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RESEARCH ARTICLE

A New Fuzzy AHP- Fuzzy VIKOR Approach in Control and Management of The Angiography Procedure to Prevent Disruptions: A Case Study

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Abstract

Background and objectives: A hybrid MCDM approach is presented to evaluate and prioritize the disruptions in the angiography process, in a fuzzy environment. The proposed approach is applied to a real case in a public hospital.

Methods: In this study, a new approach is utilized based on fuzzy MCDM methods. The disruptions are identified using the experts' opinions. Then, the FMEA risk factors are compared in pairs and given weights by experts, using fuzzy AHP. The Experts were then asked to rate the disruptions according to the risk factors. Finally, the disruptions were ranked using Fuzzy VIKOR.

Results and Conclusion: Results show that the risk factor occurrence has the highest importance among the three risk factors. They also suggest that the top three disruptions in the angiography process are 'absence of manual' and 'guideline on angiography procedure', 'inadequate training of personnel and exhaustion', respectively.

Practical implications: Results of this study may help hospital managers and practitioners avoid disruptions in the process and improve healthcare service quality.

Originality/value: The recent studies in the related literature were thoroughly investigated and it was found that no studies considered the disruptions identification and analysis in the angiography process. Therefore, the disruptions in the angiography process are investigated for the first time. Moreover, the efficiency and applicability of the proposed method and the rankings are validated by the experts.

Keywords: MCDM, FMEA, Fuzzy AHP, Fuzzy VIKOR, Angiography, Healthcare System.

Background and objectives:

Cardiovascular Diseases (CVDs) are one of the most common causes of death in most industrial and developing countries. CVDs have caused major social and healthcare problems in Iran and the number of patients dealing with CVD is growing [1-3]. CVDs in Iran are known as the second most common cause of death. According to the data published by the World Health Organization (WHO) in 2014, Coronary Heart Diseases (CHDs) in Iran caused approximately 29 percent of deaths and Iran's global rank in CHD is 25.

Cardiac catheterization and angioplasty are believed to be the standard CVD diagnostic and treatment methods. The cardiac catheterization is performed by inserting a thin flexible tube (catheter) into a blood vessel through the patient 's groin or arm to reach the heart [4]. It is performed to treat elective and emergency CVD patients. In elective angiography, the patient is admitted to the hospital in the cardiac section and is prepared for angiography process according to the regulations and guidelines. Then, they are transferred to the catheterization laboratory (Cath Lab). Angiography, as an important CVD treatment technique, requires precise and thorough evaluation in its process in order to identify any disruption which may affect the treatment's quality.

Failure Mode and Effects Analysis (FMEA) is a useful technique which provides information for risk management decisions. It is intended to distinguish and remove potential failures in order to improve system reliability and safety. The main concern in the healthcare industry is the patients' health and safety. Hence, disruptions may cause serious consequences to healthcare services' quality [5].

Multi-Criteria Decision Making (MCDM) is a broadly used decision methodology in engineering, management, science, and technology. This method helps decision-makers rank alternatives, according to several criteria. There are several MCDM techniques, by which alternatives are prioritized and criteria are given weights. in order to overcome the natural ambiguity and uncertainty in the decision-makers'

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judgments, the fuzzy theory may be combined with MCDM methods. These methods are known as fuzzy MCDM (FMCDM) methods.

