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Strategies for Controlling Violence Against Healthcare Workers: Application of Fuzzy Analytical Hierarchy Process and Fuzzy Additive Ratio Assessment

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Title: Strategies for Controlling Violence Against Healthcare Workers: Application of Fuzzy Analytical Hierarchy Process and Fuzzy Additive Ratio Assessment

Short title: Ranking of control measures for violence

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Abstract

Objective: The present study aimed to identify and prioritize control measures of violence against Healthcare Workers (HWs) using the Fuzzy Analytical Hierarchy Process (FAHP) and Fuzzy Additive Ratio Assessment (F-ARAS).

Background: Occupational violence is a pervasive problem in healthcare centers. Reducing violence against staff is one of the challenges for healthcare managers.

Method: At the first stage, the most common criteria and control options for violence against HWs were identified and extracted using a review of previous studies. At the next stage, criteria for selection of control measures were prioritized using the FAHP. Finally, control measures of workplace violence were prioritized using the F-ARAS method.

Results: Results of the FAHP indicated that safety and efficiency were the most important criteria. Results of the F-ARAS also revealed that “increasing number of security personnel” and “training staff” were the best recommendations for controlling violence against HWs.

Conclusion: Based on expert’s opinions, administrative measures are the optimal ways to control violence at health centers; therefore, it is suggested that violence control programs should be more focused on administrative measures.

Implications for Nursing Management: These results could assist nursing management to take best strategies for controlling occupational violence based on multi-criteria decision-making methods.

Keywords: Occupational violence; Healthcare workers; Ranking; Control strategies; Fuzzy Analytical Hierarchy Process (FAHP); Fuzzy Additive Ratio Assessment (F-ARAS)

1- Introduction

Violence is a widespread and worrisome problem in workplaces (CDC, 2006; Henry & Ginn, 2002). The National Institute for Occupational Safety and Health (NIOSH) introduced workplace violence as a major occupational hazard, including aggressive behavior such as physical attacks against employees or the threat of physical invasion while at work (CDC, 2006; OSHA, 2015). Workplace violence can be classified into four categories: physical violence (punching, kicking, slapping, pushing, biting, pinching, and wounding by sharp objects), verbal violence (insulting, humiliating, scaring, mocking and abusing), racial violence (threatening due to color and language, nationality, religion, place of birth, or any other situation), and sexual violence (any violent behavior related to gender which is considered as an offense by a person and threatens, insults, or embarrasses people) (Moraveji, Soleymannejad, & Bazargan, 2012).

According to the Bureau of Labor Statistics, during the 7-year period from 2011 to 2017, an average of 447 homicides and 712 intentional injuries by employees occurred annually in the United States (BLS, 2017). Among all working groups and professionals, HWs are the major victims of occupational violence, with their risk of exposure to occupational violence being 16 times higher than other employees (Moeini, Fallahi, Hossaini, & Dalvandi, 2017). Occupational Safety and Health Administration (OSHA) also reported rates of violence in the workplace in healthcare centers as much higher than with social service providers and industries (OSHA, 2015). Results of most studies indicate that more than half of nurses experience violence in the workplace during a year, despite the fact that the incidence rate of violence is not the same in different communities or sectors of healthcare centers (Cezar & Marziale, 2006; Gacki-Smith et al., 2009; Lanza, Zeiss, & Rierdan, 2006; Lin & Liu, 2005; O'Connell, Young, Brooks, Hutchings, & Lofthouse, 2000; Rafati Rahimzadeh, Zabihi, & Hosseini, 2011; Talas, Kocaöz, & Akgüç, 2011).

Violence in healthcare centers has broad consequences (Lanctôt & Guay, 2014; Nikathil, Olaussen, Gocentas, Symons, & Mitra, 2017). Lanctot and Guay (Lanctôt & Guay, 2014) in a comprehensive review study, categorized the consequences of violence in previous studies into seven categories: (1) physical (such as physical injuries), (2) psychological (such as posttraumatic stress disorder, Irritability, sleep disturbances, depression, Burnout, and anxiety), (3) emotional (e.g. anger, sadness, fear, disgust, and surprise), (4) workplace satisfaction functioning (such as quitting the job, changing employers, reducing performance and productivity and negative effects on job satisfaction) 5) patients' dissatisfaction affecting quality of care, (6) social or personal (e.g. negative effects on victim's relationships with colleagues and family) and (7) financial.

Due to high rates of workplace violence and its negative consequences for victims, it is important to implement strategies that prevent workplace violence or mitigate its negative effects. There is no possibility of performing or testing all control strategies due to various financial and technical limitations. Due to the wide variety of criteria for choosing control strategies, it is difficult to identify optimal strategies. There are many ways to classify control strategies. The use of multiple criteria decision-making (MCDM) method is the most efficient way to achieve this goal. The MCDM is a decision-making tool for complex multi-criteria issues that considers qualitative and quantitative aspects of problems in the decision-making process. These methods scientifically and systematically determine decision-maker's priorities to help them choose between several options that usually have different outcomes (Garfi, Tondelli, & Bonoli, 2009).

