



# Capability of Different Multi-Criteria Decision-Making Techniques in the Performance Assessment of the Hospitals in Terms of Medical Waste Management

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## Abstract

**Background:** Assessing the performance of hospitals in waste management requires considering several criteria of different types. The multiplicity of the criteria and how they are weighed and, ultimately, the ranking of hospitals; are among the most complex challenges faced by the environmental health authorities. This research tried to assess the capability of four commonly used multi-criteria decision-making methods, as well as a hybrid technique for performance assessment of six hospitals in Tehran City, Iran, in 2018 regarding waste management.

**Methods:** The effective criteria and sub-criteria were identified by reviewing the relevant literature. The data collection tool was a self-constructed checklist developed based upon the identified criteria and sub-criteria and analysis of the collected data was done in MATLAB software. The sample hospitals were ranked based on the scores given to the management performance of hospitals.

**Results:** The final rankings by the different techniques did not differ significantly. According to the results of the hybrid method, among six studied hospitals, the top three hospitals were Hospital C, B, and A respectively, regarding hospital waste reduction criteria. These hospitals generally had an acceptable performance in terms of waste management, especially waste disinfection and separation at the origin.

**Conclusion:** In assessing the performance and ranking of hospitals in terms of waste management, hybrid multi-criteria decision-making techniques can be used as a useful tool in waste management planning. By identifying the areas in need of corrective actions and choosing the appropriate strategy, they pave the way for improving the performance of hospitals in the field of waste management.

**Keywords:** Performance; Waste minimization; Hospital waste



## Introduction

Improper management of hospital waste has serious consequences for the environment and human health (1). The performance assessment of hospitals as an important issue in management of medical centers and understanding hospital status can be implemented using different criteria (2). Many methods and criteria have been presented so far to assess the performance of hospitals in the field of waste management. Ansari et al. (3) developed an economic and environmental performance index to assess the performance of hospital waste management and concluded that developing countries are more vulnerable to the threats of hospital wastes. Zamparas et al. (4) evaluated the performance of the healthcare unit of Patras in Greece using a multi-criteria model. Castillo-Giménez et al. (5), assessed the performance of 27 members of the European Union in municipal waste treatment using a hybrid index, data envelopment analysis and multi-criteria decision-making techniques. Baghapour et al. (6) used consensus-based fuzzy multi-criteria group decision-making models to develop an indicator for assessing the process performance of waste management in hospitals.

Currently, waste management in Iran is not much satisfactory at different stages (1). Unfortunately, improper separation of waste components at the origin and poor understanding of the responsibility of medical centers' managers have led to the high rate of hospital waste generation in Iran (7). The average generation of infectious waste in large cities of Iran such as Tehran (49.7%), Mashhad (34.90%), Isfahan (20-25%), Tabriz (29.89%) and Fars Province (45.6%), is much higher than the international standards (7-12). Since the approval of Waste Management Act in 2005 and its amendment in 2008, waste management has improved; however, due to the lack of accurate instructions and failure to properly implement them, it is not much desirable yet (13-15).

We aimed to evaluate the performance of six selected hospitals in Tehran City using a combination of multi-criteria decision-making methods.

## Methods

This study was conducted after obtaining the approval of the Ethics Committee (Code: IR.SBMU.RETECH.REC.1396.1137). In addition, to maintain the confidentiality of the information, the names of the hospitals were not provided.