Studies regarding MCDM have drawn researchers' attention in different research areas such as manufacturing and service quality in different industries. Beheshtinia and Omidi [6] used four different MCDM techniques to evaluate service quality in the banking industry. The employed the AHP and MDL techniques to determine the weight of the criteria and utilized the TOPSIS and VIKOR Methods to determine the ranking of the banks. Sedady and Beheshtinia [7] presented a new MCDM technique, named TOPKOR, in order to prioritize the construction of renewable power plants according to PESTEL criteria. Beheshtinia and Nemati-Abozar[8] addressed the supplier selection problem by presenting a hybrid fuzzy MCDM model based on the MDL and TOPSIS methods in a fuzzy environment. Also, data envelopment analysis is used by various researches for performance evaluation [9-11]. Shafii et al. [12] analyzed and ranked the hospital managers using Fuzzy AHP-TOPSIS. They developed a performance assessment model in five main dimensions, including functional, professional, organizational, individual and human. Hence, these approaches are being increasingly used in healthcare studies. Such studies used different FMEA and MCDM combinations in hospital service quality, purchasing process and emergency department, healthcare management and medical centers performance evaluation. Chang [13] evaluated and analyzed the hospital services in private and public hospitals, according to six important criteria using the fuzzy VIKOR method. In another study, the working process in the emergency department was analyzed and prioritized by Chanamool and Naenna [14], using fuzzy FMEA. More related studies include the study of Liu et al. [15], in which utilized a FMEA and fuzzy VIKOR combination to analyze the risk of general anesthesia process. They also used questionnaires to involve the experts' opinions in rank six failure modes in general anesthesia process with respects to FMEA risk factors. As the result, respiratory depression was defined as the most serious failure mode in the process. Following this study, Liu et al. [16] evaluated the same failure modes using a combination of FMEA, FAHP, Shannon entropy and FVIKOR. The Same results were also obtained using this method and respiratory depression was again the most important failure mode.
Torkzad and Beheshtinia [17] evaluated the service quality of four public hospitals using the combination of four hybrid MCDM approaches. In order to obtain the final ranking of hospital service quality criteria, they aggregated the result of these approaches using the Copland.

Several studies used the FMEA and MCDM methods combination in order to identify and analyze disruptions in surgeries and related processes. Al-Hakim [18] conducted a study observing surgeries in two hospitals' operating rooms and using an object-centered strategy, they recorded the surgeons unnecessary waiting times. Jamshidi et al. [3] also proposed a fuzzy FMEA method to prioritize the medical devices, considering several risk assessment factors and all aspects of hazards and risks in medical device prioritization.

Regarding the angiography process, [19] used time series to evaluate the effect of the x-rays' increasing trend on the angiography treatment process. Jayakar and Alter [20] collected information about patients who undergo angiography treatment to study the effect of music on reducing angiography patients' anxiety. Azami-Aghdash et al. [21] surveyed customer quality service for cardiovascular patients. A similar study has been made to analyze the angiography process service quality [1]. However, no studies were found regarding the disruptions identification and analysis in the angiography process. Thus, the Analytic Hierarchy Process (AHP) and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methods are combined to propose a new hybrid method, in order to analyze the disruptions in the angiography process in a fuzzy environment. The present study aims to identify and prioritize the disruptions in the angiography process in a Kowsar hospital, Semnan, Iran. This paper's main contributions are as follows:

- Risk analysis in the angiography process is considered for the first time in the literature.
- A total of fifty disruptions which affect the angiography process are defined and ranked.
- A new hybrid method based on FMEA and MCDM under fuzzy environment is proposed in order to prioritize the disruptions in the angiography process.

Methods:

A new method is proposed in order to identify and prioritize the disruptions. The new method was then implemented on a real case in Kowsar hospital's cardiology section in Semnan, Iran. The disruptions in the angiography are determined by the recent studies in the literature and gathering the healthcare experts' opinions.

Then, the decision-makers' opinions regarding the relative importance of the criteria derived from the FMEA method, as well as the importance of each disruption, with respect to each risk factor, are obtained by using several questionnaires. The Fuzzy AHP method is used in order to determine the criteria's relative weights. Afterward, the fuzzy VIKOR method is utilized to rank the disruptions (Figure 1).

The steps required for using the proposed method are explained as follows:

Step I: Identify the disruptions in the angiography process as the FMEA failure modes, using the literature review and the experts' opinions
Step II: Assign weights to the FMEA risk factors, using the fuzzy AHP method.

Step III: Rank the disruptions in the angiography process, using the fuzzy VIKOR method.

