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Fuzzy MCDM Model for Selection of Infectious Waste Management Contractors

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Abstract: Healthcare supply chains are under pressure to drive down costs because of digital business, shifting customer needs and new competition. Medical waste generated from medical facilities includes medical activities and daily-life activities of patients and their family members. According to statistics of the Department of Health Environmental Management, Vietnam currently has more than 13,500 medical facilities, including hospitals from central to provincial and district levels and private hospitals and medical facilities. Preventive medicine generates about 590 tons of medical waste/day and is estimated to be about 800 tons/day. Medical waste includes ordinary medical waste and hazardous medical waste; in which ordinary medical waste accounts for about 80%–90%, only about 10%–20% is hazardous medical waste including infectious waste and non-infectious hazardous waste. This is an environmental and occupational health issue that needs attention in developing countries like Vietnam. Handling large amounts of medical waste to ensure environmental and personal hygiene, doing so inefficiently creates potential hazards to the environment and increases operating costs. However, hospitals lack objective criteria and methods to evaluate and select the most optimal infectious medical waste, relying instead on their own subjective assessment and prior experience. Therefore, the author proposed a fuzzy multicriteria decision making (MCDM) model including Fuzzy Analytic hierarchy process (FAHP) and the Weighted Aggregated Sum-Product Assessment (WASPAS) for infectious medical waste contractors' selection in this research. The proposed Fuzzy MCDM method is in-tended to provide a more efficient, accurate method in the selection of infectious medical waste contractors than subjective assessment methods, thus reduce potential risks to hospitals. The results of this study can be applied to evaluate and select contractors in other industries.

Keywords: MCDM model; fuzzy theory; fuzzy AHP; WASPAS; medical waste contractors

1 Introduction

Medical waste is any kind of waste that contains infectious material (or material that's potentially infectious). This definition includes waste generated by healthcare facilities like physician's offices, hospitals, dental practices, laboratories, medical research facilities, and veterinary clinics [1]. Solid waste generated from medical examination and treatment establishments is classified into 03 types: infectious waste, non-infectious hazardous waste, and ordinary waste. Infectious waste is generalized as waste containing blood, urine, feces, secretions of the patient such as cotton, gauze, medical gloves, masks, etc.

Currently, the issue of medical waste management in general and medical waste classification in particular is increasingly being focused by the government and the community. If not handled properly, they will pose a serious threat to public health, pollute the environment and affect other living organisms [2]. With its specific characteristics, infectious medical waste from hospitals needs to be thoroughly treated before being discharged into the environment to avoid environmental pollution, spread of diseases and protect human health [3]. Therefore, choosing a suitable contractor for the treatment of infectious medical waste is an important issue. However, hospitals lack objective criteria and methods to evaluate and select the most optimal infectious medical waste, relying instead on their own subjective assessment and prior experience. Therefore, the author proposed a multicriteria decision making model (Fuzzy AHP - WASPAS) of infectious medical waste contractors' selection in this research.

MCDM model is widely applied in solving daily life decision-making problems. It is the ranking of objects based on a diverse set of criteria to serve the goal of the decision maker [4]. The evaluation criteria even contradict each other. They are divided into two basic criteria groups: benefit criteria and non-benefit criteria (also known as cost criteria). Criteria can have different roles in the decision problem, and it is characterized by the weight of the criteria in the MCDM model. There are many methods to solve multi-criteria models that have been used in research by many authors around the world [4]. In this research, the author used Fuzzy AHP model for defining the weight of all criteria in the first stage, and then WASPAS is applied for ranking all potential contractors in final stage.

The remainder of the paper introduces literature review, methods to assist the authors in building the Fuzzy MCDM model. Then, Fuzzy AHP and WASPAS model is applied to select the best of infectious medical waste contractors. The results and contributions are discussed at the end of this paper.