Despite the fact that a great number of studies have been conducted on occupational violence against HWs, most of them have not reported statistics for the incidence of violence and its contributing factors (Cezar & Marziale, 2006; Cheraghi et al., 2014; Dehnadi-Moghaddam et al., 2013; Gillespie, Gates, Miller, & Howard, 2010; Moraveji et al., 2012; Mozafari & Tavan, 2013; Soheili, Mohammadpour, Jafarizadeh, Habibzadeh, & Mehryar, 2014; Talas et al., 2011); moreover few studies have investigated strategies for preventing or controlling violence (Havaei, Macphee, & Lee, 2019; Morphet, Griffiths, Beattie, Reyes, & Innes, 2018; Spelten et al., 2017; Vladutiu, Casteel, Nocera, Harrison, & Peek- Asa, 2016; Zamanzadeh & Abdollahzadeh, 2007). The aim of this study is to prioritize violence control strategies using scientific and valid methods such as the MCDM and to cover the existing limitations.

2- Method

The present study employed a cross-sectional, qualitative and applied research design to identify and prioritize methods for preventing or reducing violence against HWs. The research was conducted at three dependent stages as shown in Fig. 1. The total sample size of the study consisted of 40 staff and managers (experts) of hospitals (Blinded for peer review)(15 in the second phase and 25 in the third phase of the study). The selection of effective criteria for choosing control strategies was conducted after consulting15 experts, including occupational health experts working in health centers and hospital managers. The second statistical sample consisted of 25 physicians, nurses, security forces, and managers of hospitals who had higher knowledge about the risk of occupational violence and violence prevention methods or who were more exposed to violence. Both panels of experts had more than 5 years of experience. To avoid bias, two samples were selected independently. Like other studies conducted by the MCDM, a purposive sampling method was done in the present study; and the sample size was calculated according to similar studies (Cancela, Fico, & Waldmeyer, 2015; Hsu, Hsieh, Yang, & Lu, 2015; Mühlbacher, Juhnke, & Kaczynski, 2016; Olivieri et al., 2012; Rajabi, Jahangiri, Molaeifar, Honarbakhsh, & Farhadi, 2018). While there is no absolute law on the number and method of choosing members of the expert group in MCDM methods, sampling methods in most studies conducted in this field are purposive (non-random). The sample size is less than 30 (Mühlbacher et al., 2016; Rajabi et al., 2018).

Figure 1: Steps of study [about here]

Stage 1: Identification of control criteria and options

At this stage, 8 general criteria were extracted based on a review of conducted studies conducted on the selection of control strategies (Ishaqi, Golmohammadi, & Khorram, 2012; Molaei Far et al., 2018; Sekhavati, Zadeh, Fam, & Zarandi, 2014). Subsequently, studies conducted on strategies for prevention or reducing the occupational violence against HWs were reviewed (Berry, McNeely, Beauregard, & Lagoe, 2013; Gallant-Roman, 2008; D. Gates et al., 2011; D. M. Gates, Ross, & McQueen, 2006; Gillespie et al., 2010; Henry & Ginn, 2002; Morphet et al., 2018; OSHA, 2015 ; Carol W. Runyan, 2001; Vladutiu et al., 2016; Wassell, 2009), and the most commonly used control strategies were extracted. The output of this stage constituted the input of the second and third research stages respectively. The criteria and options identified in the first step were then reviewed and edited by a panel of experts.

Stage 2: Weighing the criteria by the Fuzzy Analytic Hierarchy Process

In the present study, the Fuzzy Analytic Hierarchy Process (FAHP) was utilized to weigh the criteria for choosing control strategies. The FAHP is the upgraded version of the Analytic Hierarchy Process (AHP) in which fuzzy numbers are used instead of absolute values (Rokhsari & Sadeghi-Niaraki, 2015). The use of a fuzzy system increases the power of the method and is widely used in uncertainty conditions (Mamdani, 1974). Fuzzy theory, which is interpreted as inaccurate logic, is a part of operations research science in which quantitative and qualitative data are converted through new ways (Chang, 1996). In a fuzzy system, linguistic variables are used instead of numbers; then linguistic scales are converted to triangular or trapezoidal numbers.

Since the measurement of some criteria was qualitative and subjective and because of the lack of numerical value for qualitative data, the evaluation of criteria was done on a linguistic scale. The triangular fuzzy numbers were used to show linguistic variables (Table 1).