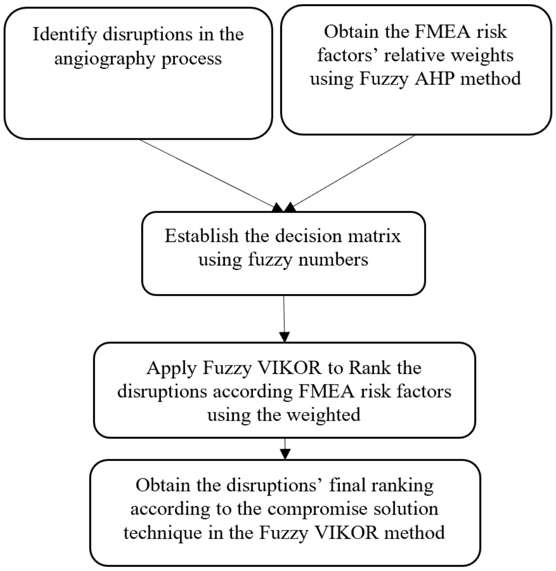

Figure 1. The conceptual model of the research steps

Fuzzy set theory

Fuzzy set theory was first presented by Zadeh [22] to deal with real-world problems in which a source of uncertainty and ambiguity is involved. The fuzzy set theory's main advantage over the conventional set theory is the involvement of vagueness and ambiguity in human reasoning in the decision-making process by converting linguistic variables into fuzzy numbers.

Linguistic variables are usually used when dealing with situations which are too complex to be defined by conventional quantitative expressions. Linguistic variables are expressed by natural or artificial words and sentences so that their values may reflect the approximate characteristics of a phenomenon [23].

Triangular and trapezoidal fuzzy numbers are the most commonly used fuzzy numbers both in theory and practice. However, triangular fuzzy numbers are more popular applications as they are less complex and easier to employ. Therefore, triangular fuzzy numbers are selected for representing the linguistic variables in this study.

FMEA

Failure mode and effects analysis is a useful technique which provides information for risk management decisions. It is intended to distinguish and remove potential failures in order to improve system reliability and safety. To analyze a process, product or a system by using FMEA, a team with different functional expertise is established and all possible potential failure modes are identified in systematic brainstorming sessions. Then, the identified failure modes are critically analyzed according to the three risk factors: occurrence, severity, and detection. FMEA is intended to prioritize the failure modes and find the most serious risk items and assign the limited resources to them [24]. The RPN for each failure mode is calculated by Equation 1. O, S and D represent the occurrence, severity and detection risk factors, respectively.

$$RPN = O \times S \times D \qquad (1)$$

Each risk factor is evaluated by a number in the range of one to ten. A failure mode's RPN indicates the amount of risk for the system. Therefore, failure modes may be ranked by the RPN in a list, in which failure modes with greater risks, have higher ranks the list. Then corrective actions will be preferentially taken. After the corrections, RPNs should be recalculated to check the corrective actions' efficiency for certain risk and to see whether they have gone down the list. [24]. In fuzzy FMEA, the experts rate the risk factors using linguistic terms. Although various techniques such as key performance indicator (KPI), data envelopment analysis (DEA), balance score card (BSC) are proposed for performance evaluation in organizations, but FMEA is a broadly-used risk assessment technique, it has been used by recent studies in healthcare industry. [25]. Successful implementation of FMEA in different industries has drawn researches' attention to applying this method to the healthcare industry in order to improve the healthcare services quality [26]. In this research, the fuzzy FMEA approach is used for risk assessment. The fuzzy FMEA's main advantages comparing the traditional FMEA are listed as follows [27, 28]:

- In Fuzzy FMEA, a combination of input factors is considered; which means that when the combination of O, S and D parameters gives a higher value, then the failure mode has a higher RPN.
- Despite the traditional FMEA, fuzzy FMEA considers the nonlinear interactions of O, S, and D.
- Fuzzy FMEA allows better incorporation of experts' options in the model by using linguistic values. Thus, the failure mode detection process is performed better.
- Fuzzy FMEA shows more flexibility in terms of weighting input variables.
- Fuzz FMEA enables using both quantitative data and vague and qualitative information, thereby increasing flexibility.