2 Literature Review

In the several literatures have focused their research on the investigations of medical wastes, factory wastes, solid municipal wastes, hazardous wastes, etc. Önüt et al. [5] used the AHP and The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) approaches under fuzzy environment to transshipment solid waste site selection. Şener et al. [6] studied landfill site selection by the Geographic Information System (GIS), the Analytical Hierarchy Process (AHP), and the remote sensing methods for the Senirkent-Uluborlu Basin. Mihajlović et al. [7] combined WASPAS and AHP methods in choosing the logistics distribution center location in Serbia. Khaldi et al. [8] proposed to use AHP and GIS models to select a solid waste landfill in Dammam city. Chitsazan et al. [9] used an integrated fuzzy logic, AHP and weighted linear combination (WLC) method in site selection of Urban waste landfill. Besides, Abdulaali et al. [10] showed that AHP, Fuzzy logic and GIS can be integrated for waste management decision issues related to site selection to reduce negative effects on the environment and inhabitants in Nasiriyah, Iraq. In the context that the

Chinese government is developing on waste treatment problems, Shi et al. [11] reviewed site selection of construction waste recycling plant with green environmental protection criteria. Ferronato and Torretta [12] proposed main impacts into waste mismanagement in developing countries, focusing on environmental contamination and social issues. Ekmekçioğlu et al. [13] extended an integrated framework with FAHP and Fuzzy TOPSIS models for assessing municipal waste treatment techniques in Istanbul. Eskandari et al. [14] discussed a combined AHP and GIS model to landfill site selection for municipal solid wastes in mountainous areas. Dorn et al. [15] application massburn technologies and solid recovered fuel (SRF) to solve municipal solid waste problems and future perspectives in China. Geneletti [16] combined stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites. Mishra and Rani [17] used fuzzy WASPAS method to healthcare waste disposal location selection. Karamouz et al. [18] proposed a framework to rank the hospitals in Ahvaz, Iran in terms of hospital waste collection. A. Puška et al. [19] suggested a model with full consistency method (FUCOM) and compromise ranking of alternatives from distance to ideal solution (CRADIS) for selection of the type of incinerators that best solve the problem of healthcare waste in secondary healthcare institutions in Bosnia and Herzegovina. During the period of COVID-19, the medical waste disposal capacity is seriously inadequate, Ma et al. [20] some suggested guidelines for emergency treatment of medical waste from COVID-19 in China. Belhadi et al. [21] applied an integrated method with AHP and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) to selection of waste management strategy during the COVID-19 pandemic. Aung et al. [22] oriented the AHP and analytic network process (ANP) are used to assess medical waste management system in Myanmar. Azizkhani et al. [23] pro-posed the AHP and TOPSIS method to selection of medical waste management treatments in Urband and Rural areas. Nzediegwu et al. [24] discussed how to solid waste management for COVID-19 spread in developing countries. Sangkham [25] proposed about the treatment of medical waste the because the novel human coronavirus (SARS-CoV-2) pandemic can affect the community. Turskis et al. [26] proposed a fuzzy multi-attribute performance measurement (MAPM) framework using the merits of both a novel fuzzy WASPAS and AHP to select the best shopping center construction site in Vilnius.

Najjari and Shayesteh [27] discussed to be combined fuzzy-AHP and GIS for hazardous waste site selection in Nahavand, Iran. Gumus [28] utilized the methods of fuzzy-AHP and TOPSIS to evaluate hazardous waste transportation firms. Duan et al. [29] presented on China's hazardous waste pollution control. Karamouz et al. [30] used metaheuristic algorithms to solve a multi-objective industrial hazardous waste location routing problem considering incompatible waste types. Büyüközkan and Göçer [31] developed intuitionistic fuzzy and integrated multi criteria decision making (MCDM) approach to support the hazardous waste transportation firm selection process. Ali et al. [32] adopted the AHP method to give the most sustainable solve the problem of hazardous waste. Accordingly, Ali et al. [33] integrated a DEA and TOPSIS method for hazardous wastes management in USA. Abessi and Saeedi [34] presented by using GIS and AHP method to selection the optimal site for landfilling of the hazardous wastes in Qazvin prov-ince. Zavadskas et al. [35] proposed a new extension of WASPAS method to selection a construction of a waste incineration plant. Kabir and Sumi [36] used fuzzy-AHP and Preference Ranking Organization Method for Enrichment of Evaluations methods to choose the best location for Hazardous waste transportation firm in Bangladesh.