This cross-sectional study began in 2018. In order to determine the most important criteria and sub-criteria affecting the waste management performance of hospitals, a review of relevant domestic and international scientific resources was performed. The data collection tool was a checklist prepared by researchers, including 11 criteria and 29 sub-criteria affecting the proper hospital waste management. The checklist had quantitative and qualitative questions and was designed according to those sub-criteria and using Likert scale. The qualitative sub-criteria were scored based on the Likert scale (1 to 9) as well as the intermediate judgment values (2, 4, 6, 8). The criteria are of the maximization type, the scores were: very low=1, low=3, medium= 5, high=7, and very high=9. Moreover, each criterion was weighted by the experts (from 1 to 10). Notably, the checklist was developed from the validated checklists found in the literature reviews. Furthermore, to evaluate the criteria according to the objectives of the research, an expert team of environmental health experts of the hospitals was formed, who were well versed in waste management issues. The checklists were given to the team members at the target hospitals. In this study, a purposeful and judgmental method was used to select the hospitals. In this sampling method, a sample of the society is selected based on the judgment and expert opinion of the researcher and the approval of the relevant experts. Finally, six main and general hospitals affiliated to Shahid Beheshti University of Medical Sciences, with high admission capacity and per capita pro-

duction of infectious waste were purposefully selected so that they can be representative of the true characteristics of the whole society. Due to the existing constraints, these hospitals are not named here and they are referred to using alphabet letters. After collecting the hospital data using the above-mentioned checklist, a combination of four methods: TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), VIKOR (in Serbian: Vlse Kriterijumska Optimizacija Kompromisno Resenje; means Multi-criteria

Optimization and Compromise Solution), SAW (Simple Additive Weighting), and AHP (Analytic Hierarchy Process) methods were used to rank the hospitals according to the waste reduction criteria. MATLAB (2017) software was used for this purpose. At first, the waste management performance of each hospital was calculated using each method and then, the weighted average of the results of the four methods was computed and considered as the final result. The conceptual model of this study is shown in Fig. 1.

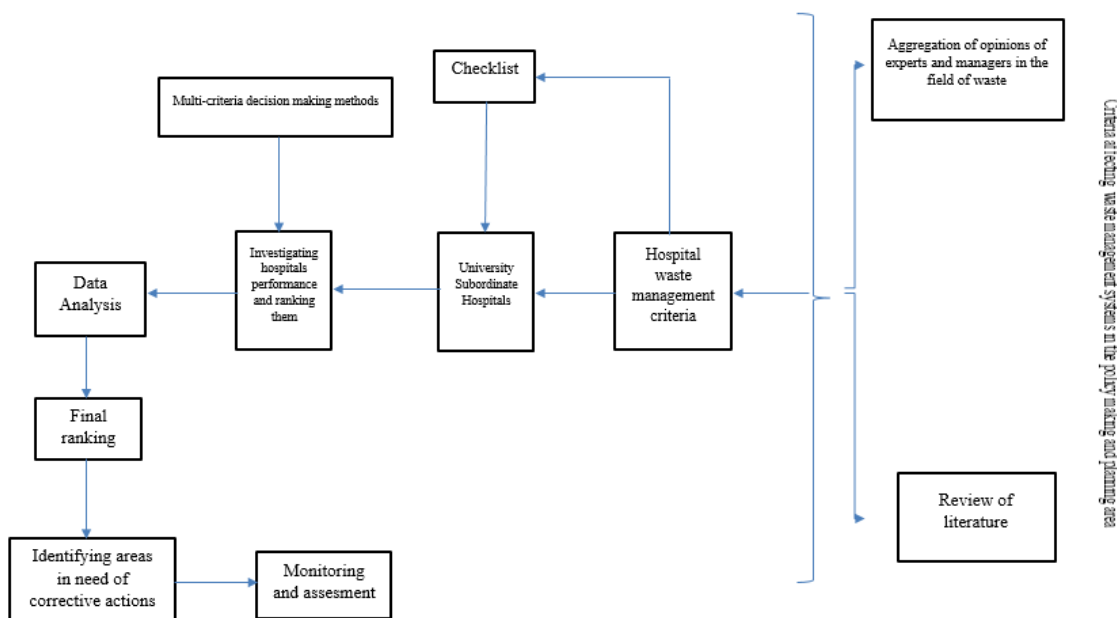


Fig. 1: Conceptual model of the research

### TOPSIS algorithm

- 1- Formation of decision matrix.
- 2- Normalization of the decision matrix:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^m x_{ij}^2}} \quad \forall i, j$$

Where;  
 X= decision matrix;  
 i= a subscript for options,  
 j= a subscript for criteria,

$x_{ij}$ = element of  $i^{th}$  option and  $j^{th}$  criterion in the decision matrix, and  
 $n_{ij}$ = normalized element of  $i^{th}$  option and  $j^{th}$  criterion in the decision matrix.