Fuzzy AHP

The conventional AHP uses a nine-point scale of exact numbers to capture the expert's knowledge. Thus, the ambiguity in human judgments is not sufficiently reflected by this technique. Therefore, the AHP was developed by using the concept of fuzzy numbers and is more suitable for real-world problems with an uncertain pairwise comparison environment [29]. Several Fuzzy AHP methods are proposed by various artists and they can effectively solve the hierarchical fuzzy problems. In this paper, the relative weights are given to the risk factors using the fuzzy AHP method [12]. Fuzzy AHP was developed to remedy the traditional AHP's shortcomings and increase its efficiency in actual practice[16]. In this study, the fuzzy AHP extent method, introduced by Chang's is utilized for giving weights to the criteria [30]. This method is explained in the following steps:

Step I: Performance comparison

Experts are asked to assign one of the linguistic variables mentioned in Table 1 to each pairwise comparison among all criteria. Given $\tilde{a}_{ij}^k = \left(a_{ij1}^k, a_{ij2}^k, a_{ij3}^k\right)$ $(i = 1,2,\ldots,(n-1), j = 2,3,\ldots,n)$ be the fuzzy relative importance obtained from the k^{th} expert comparing criterion *i* with criterion j, the aggregated fuzzy relative importance is calculated as follows:

$$\tilde{a}_{ij} = \left(a_{ij1}, a_{ij2}, a_{ij3}\right) \quad i = 1,2,\ldots,(n-1), j = 2,3,\ldots,n \tag{2}$$

Where $a_{ij1} = \sum_{k=1}^{k} a_{ij1}^k$, $a_{ij2} = \sum_{k=1}^{k} a_{ij2}^k$, $a_{ij3} = \sum_{k=1}^{k} a_{ij3}^k$,

Table 1: Linguistic variables for rating the risk factor weights

Linguistic variables	Triangular Fuzzy Numbers
Very Low (VL)	(0.4, 0.5, 0.66)
Low (L)	(0.5, 0.66, 1)
Moderately Low (ML)	(0.66, 1, 1)
Equal (E)	(1, 1, 1)
Moderately High (MH)	(1, 1, 1.5)
High (H)	(1, 1.5, 2)
Very High (VH)	(1.5, 2, 2.5)

Step II: Fuzzy pairwise comparison matrix

The aggregated fuzzy relative importance for all pairwise comparisons construct the fuzzy pairwise comparison matrix ($\tilde{A}$), such that

$$\tilde{A} = \begin{bmatrix} \tilde{a}_{11} & \cdots & \tilde{a}_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{\tilde{a}_{1n}} & \cdots & \tilde{a}_{nn} \end{bmatrix} = \begin{bmatrix} 1 & \cdots & \tilde{a}_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{\tilde{a}_{1n}} & \cdots & 1 \end{bmatrix} \tag{3}$$

Step III: Fuzzy synthetic extent value calculation

Calculate the fuzzy synthetic extent value for each row of the matrix $\tilde{A}$. The fuzzy synthetic extent value for the i^{th} criterion is defined as

$$S_i = \sum_{j=1}^{n} \tilde{a}_{ij} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{n} \tilde{a}_{ij}\right]^{-1} \tag{4}$$

To obtain $\sum_{j=1}^{n} \tilde{a}_{ij}$ perform the fuzzy addition operation for the n rows of the matrix $\tilde{A}$. The fuzzy addition for the i^{th} criterion is calculated as follows:

$$\sum_{j=1}^{n} \tilde{a}_{ij} = \left(\sum_{j=1}^{n} a_{ij1}, \sum_{j=1}^{n} a_{ij2}, \sum_{j=1}^{n} a_{ij3}\right) \tag{5}$$

In order to obtain $\left[\sum_{i=1}^{n}\sum_{j=1}^{n} \tilde{a}_{ij}\right]^{-1}$ the fuzzy addition operation for all $\tilde{a}_{ij}$ in the matrix $\tilde{A}$ is inversed as follows:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{n} \tilde{a}_{ij}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij1}}, \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij2}}, \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij3}}\right) \tag{6}$$

Step IV: Fuzzy values Comparison

The possibility degree of $\tilde{a} = (a_1, a_2, a_3) \geq \tilde{b} = (b_1, b_2, b_3)$ is expressed by $V(\tilde{a} \geq \tilde{b})$ and is defined as:

$$V\left(\tilde{a} \geq \tilde{b}\right) = hgt\left(\tilde{a} \cap \tilde{b}\right) = \begin{cases} 1, & \text{if } a_2 \geq b_2 \\ 0, & \text{if } b_3 \geq a_1 \\ \dfrac{b_1 - a_3}{(a_2 - a_3) - (b_2 - b_1)}, & \text{if Otherwise} \end{cases} \tag{7}$$

In order to compare $\tilde{a}$ and $\tilde{b}$, both values of $V\left(\tilde{a} \geq \tilde{b}\right)$ and $V\left(\tilde{b} \geq \tilde{a}\right)$ are required.