As mentioned in the literature review, MCDM is a branch of operational research that finds optimal results in complex decision-making scenarios including various indicators, conflicting objectives, and criteria. This popular tool in the sustainable supplier selection field is getting attention because of its the flexibility for decision makers in finalizing decisions while considering all the criteria, but there are still very few studies using the MCDM based on fuzzy sets to develop a decision making in healthcare industry because of the uncertainties in evaluation from experts and literature. Thus, the author proposed fuzzy MCDM model for selection of infectious waste management contractors in this research.

3 Methodology

3.1 SERVQUAL Model

The concept of a fuzzy set was introduced by Lotfi A. Zadeh. The triangular fuzzy number (TFN) is defined (k, h, g), where k, h and g (k ≤h ≤ g) are parameters that determine the least likely value, the most promising value, and the greatest conceivable value in TFN. TFN may be characterized as follows:

$$\left(\frac{x}{\tilde{M}}\right) = \begin{cases} 0, & \\ \frac{x-\mathrm{k}}{\mathrm{h}-\mathrm{k}} & if\ x < h, \\ \frac{\mathrm{g}-x}{\mathrm{g}-\mathrm{h}} & if\quad k \le x \le h, \\ & if\quad h \le x \le g, \\ 0, & if\quad x > g, \end{cases} \tag{1}$$

The following is an example of a fuzzy number:

$$\tilde{M} = (M^{o(y)}, M^{i(y)}) = [\mathrm{k} + (\mathrm{h}-\mathrm{k})y,\ \mathrm{g} + (\mathrm{h}-\mathrm{g})y], y\ \in [0,1] \tag{2}$$

The left and right sides of a fuzzy number are represented by $o(y)$ and $i(y)$, respectively. The fundamental computations shown below utilize two positive TFN, $(k_1,\ h_1,\ g_1)$ and $(k_2,\ h_2,\ g_2)$.

$$(k_1,\ h_1,\ g_1) + (k_2,\ h_2,\ g_2) = (k_1 + k_2,\ h_1 + h_2, g_1 + g_2)$$

$$(k_1,\ h_1,\ g_1) - (k_2,\ h_2,\ g_2) = (k_1 - k_2,\ h_1 - h_2, g_1 - g_2)$$

$$(k_1,\ h_1,\ g_1) \times (k_2,\ h_2,\ g_2) = (k_1 \times k_2,\ h_1 \times h_2, g_1 \times g_2)$$

$$\frac{(k_1,\ h_1,\ g_1)}{(k_2,\ h_2,\ g_2)} = (k_1/k_2,\ h_1/h_2, g_1/g_2) \tag{3}$$

3.2 FAHP Model

Fuzzy Analytical Hierarchy Process (FAHP) is the fuzzy extension of the AHP methodology that would assist its limitation in opinionated with unclear decision-making environments. Let $X = \{x_1,\ x_2, \ldots .x_n\}$ be the set of objects and $K = \ \{k_1,\ k_2, \ldots .k_n\}$ be the final ranking set. According to Chang [37] extent analysis method, each alternative is counted for, and an extended analysis of its goals are analyzed. Therefore, the l extended analysis values for each alternative can be determined. These values are defined as:

$$L^1_{k_i}, L^2_{k_i}, \ldots, L^m_{k_i}, \qquad i = 1, 2, \ldots, n \tag{4}$$

where $L^j_k (j = 1, 2, \ldots ., m)$ are the TFNs

Fuzzified extent number of the i$^{\text{th}}$ object is calculated as:

$$S_i = \sum_{j=1}^{m} L^j_{k_i} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} L^j_{k_i}\right]^{-1} \tag{5}$$

The possibility that $L_1 \geq \ L_2$ is calculated as:

$$V(L_1 \geq L_2) = sup_{y \geq x}[min(\mu_{L_1}(x),), (\mu_{L_2}(y))] \tag{6}$$

where the pair (x, y) are shown with $x \geq y$ and $\mu_{L_1}(x) = \ \mu_{L_2}(y)$, then we finally have $V(L_1 \geq L_2) = 1$.

