETHEE Method," Procedia Engineering, Vol. 100, 2015, pp. 445–449.

[12] T. VuleviĆ and N. DragoviĆ, "Multi-criteria decision analysis for sub-watersheds ranking via the PROMETHEE method," International Soil and Water Conservation Research, Vol. 5, No. 1, 2017, pp. 50–55.

[13] A. Teixeira de Almeida, "Multicriteria decision model for outsourcing contracts selection based on utility function and ELECTRE method," Computers & Operations Research, Vol. 34, No. 12, 2007, pp. 3569–3574.

[14] P. Haurant, P. Oberti, and M. Muselli, "Multicriteria selection aiding related to photovoltaic plants on farming fields on Corsica island: A real case study using the ELECTRE outranking framework," Energy Policy, Vol. 39, No. 2, 2011, pp. 676–688.

[15] M. PetroviĆ, N. BojkoviĆ, I. AniĆ, M. StamenkoviĆ, and S. P. Tarle, "An ELECTRE-based decision aid tool for stepwise benchmarking: An application over EU Digital Agenda targets," Decision Support Systems, Vol. 59, 2014, pp. 230–241.

[16] M. Behzadian, S. Khanmohammadi Otaghsara, M. Yazdani, and J. Ignatius, "A state-of the-art survey of TOPSIS applications," Expert Systems with Applications, Vol. 39, No. 17, 2012, pp. 13051–13069.

[17] A. Shukla, P. Agarwal, R. S. Rana, and R. Purohit, "Applications of TOPSIS Algorithm on various Manufacturing Processes: A Review," Materials Today: Proceedings, Vol. 4, No. 4, 2017, pp. 5320–5329.

[18] A. K. Srirangan and P. Sathiya, "Optimisation of Process Parameters for Gas Tungsten Arc Welding of Incoloy 800HT Using TOPSIS," Materials Today: Proceedings, Vol. 4, No. 2, 2017, pp. 2031–2039.

[19] M. Uyan, "GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey," Renewable and Sustainable Energy Reviews, Vol. 28, 2013, pp. 11–17.

[20] R. P. Singh and H. P. Nachtnebel, "Analytical hierarchy process (AHP) application for reinforcement of hydropower strategy in Nepal," Renewable and Sustainable Energy Reviews, Vol. 55, 2016, pp. 43–58.

[21] M. Azizkhani, A. Vakili, Y. Noorollahi, and F. Naseri, "Potential survey of photovoltaic power plants using Analytical Hierarchy Process (AHP) method in Iran," Renewable and Sustainable Energy Reviews, Vol. 75, 2017, pp. 1198–1206.

[22] T. L. Saaty, K. Peniwati, and J. S. Shang, "The analytic hierarchy process and human resource allocation: Half the story," Mathematical and Computer Modelling, Vol. 46, No. 7–8, 2007, pp. 1041–1053.

[23] C. Ünal and M. G. Güner, "Selection of ERP suppliers using AHP tools in the clothing industry," International Journal of Clothing Science and Technology, Vol. 21, No. 4, 2009, pp. 239–251.

[24] L. A. Zadeh, "Fuzzy sets," Information and Control, Vol. 8, No. 3, 1965, pp. 338–353.

[25] K. Ransikarbum and W. Chanthakhot, "An Analysis of Fire Assembly Pointusing Information Entropy Weight and Technique for Order Preference by Similarity to Ideal Solution," Thai Industrial Engineering Network Journal, Vol. 6, No. 1, 2020, pp. 54-64.

[26] K. Ransikarbum, "Multi-Criteria Decision Analysis-based Orientation Selection Problem for Integrated 3D Printing and Subtractive Manufacturing," The Journal of Industrial Technology, Vol. 16, No. 1, 2020, pp. 15-30.

[27] K.Wisetla and K. Ransikarbum, "Process Planning in FDM 3D-Printed Acrylonitrile-Butadiene-Styrene Using Integrative DEA and TOPSIS," Journal of Science and Technology, Ubon Ratchathani University, Vol. 22 No. 1, 2020, pp. 22-32.

[28] C. Chaiyaphan and K. Ransikarbum, "Criteria Analysis of Food Safety using the Analytic Hierarchy Process (AHP)-A Case study of Thailand's Fresh Markets," in E3S Web of Conferences, Vol. 141, 2020, pp. 1–7.

[29] Y.-J. Wang, "The evaluation of financial performance for Taiwan container shipping companies by fuzzy TOPSIS," Applied Soft Computing, Vol. 22, 2014, pp. 28–35.

[30] J.-F. Chen, H.-N. Hsieh, and Q. H. Do, "Evaluating teaching performance based on fuzzy AHP and comprehensive evaluation approach," Applied Soft Computing, Vol. 28, 2015, pp. 100–108.

[31] E. B. BeŞikçi, T. Kececi, O. Arslan, and O. Turan, "An application of fuzzy-AHP to ship operational energy efficiency measures," Ocean Engineering, Vol. 121, 2016, pp. 392–402.

[32] M.-C. Chiu and M.-C. Hsieh, "Latent human error analysis and efficient improvement strategies by fuzzy TOPSIS in aviation maintenance tasks," Applied Ergonomics, Vol. 54, 2016, pp. 136–147.

[33] W. Meethom and T. Triwong, "A Multi-attribute Urban Metro Construction Excavated Soil Transportation Decision Making Model Based on Integrated Fuzzy AHP and Integer Linear Programming," King Mongkut's University of Technology North Bangkok International Journal of Applied Science and Technology, Vol. 9, No. 3, 2016, pp. 153–165.