- 3- Formation of a weighted normalized matrix:

$$v_{ij} = n_{ij} w_j$$

$v_{ij}$  is the weighted normalized element of the  $i^{th}$  option and  $j^{th}$  criterion in the decision matrix and  $w_j$  is the weight of the  $j^{th}$  criterion.

- 4- Calculation of the positive and negative ideas:  
 For those criteria with a positive nature.

$$V_j^+ = \max_i \{v_{ij}\}$$

$$V_j^- = \min_i \{v_{ij}\}$$

For those criteria that have a negative nature.

$$V_j^+ = \min_i \{v_{ij}\}$$

$$V_j^- = \max_i \{v_{ij}\}$$

In these equations,  $V_j^+$  are positive ideals of the  $j^{\text{th}}$  criterion and  $V_j^-$  are the negative ideals of that criterion.

5- Distance from positive and negative ideas and calculation of ideal solution

$$d_i^+ = \sqrt{\sum_{j=1}^m (v_{ij} - V_j^+)^2}$$

$$d_i^- = \sqrt{\sum_{j=1}^m (v_{ij} - V_j^-)^2}$$

$$CL_i^* = \frac{d_i^-}{d_i^- + d_i^+}$$

$d_i^+$  = Euclidean distance of the  $i^{\text{th}}$  option from the positive ideal,  $d_i^-$  = Euclidean distance of the  $i^{\text{th}}$  option from the negative ideal, and  $CL_i^*$  is the earned score of the  $i^{\text{th}}$  option, ranging from 0 to 1. Whatever this value is closer to 1, the option would be closer to the ideal solution (16, 17).

### VIKOR algorithm

1- Formation of decision matrix.

2- Normalization of data:

$$n_{ij} = \frac{x_{ij}}{\sum_{j=1}^m x_{ij}}$$

$X$  = decision matrix;

$i$  = a subscript for options,

$j$  = a subscript for criteria,

$x_{ij}$  = element of the  $i^{\text{th}}$  option and the  $j^{\text{th}}$  criterion in the decision matrix, and

$n_{ij}$  = normalized element of the  $i^{\text{th}}$  option and the  $j^{\text{th}}$  criterion in the decision matrix.

3- Determination of the ideal positive and negative points for each criterion: For criteria with positive nature:

$$f_j^* = \max_i \{n_{ij}\} \quad \forall j \quad [5]$$

$$f_j^- = \min_i \{n_{ij}\}$$

For those criteria with negative nature:

$$f_j^* = \min_i \{n_{ij}\}$$

$$f_j^- = \max_i \{n_{ij}\}$$

In the above equations,  $f_j^*$  are the positive ideals of the  $j^{\text{th}}$  criterion and  $f_j^-$  negative ideals of the  $j^{\text{th}}$  criterion.

4- Determination of utility and regret:

$$S_i = \sum_{j=1}^m W_j \frac{f_j^* - n_{ij}}{f_j^* - f_j^-} \quad \forall i \quad [8]$$

$$R_i = \max_j \{W_j \frac{f_j^* - n_{ij}}{f_j^* - f_j^-}\}$$

In the above equations,  $W_j$  is the weight of the  $j^{\text{th}}$  criterion,  $S_i$  is the utility value of the  $i^{\text{th}}$  option, and  $R_i$  is the regret value of the  $i^{\text{th}}$  option.