Table 1: Linguistic Scale and corresponding fuzzy numbers for FAHP (Rajabi et al., 2018)

Linguistic Scale	Triangular fuzzy number	Reciprocal value of triangular fuzzy number
Just equal	(1, 1, 1)	(1, 1, 1)
Equally important	(0.5, 1, 1.5)	(0.66667, 1, 2)
Weakly important	(1, 1.5 ,2)	(0.5, 0.66667 ,1)
Strong more important	(1.5, 2, 2.5)	(0.4, 0.5, .66667)
Very Strong more important	(2, 2.5, 3)	(0.3333, 0.4, 0.5)
Absolute more important	(2.5, 3, 3.5)	(0.285714, 0.333, 0.4)

The geometric mean formula was used to combine the results of the expert group. Chang's extent analysis method, as the most widely used and simplest method, was applied to solve the FAHP calculations (Aggarwal & Singh, 2013; Chang, 1996). Details of FAHP calculations with the extent analysis method are presented in Appendix A.

One of the important issues in the FAHP method is the calculation of the consistency of expert opinions. To measure this, the pairwise comparison matrixes were evaluated by the Consistency Ratio (CR). The CR was obtained from dividing the Consistency Index (CI) by the random Consistency Index (RI) that was obtained from guidelines (Mazurek, 2017). If the calculated consistency ratio is less than 0.1, then the paired comparison and judgments are acceptable. Otherwise, the study continues until the desired consensus is reached. In this study, the second phase was repeated three times. For the first time, minor changes were made based on the opinions of the expert group on the selected criteria to reach a consensus of expert opinions.

(C) Prioritizing control strategies for occupational violence using the Fuzzy-ARAS method

After determining the weights of criteria in the previous step, control options (alternatives) of violence against the HWs were prioritized using the Fuzzy-ARAS method. This method is a relatively new technique that was developed by Zavadsk and Tursk who argued that complicated phenomena in the world could be understood by simple comparisons. This technique is a powerful way to choose the degree of utility of different options and is relatively simple (Turskis & Zavadskas, 2010). Due to the capabilities of this method, it has been used in several different studies (Keršulienė & Turskis, 2011, 2014; Turskis, Lazauskas, & Zavadskas, 2012). This study appears to be the first that conducted research with the F-ARAS method in the field of healthcare.

At this stage, the panel of experts was asked to evaluate the control strategies based on weighted criteria from the previous stage. To this end, the linguistic scales were used and converted to corresponding absolute scales (Table 2).

Table 2: Linguistic scale and related fuzzy numbers for F-ARAS

Linguistic Scale	Fuzzy number
Very Good (VG)	(7, 9, 9)
Good (G)	(5, 7, 9)
Fair (F)	(3, 5 ,7)
Poor (P)	(1, 3, 5)
Very Poor (VP)	(1, 1, 3)

The optimality function and degree of the alternative utility were used to prioritize control strategies by the F-ARAS method. Higher values of these two indices for each of the control strategies indicated that they were better than the other control strategies. Details of F-ARAS calculations are provided in appendix A.

3- Findings

In this study, 8 criteria and 17 options for controlling violence against healthcare workers were identified and prioritized using the combination of FAHP and F-ARAS methods. Figure 2 indicates the results of calculating the relative weight of criteria for the selection of control measures using the FAHP method. Among 8 identified criteria, "safety", "efficiency", and “possibility for implementation” had the highest weights.

Figure 2. Relative weight for selection criteria of violence control measures using the FAHP method [about here]

The final results of the study indicated that among 17 investigated control strategies, “increasing number of security personnel”, “training staff on how to manage occupational violence”, and “prevention or restriction of the employee from work alone in high-risk area” were the best strategies for reducing or preventing occupational violence. Table 3 and Figure 3 present the results of prioritizing control strategies for occupational violence using the F-ARAS method.

Table 3: Identified control strategies for violence against healthcare workers and their values of the optimality function (S_i) by the F-ARAS method

Code	Alternatives (control measures)	S_i
A1	Elimination or substitution therapeutic procedures where the risk of violence is high	0.2773
A2	Using physical barriers (such as guards or door locks to reduce employee exposure to the hazard)	0.2911
A3	Installation of metal detectors	0.2825
A4	Installation of panic buttons or pagers	0.2989
A5	Improving lighting in indoor and outdoor areas	0.3172
A6	Increasing the number of exit routes in each space	0.3000
A7	Monitoring workplace using closed circuit videos	0.3137
A8	Providing impact-resistant and bulletproof glass at nurses’ stations	0.2812
A9	Increasing the depth of counters at nurses’ stations	0.2870
A10	Providing comfortable areas to reduce stress of patients and their companion	0.3108
A11	Elimination of items that could be used as weapons	0.3209
A12	Informing visitors about consequences of violence against HWs	0.3127
A13	Control of visitor entry	0.3187
A14	Prevention or restriction of employee from working alone in high risk areas	0.3233
A15	Post-incident tracking	0.3201
A16	Increasing number of security personnel	0.3523
A17	Training staff on how to manage occupational violence	0.3388

Figure 3: Prioritization results of control strategies based on the degree of utility using F-ARAS method [about here]

4- Discussion

The present study aimed to identify the criteria and options of control measures to prevent violence against HWs and rank them using a combination of FAHP and F-ARAS methods. The results obtained from the consensus of experts by the FAHP method indicated that the "safety" and "efficiency" criteria had the highest weights and should be prioritized when selecting of control measures of violence against HWs.