Step V: Calculation of priority weights

In order for a convex fuzzy number $\tilde{a}$ to be greater than *k* convex fuzzy numbers $\tilde{a}_i$ *(i=1, 2, 3, …, k)*, the possibility degree is defined as:

$$V(\tilde{a} \geq \tilde{a}_1, \tilde{a}_2, \ldots, \tilde{a}_k) = V[(\tilde{a} \geq \tilde{a}_1 \text{ and } \tilde{a} \geq \tilde{a}_2 \text{ and }, \ldots, \tilde{a} \geq \tilde{a}_k)] = \min V(\tilde{a} \geq \tilde{a}_i), \tag{8}$$

if $m(P_i) = \min V(S_i \geq S_k)$ for *k=1, 2, 3, …, n; k ≠ i.*

Then the weight factor is given by: $W_p = [m(P_1), m(P_2), \dots, m(P_n)]^T$, where P_i *(i=1, 2, …, n)* are n elements.

Step VI: Normalized weight vector calculation

$$W = [W(P_1), W(P_{12}), \dots, W(P_n)]^T, \quad (9)$$

where *W* is a non-fuzzy number.

Fuzzy VIKOR

The fuzzy VIKOR method has been developed in order to deal with decision-making problems in an environment, where both criteria and weights could be defined by fuzzy sets [31]. In this paper, the VIKOR method is used in order to rank the failure modes according to the risk factors [13].

Suppose *K* decision-makers DM_K *(K=1, 2, …, K)* are involved in a MCDM problem and there are *m* alternatives A_i (*i*=1, 2, …, *m*) which are evaluated according to *n* criteria C_j (*j*=1, 2, …, *n*). Then, $\tilde{x}_{ij}^k = (x_{ij1}^k, x_{ij2}^k, x_{ij3}^k)$ is the *i*th alternative fuzzy rating with respect to the *j*th criterion given by the *K*th decision maker. For an alternative A_i, the VIKOR method consists of the following steps:

Step I: Fuzzy decision matrix

First, the experts are asked to rate the failure modes according to the risk factors, using the linguistic variables in Table 2. Then, obtain the alternatives' aggregated fuzzy ratings ($\tilde{x}_{ij}$) with respect to each criterion by aggregating the decision makers' options and construct the fuzzy decision matrix ($\widetilde{D}$) with *m* alternatives and *n* criteria. Each $\tilde{x}_{ij}$ is defined as:

$$\tilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}) \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n, \quad (10)$$

where

$$x_{ij1} = \sum_{k=1}^{k} x_{ij1}^k, \quad x_{ij2} = \sum_{k=1}^{k} x_{ij2}^k, \quad x_{ij3} = \sum_{k=1}^{k} x_{ij3}^k,$$

Table 2: Linguistic variables for rating the failure modes

Linguistic variables	Triangular Fuzzy Numbers
Very Low (VL)	(0, 0, 1)
Low (L)	(0, 1, 1)
Medium (M)	(1, 3, 5)
High (H)	(3, 5, 6)
Very High (VH)	(5, 6, 6)

and the fuzzy decision matrix is expressed ($\widetilde{D}$) by:

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{a}_{1m} & \cdots & \tilde{x}_{mn} \end{bmatrix}, \quad (11)$$

in which $\tilde{x}_{ij}$ indicates the *i*th alternative's rating with respects to the *j*th criteria.

Step II: Calculation of the fuzzy best $\tilde{f}_j^*$ and the worst $\tilde{f}_j^-$ values

$$f_j^* = \begin{Bmatrix} \max_i \tilde{x}_{ij}, & \text{for benefit criteria} \\ \min_i \tilde{x}_{ij}, & \text{for cost criteria} \end{Bmatrix}, \quad i = 1, 2, \dots, m, \quad (12)$$

$$f_j^- = \begin{Bmatrix} \min_i \tilde{x}_{ij}, & \text{for benefit criteria} \\ \max_i \tilde{x}_{ij}, & \text{for cost criteria} \end{Bmatrix}, \quad i = 1, 2, \dots, m, \quad (13)$$

Step III: Defuzzification of the fuzzy variables

Defuzzify the fuzzy best $\tilde{f}_j^*$ and the worst $\tilde{f}_j^-$ values using the BNP method.