Since L_1 and L_2 are convex fuzzy numbers, we have:

$$V(L_1 \geq L_2) = 1, \ if \ l_1 \geq l_2 \tag{7}$$

And

$$V(L_2 \geq L_1) = hgt(L_1 \cap L_2) = \mu_{L_1}(d) \tag{8}$$

where d is the ordinate of the highest crossing point D of μ_{L_1} and μ_{L_2}

With $L_1 \ = \ (o_1, \, p_1, \ \ q_1)$, and $L_2 = (o_2, p_2, \, q_2)$, the ordinate of point D is calculated by (9):

$$V(L_2 \geq L_1) = hgt(L_1 \cap L_2) = \frac{l_1 - q_2}{(p_2 - q_2) - (p_1 - o_1)} \tag{9}$$

In order to compare L_1 and L_2, we need to calculate the values of $V(L_1 \geq L_2)$ and $V(L_2 \geq L_1)$.

The possibility for a convex fuzzy number to be higher than the k convex fuzzy numbers $L_i(i = 1, 2, \ldots k)$ is calculated as:

$$V(L \geq L_1, L_2, \ldots, L_k) = V[(L \geq L_1) \ and \ (L \geq L_2) \ ] \tag{10}$$

$(L \geq L_k) = \min \text{V}(\text{L} \geq L_i), \ i = 1, 2, \ldots, \ k$

Assume that:

$$d'(B_i) = min V(S_i \geq S_k) \tag{11}$$

for k = 1, 2, . . . n and k # i, the weight vector is calculated as:

$$W' = (d'(B_1), d'(B_2), \ldots d'(B_n))^T, \tag{12}$$

where B_i are n elements.

The Normalized weight vectors are defined as

$$W = (d(B_1), d(B_2), \ldots ., d(B_n))^T \tag{13}$$

with W is a defuzzified number.

3.3 Weighted Aggregated Sum Product Assessment (WASPAS)

In order to calculate the ranking for the alternatives of the study, the well-known WASPAS model is utilized, available in multiple software. For each alternative, their ranking is determined by the product between the rating of each criterion's weight [38,39].

Step 1: The decision matrix is normalized.

The normalization approach is initially determined whether the criteria is advantageous or disadvantageous. For an advantageous decision criterion, the normalization is shown in Eq. (12) as follows:

$$q_{ij} = \frac{x_{ij}}{\max x_{ij}}, \ i = 1, 2, \ \ldots, \ n; j = 1, \ 2, \ \ldots, \ m \tag{14}$$

For a disadvantageous decision criterion, then it is shown in Eq. (15):

$$q_{ij} = \frac{x_{ij}}{\min x_{ij}},\ i = 1, 2,\ \ldots,\ n; j = 1,\ 2,\ \ldots,\ m \tag{15}$$

Step 2: The relative importance of the i[th] alternative is determined, using the Weighted Sum Model as follows:

$$S_i^1 = \sum_{j=1}^{n} q_{ij} \times w_j \tag{16}$$

Step 3: The performance index of the i[th] alternative is calculated using the Weighted Product Model as determined in Eq. (17):

$$S_i^2 = \prod_{j=1}^{n} (q_{ij})^{w_j} \tag{17}$$

Step 4: The total relative importance is calculated by a combination of Eqs. (16) and (17), applying the WASPAS model.

The weighted combination of the addition and multiplication methods for WASPAS application is determined as follows:

$$S = \lambda S_i^1 + (1 - \lambda) S_i^2 = \lambda \sum_{j=1}^{n} q_{ij} \times w_j + (1 - \lambda) \prod_{j=1}^{n} (q_{ij})^{w_j} \tag{18}$$

With λ as the coefficient where $\lambda \in [0, 1]$. If the decision-makers do not have any opinionated reference in relation to the coefficient, its value is defaulted to $\lambda = 0.5$.