5- Calculation of VIKOR index:  $Q_i$  is the obtained score of the  $i^{\text{th}}$  option. The value of  $\nu$  is the coefficient of significance considered for the distance of utility and regret of the  $i^{\text{th}}$  option from the ideal points of utility and regret.

$$Q_i = \nu \left[ \frac{S_i - S^*}{S^- - S^*} \right] + (1 - \nu) \left[ \frac{R_i - R^*}{R^- - R^*} \right] \quad \forall i \quad [9]$$

$$S^* = \min S_i \quad \forall i, j \quad [10]$$

$$S^- = \max S_i$$

$$R^* = \min R_i$$

$$R^- = \max R_i$$

The best option is the option with the smallest  $Q_i$ , provided that the following two conditions are met:

Condition 1: If the options  $A_1$  and  $A_2$  are ranked first and second among a total number of  $m$  options, the following relationship must exist:

$$Q(A_2) - Q(A_1) \geq \frac{1}{m-1}$$

Condition 2: Option  $A_1$  should be recognized as a top-ranking in at least one of the groups  $R$  and  $S$ . If the first condition is not met, both options will be the best. If the second condition is not met, both  $A_1$  and  $A_2$  options are selected as the top option (18).

**SAW algorithm**

- Quantify the decision-making matrix if there are qualitative criteria in the matrix,
- Normalize the decision matrix values using the linear method,
- Calculate the criteria weight,
- Multiply the weight of the criteria in the normalized matrix, and
- Select the most appropriate option (19).

$$A^* = \left\{ A_i \mid \text{Max} \sum_{j=1}^n n_j w_j \right\}$$

**AHP algorithm**

- Plot the decision tree of the hierarchy,
- Do pairwise comparisons: Pairwise comparisons are performed by experts using a scale of 1 to 9 to determine, by each criterion, the relative importance of each option over the other options (19,20).
- Normalize pairwise comparison matrices: To normalize each criterion, the value of each element is divided by the sum of its column.
- Calculate the relative weights (the arithmetic mean of each row of the normalized matrix of pairwise comparisons): The arithmetic mean of each row is calculated to determine the relative weights of each criterion. To calculate the relative weights of each option, the steps mentioned above are repeated.
- Multiply the relative weights of the criteria and options. After calculating the rela-

tive weights of the criteria and options, they are multiplied together.

$$W_i = \sum_j w_{ij} v_j \quad \forall i \quad [22]$$

$w_{ij}$  is the weight of the  $i^{th}$  option compared to the  $j^{th}$  criterion and  $v_j$  is the weight of the  $j^{th}$  criterion.

Rank the options: Arrange the values obtained by multiplying the criteria and options by the value (in order) and prioritize the options.

- Calculate the inconsistency ratio: If the inconsistency ratio is less than or equal to 0.1, the pairwise comparisons are consistent. The ratio is calculated as follow:
  - Step 1: The matrix of pairwise comparisons of the criteria is multiplied by the relative weight vector of the criteria.
  - Step 2: The resultant value of the first step is divided by the relative weights of the criteria.
  - Step 3: The arithmetic mean of the values from the second stage of calculation is calculated and called  $\lambda_{Max}$ .
  - Step 4: inconsistency criterion is calculated by the following equation:

$$II = \frac{\lambda_{Max} - n}{n - 1}$$

In which,  $n$  is the number of criteria.

Step 5: inconsistency ratio is computed by the following equation (19,20):

$$IR = \frac{II}{IRI}$$

**Results**

This study aimed to rank six main public hospitals in Iran. Table 1 presents the checklist designed to rank the selected hospitals in terms of waste control. It contains criteria and sub-criteria affecting the proper management of hospital waste found by a review of literature as well as

opinions of experts. In front of each sub-criterion, the scale of measurement is presented using Likert scale, number and percent, type of criterion (i.e. qualitative or quantitative), goal (maximization), weight of criteria based on the weight-average provided by the experts, and scores obtained by each hospital.