Results of ranking control measures based on the F-ARAS method also indicated that “increasing the number of security personnel,” “training staff on how to manage occupational violence,” and “preventing or restricting of employees from working alone in high-risk areas” had the highest impact on reducing or preventing occupational violence. As mentioned earlier, there are few studies on methods for controlling occupational violence against HWs, and there are no studies that systematically prioritize methods of controlling violence. Nonetheless, several studies have examined violence control strategies and the results of most of them are consistent with the present study. Stirling et al. found that increasing the number of security staff and improving security systems were effective for violence control (Stirling, Higgins, & Cooke, 2001). Zamanzadeh et al. also mentioned the limitating clients' access to hospitals as the most common approach for controlling violence against nurses (Zamanzadeh & Abdollahzadeh, 2007).

According to the results of the present study, increasing the number of security personnel and training staff were the best ways to control violence in healthcare centers. Many studies emphasized the role of education and increased awareness of staff and patients in reducing the incidence of violence or reducing consequences of violence in healthcare centers (Deans, 2004; Fernandes et al., 2002; D. Gates et al., 2011; Ishak & Christensen, 2002; Carol W Runyan, Zakocs, & Zwerling, 2000), although there were many contradictions in the effectiveness of training in previous studies (Wassell, 2009). In general, education should be provided to enhance the staff's knowledge, attitude, and skill for preventing or controlling verbal and physical violence (Hills et al., 2015). Training programs should be implemented, such as increasing the staff's knowledge about legal responsibilities, organizational procedures and policies, and strategies for interacting with patients to prevent violence (CDC, 2006). OSHA also mentions education as a key component of programs to address violence and emphasizes the need for educational programs in two ways, including general and specialized education for employees, managers, supervisors and security personnel in healthcare centers. OSHA also recommends applying policies and procedures for preventing violence in the workplace, identifying risk factors and violent behavior, strategies for interacting with patients and managing violence in the workplace, training programs designed to familiarize employees with safety equipment such as alarm systems, and methods of protecting themselves and colleagues during the violent episodes (OSHA, 2015). Contrary to the above studies, the study by Havaei et al showed that nursing education was not an effective violence prevention strategy for nurses' perceptions of safety (Havaei et al., 2019).

Based on the consensus of experts with regard to all criteria for choosing a control strategy, administrative measures are more appropriate towards engineering (environmental) control measures of violence against the HWs. However, it is always recommended that administrative measures should be taken after the implementation of engineering measures in order to reduce the residual risk, or if engineering measures cannot be implemented (OSHA, 2015). Most studies have found that implementing environmental control measures was the most effective way to address workplace violence. However, these solutions seem to be more effective based on the availability of social and economic resources; and management practices are more effective than environmental measures to control the risk of violence in healthcare centers (Wassell, 2009). In fact, various aspects affecting the selection of the appropriate strategy such as cost, capability for implementation, and the comprehensiveness of the model should be taken into account when implementing a control strategy. Accordingly, most studies conducted on the control of violence in medical centers have suggested that the implementation of organizational and managerial interventions (including educational programs) is most effective in improving the control of violence against staff in healthcare centers (Barish, 2001; Flannery Jr et al., 1998; Henry & Ginn, 2002; Morrison & Love, 2003). Some studies have shown that the focus of organizational measures on patients, like employees, can reduce the incidence of violence in medical centers. In one of these studies, Kraus found that the patient management strategy reduced type II violence (violence of patients or relatives against employees) in medical centers (Kraus, Blander, & McArthur, 1995).

Despite the greater impact of managerial and organizational strategies over environmental solutions (engineering), the results of the present study indicated that roles of environmental strategies such as the removal of hazardous equipment, appropriate environmental designs, providing adequate lighting, using closed circuit videos, and implementing physical protections and barriers should not be ignored in the control of violence. Therefore, it is suggested that environmental strategies be used along with administrative practice in violence control programs at workplaces. This result was consistent with the findings of several studies; in one of these studies, Arnetz found that intervention strategies such as increasing the number of security personnel, training staff, designing panic buttons, increasing the number of closed circuit video cameras, and modifying shifts to prevent staff from working alone in a unit were useful in reducing the rate of violence in the workplace (Arnetz et al., 2017). The results of a study by Hunter and Love indicated that an intervention plan including several environmental and administrative measures was very effective in reducing violence in hospitals (Hunter & Love, 1996).

5- Research Limitations

The type of violence control strategies may vary depending on the technical, economic, managerial, and cultural characteristics of the study location. Therefore, violence control measures investigated in this study may not be comprehensive and fully generalizable to healthcare centers in other regions.