The alternatives are then finally ordered based on the index of performance, and the optimal supplier will have the greatest score.

4 Case Study

Medical waste is any waste that contains an infectious substance (or potentially infectious material). This includes waste generated by medical facilities such as doctors' offices, hospitals, dental clinics, laboratories, medical research facilities, and veterinary clinics [40].

Medical waste may contain bodily fluids such as blood or other contaminants. The Medical Waste Tracking Act of 1988 defines medical waste as waste generated in the course of medical research, testing, diagnosis, vaccination, or treatment of humans or animals. Some examples are glasses, bandages, gloves, discarded sharps such as needles or scalpels, gauze, and tissues [41].

Medical waste disposal is one of the daily challenges facing healthcare providers. However, hospitals lack objective criteria and methods to evaluate and select the most optimal infectious medical waste, relying instead on their own subjective assessment and prior experience. Therefore, the author proposed a fuzzy multicriteria decision making model (Fuzzy Analytic hierarchy process (FAHP) - Weighted Aggregated Sum-Product Assessment (WASPAS)) of infectious medical waste contractors' selection under in this research.

Based on literature review and experts, there are fifteen criteria, and five contractors are defined. Hierarchy Structure is shown in Fig. 1.

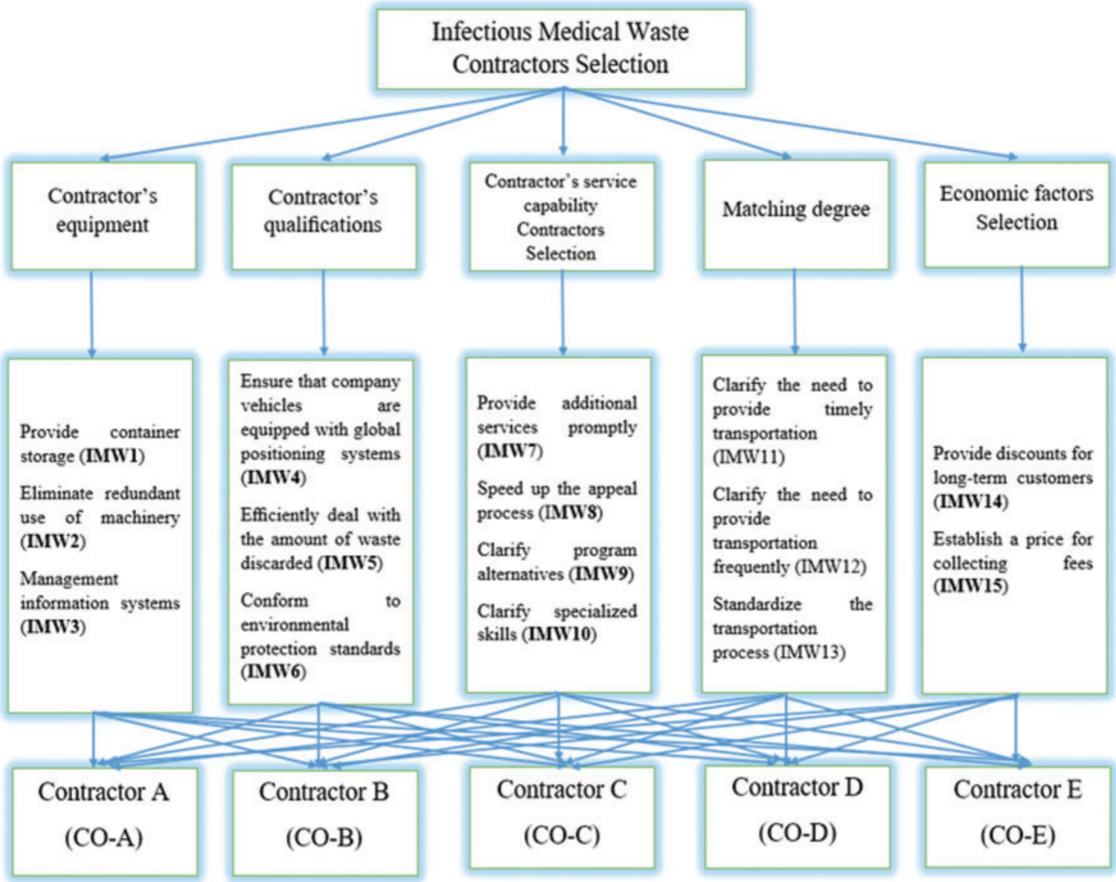

Figure 1: Hierarchy Structure of infectious medical waste contractors' selection process