According to Table 1, 11 criteria and 29 sub-criteria were selected for the performance as-

essment of the hospitals in terms of waste control. Human resources, patients, technology, support of managers, data and information, intersectoral collaboration, rules and regulations, a proper model for supplies and equipment management, hospital supplies and equipment, separation at the origin, and disinfection were the main criteria.

**Table 1:** Criteria for rank hospitals in terms of waste management (21-26)

Criterion	Sub-criterion	Measurement unit	Criterion type	Goal	Weight	Hospital						
						A	B	C	D	E	F	
Human source	Re-	Level of planned training of managers	Likert scale	Qualitative	Max	9	5	7	8	7	5	5
		Level of planned training of staff				10	7	8	9	7	6	6
		Inter-departmental collaboration (Office of Nursing and Management)				9	7	9	9	7	7	7
		Inter-departmental collaboration (doctors and other departments)				7	3	3	4	3	3	3
		Active involvement of Environmental Health Unit in waste reduction programs				9	9	9	9	7	7	7
		Skills of specialist	Person (number of specialists)	Quantitative		10	4	5	5	4	7	5
		Level of social income	Likert scale	Qualitative		8	5	5	5	6	5	5
		Culturalization and modifying consumption patterns (modifying the cul-	Likert scale	Qualitative		8	5	6	7	5	5	5

	ture of consumerism)										
Patients	Level of education	Likert scale	Qualitative	Max	8	5	5	5	6	5	5
Technology	Waste disinfection technology	Likert scale	Qualitative	Max	10	9	9	9	9	9	9
Managers' support	Number of the defined projects (health, economic)	Number	Quantitative	Max	9	3	7	7	2	1	2
	Progress of waste programs (%)	%			9	100%	100%	100%	100%	100%	100%
	Number of comprehensive waste management plans	Number			10	1	1	1	1	1	1
	Evaluation of programs	Likert scale	Qualitative		9	7	8	9	6	6	6
	Supervision (incentive, punitive leverage)				10	7	8	9	7	7	7
	Certificate of quality management	Number	Quantitative		7	0	2	0	1	0	2
	Developing specific sanitary waste management practices from production to the final disposal				9	14	10	14	11	10	10
Data and information	Collection	Likert scale	Qualitative	Max	8	9	9	9	7	7	7
	Documentation				8	9	9	9	7	7	7
Intersectoral collaboration	Level of cooperation with the Department of Environment	Likert scale	Qualitative	Max	9	7	8	9	7	6	7
	Level of cooperation with the municipality				9	7	8	9	7	7	6
Rules and regulations (level of implementation of laws, regulations and guidelines)	Accreditation Standards of Hospitals	Likert scale	Qualitative	Max	9	7	7	7	7	7	7



A correct pattern for management of supplies and equipment	Implementation of new management and warehousing methods	Likert scale	Qualitative	Max	9	5	5	6	5	5	5
Hospital Supplies and equipment	Quality of supplies and equipment	Likert scale	Qualitative	Max	9	5	5	6	5	5	5
Separation at origin	Separation at origin	Likert scale	Qualitative	Max	10	7	8	9	7	7	7
	Collection by color code				10	9	9	9	7	7	7
	Separate collection of radioactive waste				10	9	9	9	9	9	9
	Keeping in proper conditions				10	7	8	9	7	7	5
Disinfecting (degree of waste disinfection)	Disinfection tests	Likert scale	Qualitative	Max	10	9	9	9	9	9	9

Fig. 2 provides a comparison of the scores using different methods. Generally, the scores of Hospital C determined by different methods were higher than other studied hospitals. Hospital E earned the lowest scores in each method. This may attribute to the poor performance of these hospitals in the management of medical waste, particularly minimization of waste production. Based on the obtained scores, the hospitals were ranked using the above methods (Fig. 3). The

rankings of the different methods show no significant difference.