6- Conclusion and practical suggestions

According to the results of the present study, measures should be taken to increase the number of security personnel and to train staff and clients of healthcare centers in order to control the occupational violence against HWs. Moreover, work schedules should be modified to prevent employees working alone in a unit and there should be control over entry and exit to the unit. Staff training programs should include ways to quickly identify violent and stressful behavior or identify any symptom or situation that may lead to violence in the workplace, strategies for the management and control of people during incidences of violence at work, and appropriate methods for dealing with patients and their relatives to prevent the occurrence of violence against HWs. To create a more effective violence control program, it is necessary to consider environmental solutions such as installing CCTV cameras, redesigning hazardous areas, and removing dangerous equipment that may be used violently.

7- Implications for nursing managers

Due to the diversity of quantitative and qualitative criteria, decision making is one of the most difficult responsibilities of managers, including nursing managers. Therefore, in recent years mathematical and computer science and new techniques such as multi-criteria decision making techniques have been used as a decision support system (DSS) to help managers make optimal decisions. In this study, we introduced the FAHP and F-ARAS methods to assist nursing managers in deciding on the optimal control strategies for violence against healthcare workers.

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Appendix A: Detailed description of FAHP and FARAS

A.1. FAHP

Equation A.1 shows a general form of fuzzy triangular numbers:

$$\mu_{\tilde{m}}(x) = \begin{bmatrix} (x-l)/(m-l) & l \le x \le m \\ (u-x)/(u-m) & m \le x \le u \\ o & other\ wise \end{bmatrix} \qquad \text{Eq.A.1}$$

where l is the lower limit, u is the upper limit, and m is the median value. Therefore, fuzzy triangular numbers are shown as (l, m,u).

The steps of the calculation of FAHP based on the Extent Analysis (EA) method in this study were as follows (Chang, 1996):

Step 1: The value of fuzzy combination value of i is expressed according to the Equation A.2:

$$\mathrm{S_i} = \sum_{j=1}^{m} \mathrm{M}_{g_i}^{j} \quad \left[\sum_{i=1}^{n}\sum_{j=1}^{m} \mathrm{M_{ij}}\right]^{-1} \qquad \text{Eq.A.2}$$

The values of $\sum_{j=1}^{m} M_{g_i}^{j}$ is calculated using the equations A.3 and A.4:

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_i \sum_{j=1}^{m} m_i \sum_{j=1}^{m} u_i\right) \qquad \text{Eq.A.3}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_i \sum_{j=1}^{m} m_i \sum_{j=1}^{m} u_i\right) \qquad \text{Eq.A.4}$$

The inverse of equation A.5 was calculated as follows:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right]^{-1} = \left(\frac{1}{\sum_{j=1}^{m} l_i}, \frac{1}{\sum_{j=1}^{m} m_i}, \frac{1}{\sum_{j=1}^{m} u_i}\right) \qquad \text{Eq. A. 5}$$

Step 2: If $M_2 = (l_2, m_2, u_2)$ and $M_1 = (l_1, m_1, u_1)$ are two fuzzy numbers, the probability degree is calculated according to Equation A.6:

$$V(M_1 \ge M_2) = y \ge x\left[\min\left(\mu_{M1}(x), \mu_{M2}(y)\right)\right] \qquad \text{Eq.A.6}$$

This equation can be expressed as follows:

$$V(M_2 \ge M_1) = hgt(M_1 \cap M_2) = \mu M_2(d) = \begin{cases} 1, & if\, m_2 \ge m_1 \\ 0, & if\, l_1 \ge u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \qquad \text{Eq. A. 7}$$

Where, d is the length of the highest intersection between μM1 and μM2.

Figure 4: The intersection between M_1 and M_2 [about here]

Step 3: The probability degree of a fuzzy point like M_i larger than point K is calculated using the Equation A.8:

$$V(M \geq M_1, M_2, \dots, M_K) = V\,[(M \geq M_1)\ and\ (M \geq M_2) and\ \dots\ (M \geq M_K)] = minV\ (M \geq M_i), i = 1,2,3, \dots, k \qquad \text{Eq.A.8}$$

Assuming that the following equation is true:

$$d'(Ai) = \min V\ (Si \geq Sk) \qquad Eq.A.9$$

The weight of each vector is calculated according to the Equation A.10:

$$W' = (d'(A_1), d'(A_2), \dots, d'(A_n)\ )^T \qquad Eq.A.10$$

Step 4: Finally, the normalized weight of each vector is calculated according to Equation A.11:

$$W = (d(A1), d(A1), \dots, d(An)\ )^T \qquad Eq.A.11$$

Where, W is a non-fuzzy number.