[34] S. DožiĆ, T. Lutovac, and M. KaliĆ, "Fuzzy AHP approach to passenger aircraft type selection," Journal of Air Transport Management, Vol. 68, 2018, pp. 165–175.

[35] H. M. M. M. Jayawickrama, A. K. Kulatunga, and S. Mathavan, “Fuzzy AHP based Plant Sustainability Evaluation Method,” Procedia Manufacturing, Vol. 8, 2017, pp. 571–578.

[36] D. Walczak and A. Rutkowska, “Project rankings for participatory budget based on the fuzzy TOPSIS method,” European Journal of Operational Research, Vol. 260, No. 2, 2017, pp. 706–714.

[37] N. Wichapa and P. Khokhajaikiat, “Solving multi-objective facility location problem using the fuzzy analytical hierarchy process and goal programming: a case study on infectious waste disposal centers,” Operations Research Perspectives, Vol. 4, 2017, pp. 39–48.

[38] A. Mardani, A. Jusoh, E. K. Zavadskas, F. Cavallaro, and Z. Khalifah, “Sustainable and renewable Energy: An overview of the application of multiple criteria decision making techniques and approaches,” Sustainability (Switzerland), Vol. 7, No. 10, 2015, pp. 13947–13984.

[39] B. Vahdani, M. Salimi, and M. Charkhchian, “A new FMEA method by integrating fuzzy belief structure and TOPSIS to improve risk evaluation process,” International Journal of Advanced Manufacturing Technology, Vol. 77, No. 1–4, 2015, pp. 357–368.

[40] N. Wichapa and P. Khokhajaikiat, “Solving a multi-objective location routing problem for infectious waste disposal using hybrid goal programming and hybrid genetic algorithm,” International Journal of Industrial Engineering Computations, Vol. 9, No. 1, 2018, pp. 75–98.

[41] R. P. Kusumawardani and M. Agintiara, “Application of Fuzzy AHP-TOPSIS Method for Decision Making in Human Resource Manager Selection Process,” Procedia Computer Science, Vol. 72, 2015 pp. 638–646.

[42] C.-C. Huang, P.-Y. Chu, and Y.-H. Chiang, “A fuzzy AHP application in government-sponsored R&D project selection,” Omega, Vol. 36, No. 6, 2008, pp. 1038–1052.

[43] S. K. Patil and R. Kant, “A fuzzy AHP-TOPSIS framework for ranking the solutions of Knowledge Management adoption in Supply Chain to overcome its barriers,” Expert Systems with Applications, Vol. 41, No. 2, 2014, pp. 679–693.

[44] R. K. Shukla, D. Garg, A. Agarwal, and R. Kumar Shukla, “An integrated approach of Fuzzy AHP and Fuzzy TOPSIS in modeling supply chain coordination, Production & Manufacturing Research,” Vol. 2, No. 1, 2014, pp. 415–437.

[45] T. L. Dirwai, A. Senzanje, and M. Mudhara, “Assessing the functional and operational relationships between the water control infrastructure and water governance: A case of Tugela Ferry Irrigation Scheme and Mooi River Irrigation Scheme in KwaZulu-Natal, South Africa,” Physics and Chemistry of the Earth, Parts A/B/C, Vol. 112, 2019, pp. 12–20.

[46] C. Prakash and M. K. Barua, “An analysis of integrated robust hybrid model for third-party reverse logistics partner selection under fuzzy environment,” Resources, Conservation and Recycling, Vol. 108, 2016, pp. 63–81.

[47] N. Wichapa and P. Khokhajaikiat, “Using the hybrid fuzzy goal programming model and hybrid genetic algorithm to solve a multi-objective location routing problem for infectious waste disposal,” Journal of Industrial Engineering and Management, Vol. 10, No. 5, 2017, pp. 853–886.

[48] J. J. Buckley, “Fuzzy hierarchical analysis,” Fuzzy Sets and Systems, Vol. 17, No. 3, 1985, pp. 233–247.

[49] J. J. Buckley, T. Feuring, and Y. Hayashi, “Fuzzy hierarchical analysis revisited,” European Journal of Operational Research, Vol. 129, No. 1, 2001, pp. 48–64.

[50] O. Meixner, Fuzzy AHP group decision analysis and its application for the evaluation of energy sources [Online], Available: http://www.isahp.org/2009Proceedings/Final_Papers/50_Meixner_Fuzzy_AHP_REV_FIN.pdf [May 1, 2020].

[51] Q. Dong and O. Cooper, "A peer-to-peer dynamic adaptive consensus reaching model for the group AHP decision making," European Journal of Operational Research, Vol. 250, No. 2, 2016, pp. 521–530.

[52] S.-H. Tsaur, T.-Y. Chang, and C.-H. Yen, "The evaluation of airline service quality by fuzzy MCDM," Tourism Management, Vol. 23, No. 2, 2002, pp. 107–115.

[53] N. Wichapa, P. Khokhajaikiat, K. Sarawan and S. Gonwirat, "Selection of the Best Laptop for Educational Purposes using Hybrid Decision Making Technique," RMUTSV Research Journal, Vol. 10, No. 3, 2018, pp. 368–384.

[54] N. Wichapa, A. Choompol and T. Sudsuansee, "Using the Hybrid DEA-TOPSIS Technique for Selecting the Suitable Biomass Materials for Processing into Fuel Briquettes," The Journal of Industrial Technology, Vol. 15, No. 1, 2019, pp. 67–84.