As shown in Table 1, Hospital C has a relatively good performance in terms of the performance criteria, so it was ranked first. All of the studied hospitals earned a good score for waste disinfection and a poor score for comprehensive waste management plans.



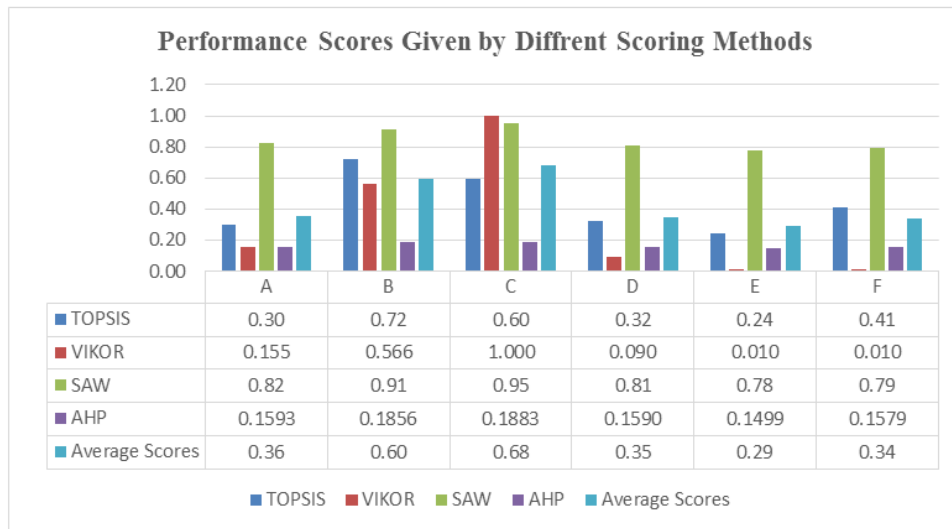


Fig. 2: Comparison of the scores using different methods in the field of waste management

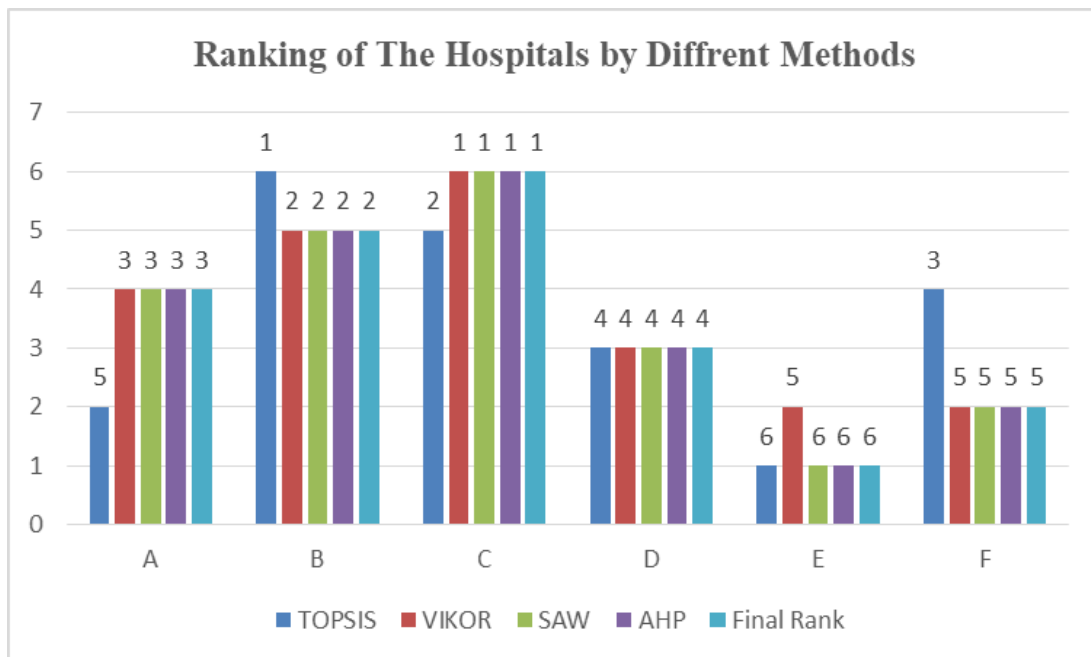


Fig. 3: Ranking of the hospitals by different methods in the field of waste management