In the first stage of this research, the authors proposed a new weighted method for solving the multi-soft set using fuzzy AHP for accurate estimation of weight coefficient. FAHP is applied for determine the weight of all criteria. The weight of all criteria is shown in Tab. 1.

Table 1: The weight of all criteria

Criteria	Fuzzy geometric mean of each row			Fuzzy weights			Normalization
IMW1	0.7277	1.0004	1.3582	0.0350	0.0660	0.1231	0.0657
IMW2	0.6559	0.8958	1.2221	0.0316	0.0591	0.1108	0.0590
IMW3	0.7542	1.0454	1.4600	0.0363	0.0690	0.1324	0.0696
IMW4	0.6943	0.9500	1.2984	0.0334	0.0627	0.1177	0.0627
IMW5	0.9109	1.2547	1.7062	0.0439	0.0828	0.1547	0.0824
IMW6	0.6404	0.8656	1.1900	0.0308	0.0572	0.1079	0.0574
IMW7	0.5905	0.8067	1.1260	0.0284	0.0533	0.1021	0.0538

(Continued)

Table 1: Continued

Criteria	Fuzzy geometric mean of each row			Fuzzy weights			Normalization
IMW8	0.7024	0.9570	1.2976	0.0338	0.0632	0.1177	0.0629
IMW9	0.8192	1.1345	1.5259	0.0395	0.0749	0.1383	0.0740
IMW10	0.7299	1.0080	1.4022	0.0352	0.0666	0.1271	0.0670
IMW11	0.6471	0.8774	1.2145	0.0312	0.0579	0.1101	0.0584
IMW12	0.9874	1.3821	1.8711	0.0476	0.0913	0.1697	0.0904
IMW13	0.7249	0.9888	1.3570	0.0349	0.0653	0.1230	0.0654
IMW14	0.6874	0.9435	1.3058	0.0331	0.0623	0.1184	0.0626
IMW15	0.7571	1.0359	1.4264	0.0365	0.0684	0.1293	0.0686

Weighted Aggregated Sum Product Assessment (WASPAS) method is presented to solve the fuzzy MCDM selection problem. WASPAS is applied for ranking all potential contractors in final stage. Weight Normalized Matrix and Exponentially weighted Matrix are shown in Tabs. 2 and 3.

Table 2: Weight Normalized Matrix

Criteria	CO-A	CO-B	CO-C	CO-D	CO-E
IMW1	0.0584	0.0657	0.0584	0.0657	0.0657
IMW2	0.0394	0.0506	0.0590	0.0443	0.0506
IMW3	0.0696	0.0609	0.0522	0.0609	0.0609
IMW4	0.0557	0.0487	0.0557	0.0418	0.0627
IMW5	0.0824	0.0824	0.0733	0.0733	0.0824
IMW6	0.0574	0.0574	0.0574	0.0502	0.0574
IMW7	0.0538	0.0538	0.0471	0.0471	0.0538
IMW8	0.0629	0.0559	0.0489	0.0489	0.0559
IMW9	0.0740	0.0576	0.0740	0.0576	0.0658
IMW10	0.0670	0.0596	0.0670	0.0670	0.0596
IMW11	0.0584	0.0519	0.0584	0.0519	0.0519
IMW12	0.0904	0.0904	0.0803	0.0904	0.0803
IMW13	0.0654	0.0654	0.0581	0.0581	0.0509
IMW14	0.0487	0.0487	0.0557	0.0626	0.0626
IMW15	0.0686	0.0686	0.0610	0.0534	0.0534

Analysis results from Tab. 4 and Fig. 2 show that that the medical sector selects the most appropriate infectious medical waste disposal contractor based on the following rank: Contractor A (0.9596), Contractor B (0.9217), Contractor C (0.9154), Contractor E (0.8902), and Contractor D (0.88555).