A.1. F-ARAS

The main steps of the F-ARAS method to prioritize control strategies of the present study were as follows(Turskis & Zavadskas, 2010):

Step 1: Forming of a Fuzzy Decision Matrix

The general form of ARAS decision-making matrix is as follows:

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{01} & \dots & \tilde{x}_{0j} & \dots & \tilde{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{x}_{i1} & \dots & \tilde{x}_{ij} & \cdots & \tilde{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mj} & \cdots & \tilde{x}_{mn} \end{bmatrix}, \quad i = \overline{0, m}\ ;\ j = \overline{1, n} \qquad \text{Eq.A.12}$$

Where, m is the number of alternatives; n is the number of criteria; $\tilde{x}_{ij}$ is the fuzzy value representing the i alternative based on j alternative; and $\tilde{x}_{0j}$ is the optimal value of j criterion:

$$\tilde{x}_{0j} = \underset{i}{max}_{\tilde{x}_{ij}}, if\ \underset{i}{max}_{\tilde{x}_{ij}}\ \ is\ preferable, and$$

$$\tilde{x}_{0j} = \underset{i}{min}_{\tilde{x}_{ij}}, if\ \underset{i}{min}_{\tilde{x}_{ij}}\ \ is\ preferable \qquad \text{Eq.A.13}$$

Step 2: Normalization of initial values of the decision matrix ($\tilde{\bar{x}}_{ij}$)

The following equation was used to normalize positive criteria:

$$\tilde{\bar{x}}_{ij} = \frac{\tilde{x}_{ij}}{\sum_{i=0}^{m} \tilde{x}_{ij}} \qquad \text{Eq.A.14}$$

Negative criteria were also normalized using the following equation:

$$\tilde{\bar{x}}_{ij} = \frac{\tilde{x}_{ij}}{\tilde{x}_{ij}^{*}} \; \tilde{\bar{x}}_{ij} = \frac{\tilde{x}_{ij}}{\sum_{i=0}^{m} \tilde{x}_{ij}} \qquad \text{Eq.A.15}$$

Step 3: Calculation of the normalized-weighted matrix ($\tilde{\hat{x}}_{ij}$):

The following equation was used to calculate normalized-weighted matrix:

$$\tilde{\hat{x}}_{ij} = \tilde{\bar{x}}_{ij}\widetilde{w}_j \;\; \text{i} = \overline{0, m} \qquad \text{Eq.A.16}$$

Where, w_j is the weight of each criterion and was calculated in the previous step using the FAHP.

Step 4: Determination the value of the optimality function and degree of the alternative utility

The value of the optimality i function is obtained according to the following equation:

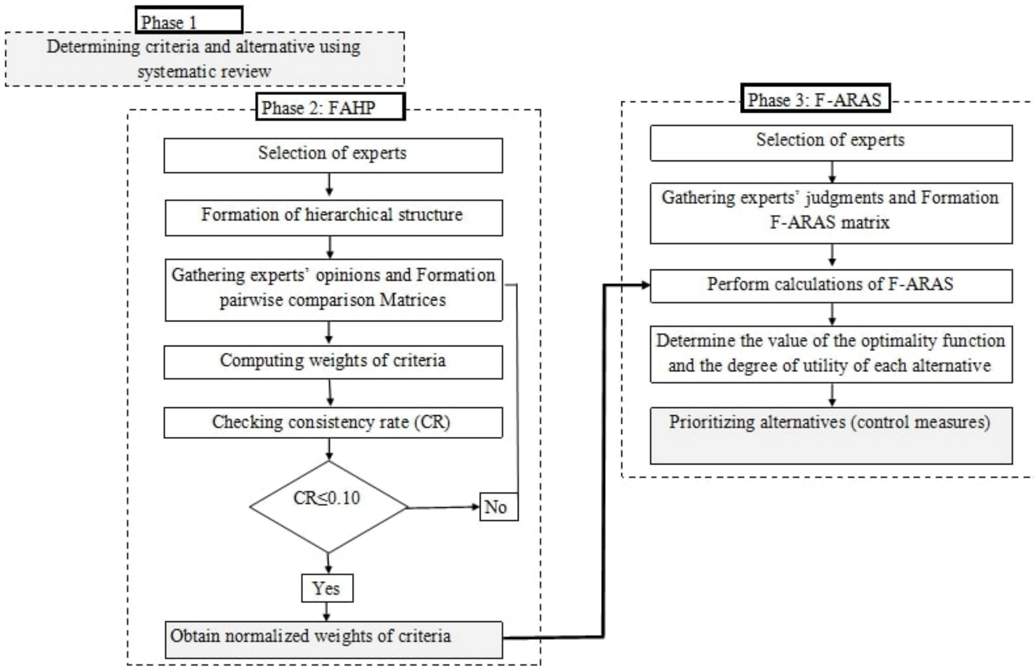
$$\tilde{s}_i = \sum_{j=1}^{n} \tilde{\hat{x}}_{ij} \, ; \;\; \text{i} = \overline{0, m} \qquad \text{Eq.A.17}$$