## Discussion

Multi-criteria decision-making techniques are commonly used to solve management problems and to select the best and most optimal alterna-

tives in management decisions. In this study, considering that each multi-criteria decision-making methods has its advantages and challenges, it was tried to use the most widely used methods to evaluate the performance of hospitals in terms of waste management.

Many multi-criteria decision-making projects and research use several methods for a specific problem. A study may use more than one method to rank alternatives, and each method may result in a different ranking set. In such cases, to integrate the results and obtain the final ranking, there are usually three well-known methods in multi-criteria decision-making techniques: average ranking method, Borda method, and Copeland method, and here, the first method was used. The findings of the methods have no significant difference. It also showed usefulness of hybrid method in ensuring that rankings are done more accurately. These findings are in line with the results reported by other researchers. For example, AHP, TOPSIS, ELECTRE, GRA, and SAW methods were integrated to solve the problem of selecting a supplier in hospitals (27). Their reported results were consistent with those found in the present study. The rankings using different methods were close to each other and lead to the same results. In another study, AHP, Fuzzy AHP, TOPSIS, Fuzzy TOPSIS, and PROMETHEE were integrated and compared for route planner and concluded that the results of AHP, Fuzzy AHP, and PROMETHEE methods were more consistent (28). Zavadskas et al (29) conducted a review study on solving decision-making problems using multi-criteria decision-making methods and reported that hybrid approaches have advantages over individual techniques, particularly in terms of applying stakeholders' preference in decision-making, handling interconnected or contradictory criteria, and minimizing the uncertainties. Zhu et al. (30) integrated VIKOR and DEMATEL methods for controlling elective admission in a public hospital in China and concluded that the hybrid method was much useful and effective in solving the admission problems and setting priorities. Mardani et al. reviewed the papers published during 1995-2015 on application of multi-criteria decision-making methods and concluded that hybrid multi-criteria decision-making and fuzzy logic were the most widely used methods during these two decades. This study also emphasized the hybrid use of multi-criteria decision-making methods (31).

This was the first study that used four commonly used ranking methods of multi-criteria decision-making to rank the performance of six hospitals regarding waste management. Büyüközkan et al. (32) used IF AHP and IF VIKOR framework to develop a strategy for selecting hazardous waste carriers. It recommended a combined use of AHP for determining the importance of criteria and VIKOR for ranking the most desirable alternatives. It also emphasized the hybrid use of multi-criteria decision-making methods. Ultimately, the results and methods presented in this study can be used to evaluate and monitor the performance of hospitals in the field of waste management.

## Conclusion

The top three hospitals regarding waste reduction criteria were Hospital C, B, and A respectively. Ranking and prioritization results using these methods lead to no significant differences. Using several methods simultaneously can assure the decision-maker that priorities are set closer to reality. The main findings of this study can be summarized as follows:

- Developing a tool for surveillance on the performance of hospitals
- Facilitating and integrating the monitoring and assessment method of medical waste management performance based on the collected data
- Identifying the main aspects of low performance of hospital waste management in Iran
- Developing a more complete checklist for assessment of medical waste management in hospitals using more criteria
- Using a hybrid approach to reduce errors and increase efficiency of calculation
- Helping the managers of medical centers to compare themselves with other centers and modifying their waste management process
- Choosing the right strategy for the areas in real need of improvement

- Improving decision-making quality of medical center managers
- Using different criteria for rational decision-making

## Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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## Conflict of interest

The authors have no conflict of interest to declare.

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