Table 3: Exponentially weighted Matrix

Criteria	CO-A	CO-B	CO-C	CO-D	CO-E
IMW1	0.9923	1.0000	0.9923	1.0000	1.0000
IMW2	0.9763	0.9909	1.0000	0.9832	0.9909
IMW3	1.0000	0.9907	0.9802	0.9907	0.9907
IMW4	0.9926	0.9844	0.9926	0.9749	1.0000
IMW5	1.0000	1.0000	0.9903	0.9903	1.0000
IMW6	1.0000	1.0000	1.0000	0.9924	1.0000
IMW7	1.0000	1.0000	0.9928	0.9928	1.0000
IMW8	1.0000	0.9926	0.9843	0.9843	0.9926
IMW9	1.0000	0.9816	1.0000	0.9816	0.9913
IMW10	1.0000	0.9921	1.0000	1.0000	0.9921
IMW11	1.0000	0.9931	1.0000	0.9931	0.9931
IMW12	1.0000	1.0000	0.9894	1.0000	0.9894
IMW13	1.0000	1.0000	0.9923	0.9923	0.9837
IMW14	0.9844	0.9844	0.9927	1.0000	1.0000
IMW15	1.0000	1.0000	0.9920	0.9829	0.9829

Table 4: Final ranking

Alternatives	Q_{i1}	Q_{i2}	Q_i
CO-A	0.9521	0.9521	0.9521
CO-B	0.9176	0.9176	0.9176
CO-C	0.9066	0.9066	0.9066
CO-D	0.8732	0.8732	0.8732
CO-E	0.9139	0.9139	0.9139

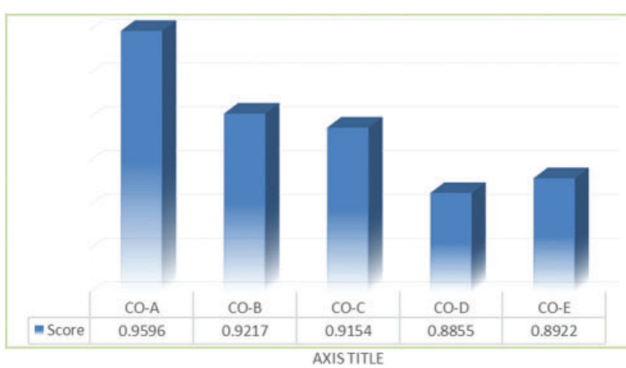

Figure 2: Results from WASPAS model

5 Conclusion

According to the Vietnam Ministry of Health's statistics, there are currently 13,511 large and small medical facilities across the country, from central to local levels, each day discharging about 450 tons. Along with that is a huge amount of wastewater with a discharge rate of 30,000–100,000m^3 per day. Medical wastewater carries a lot of dangerous viruses such as: Staphylococcus aureus, green hat bacilli, Ecoli and many other bacteria, fungi, parasites . . . . if not collected and treated up to standards, when entering the environment, it will cause many serious consequences for the soil and water environment and affect human health.

Therefore, the evaluation and selection of a contractor for the treatment of infectious medical waste is an important issue. However, hospitals lack objective criteria and methods to evaluate and select the most optimal infectious medical waste, relying instead on their own subjective assessment and prior experience. Therefore, the author proposed a multicriteria decision making model of infectious medical waste contractors' selection in this research.

The contribution of this research is to provide a more efficient, accurate method in the selection of infectious medical waste contractors than subjective assessment methods, thus reduce potential risks to hospitals. There are also some limitations in this study, due to Saaty's AHP produces reversing ranking, a new procedure was proposed based on a simple algebraic system of equations, which is considered for multi-criteria decision-making future studies.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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