Alternative with larger $\tilde{s}_i$ is preferable to other alternatives. The following equation is used for defuzzification:

$$\tilde{s}_i = \frac{1}{3}\left(s_{i\alpha} + s_{i\beta} + s_{i\gamma}\right) \qquad \text{Eq.A.18}$$

The degree of the alternative utility is calculated as follows:

$$k_i = \frac{s_i}{s_0} \;\; \text{i} = \overline{0, m} \qquad \text{Eq.A.19}$$



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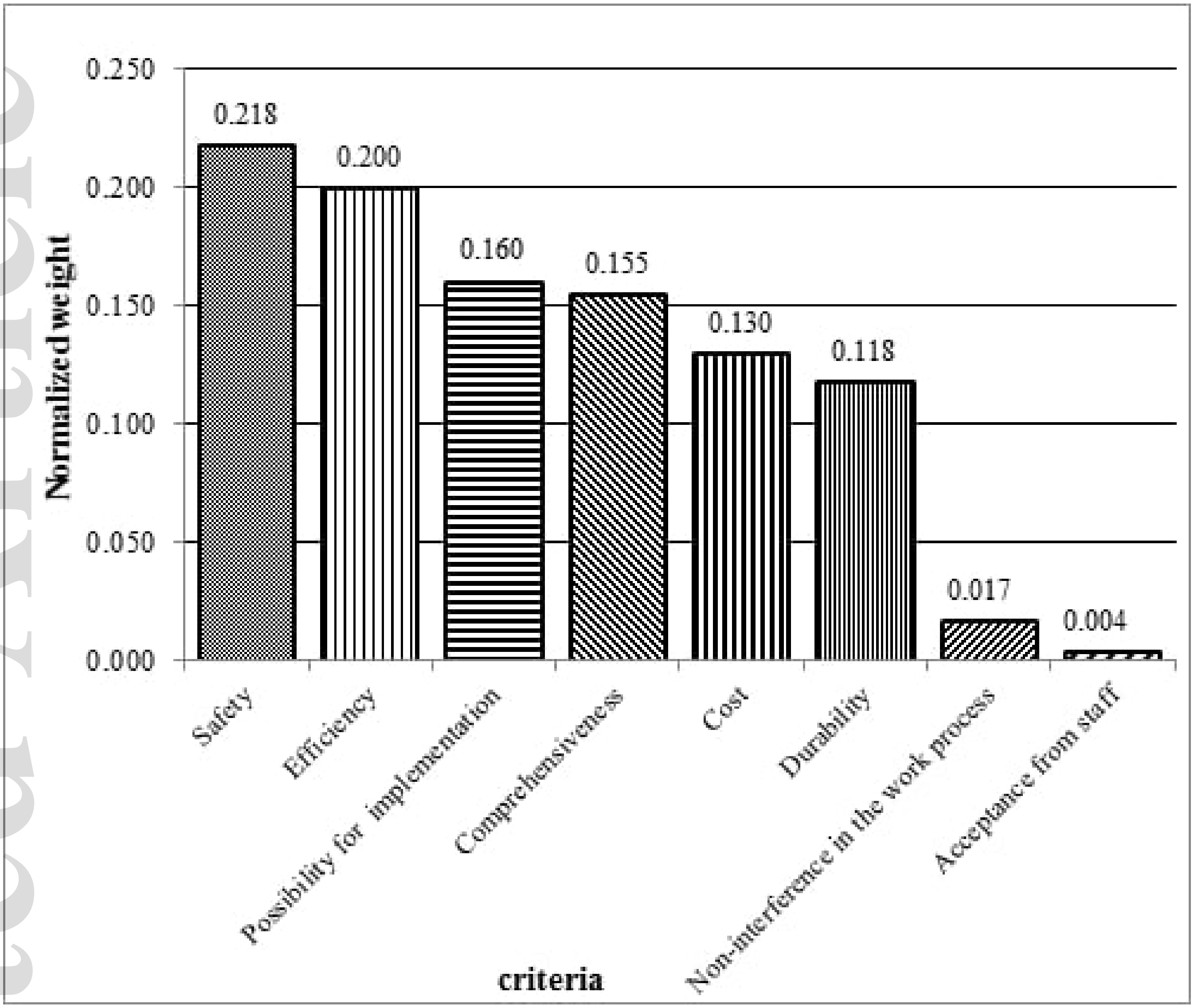

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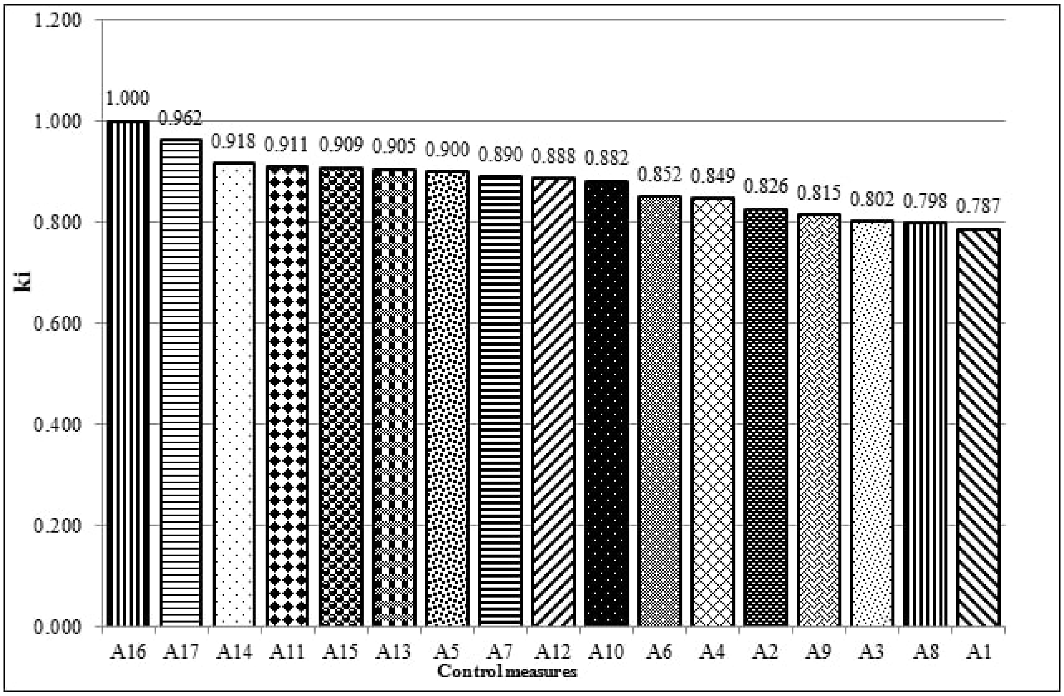

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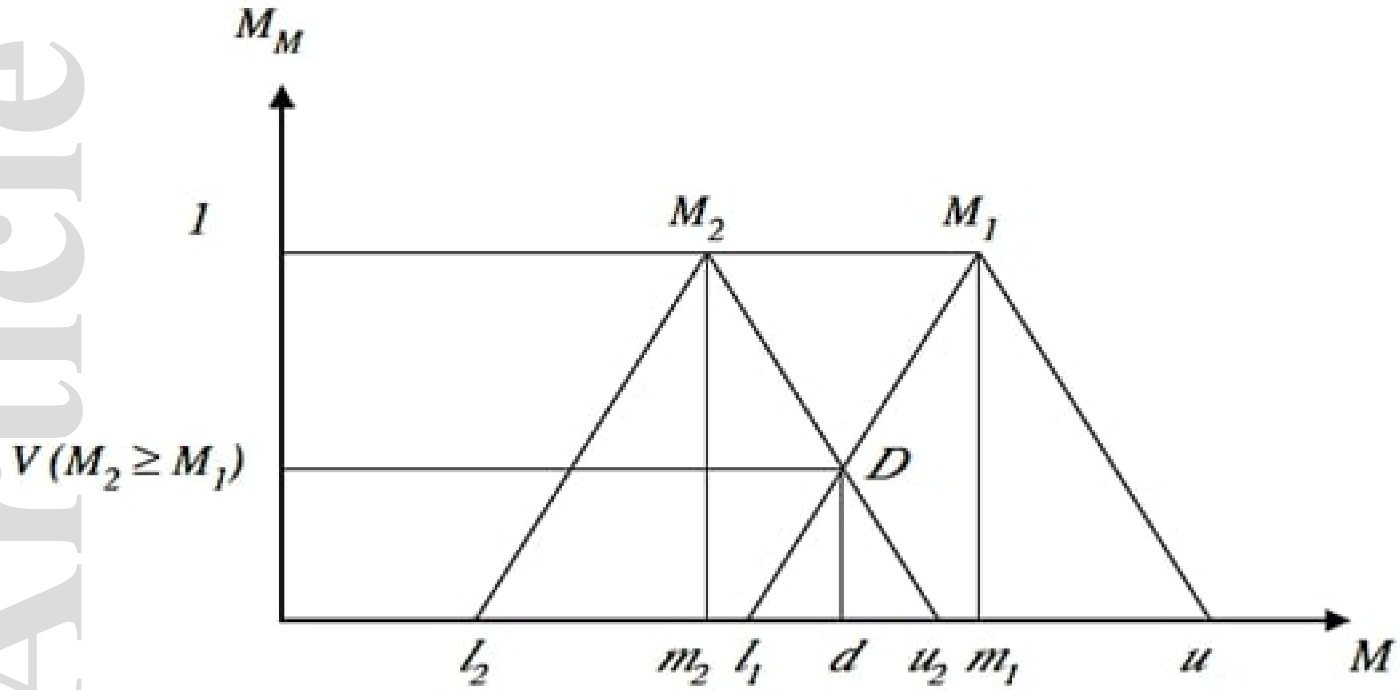

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