Step IV: Calculation of the $\widetilde{S}_i$ and $\widetilde{R}_i$ values

S_i (utility measure) and R_i (regret measure) values are obtained by the following equations:

$$\widetilde{S}_i = \sum_{j=1}^{n} \frac{w_j (f_j^* - \tilde{x}_{ij})}{f_j^* - f_j^-}, \quad (14)$$

$$\widetilde{R}_i = \max_j \left(\frac{w_j (f_j^* - \tilde{x}_{ij})}{f_j^* - f_j^-} \right), \quad (15)$$

where w_j denotes the *j*th criterion's relative importance.

Step V: Determine the $\widetilde{Q}_i$ values

The $\widetilde{Q}_i$ values are computed as:

$$\widetilde{Q}_i = v \frac{\widetilde{S}_i - S^*}{S^* - S^-} + (1 - v) \frac{\widetilde{R}_i - R^*}{R^* - R^-}. \quad (16)$$

where $S^* = \min_i S_i$, $S^- = \max_i S_i$, $R^* = \min_i R_i$, $R^- = \max_i S_i$ and v is defined as a weight for the strategy of maximum group utility and $1 - v$ is the weight if the individual regret and is calculated by the following relation [13]:

$$v = \frac{m + 1}{2m}. \quad (17)$$

The decision-making process may be undergone in one of the following circumstances: 'voting by majority rule' (when $v > 0.5$ is needed), or 'by consensus' (when $v \approx 0.5$), or 'with veto' (when $v < 0.5$).

Step VI: Defuzzify S_i, R_i, and Q_i and sort the alternatives

Defuzzify S_i, R_i, and Q_i using the BNP method and rank the alternatives by sorting *S, R,* and *Q* in decreasing order. As a result, three ranking lists are made.

Step VII: Compromise solution

The alternative $A^{(1)}$ is best ranked by the measure *Q* if the following two conditions are met:

C1. Acceptable advantage: $Q(A^{(2)}) - Q(A^{(1)}) \geq DQ$, where $A^{(2)}$ is the alternative with the second position in the ranking list by *Q* and $DQ = \frac{1}{m-1}$.

C2. Acceptable stability in decision making: The alternative $A^{(1)}$ must also be the best ranked by *S* and/or *R*. This compromise solution is stable within a decision-making process.

If one of the two conditions are not satisfied, then another set of compromise solution is proposed as follows:

- alternatives $A^{(1)}$ or $A^{(2)}$, if only condition C2 is not satisfied, or
- alternatives $A^{(1)}$, $A^{(2)}$, …, $A^{(M)}$ if the condition C1 is not satisfied; $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum M.
- **Results:**
- In this paper, a new method is proposed in order to identify and prioritize the failure modes. The new method is then implemented in a real case in Kowsar hospital's cardiology section in Semnan, Iran. The steps, mentioned in the research methodology, are explained in detail as follows:
-
- *Step I: Identify the disruptions in the angiography process*
- During the six months of this research, the patients who needed angiography treatment were studied from the stage where they entered the cardiology section to where they left it. The expert decision-makers group, consisting of six experts (two heart specialists, two angioplasty fellowships, a Cath lab supervisor and a Cath lab circular), was established in order to determine the potential failure modes in the angiography process (Table 3). A total of fifty failure modes was identified during several sessions, held with the expert group members and using the literature review. The failure modes are depicted in Table 4.
- *Step II. Assign weights using the fuzzy AHP method*

The risk factors' weights were obtained by the fuzzy AHP approach, using the data collected from the experts' opinions regarding the FMEA risk factors' importance. The pairwise comparisons among the risk factors resulted from the fuzzy AHP method are shown in Tables 5 and 6. *Step III. Rank the disruptions in the angiography process*

The failure modes were ranked with respect to the risk factors, using the fuzzy VIKOR method. Failure modes are ranked in VIKOR, based on the Utility measure (S), Regret measure (R) and the VIKOR index (Q). The values S, R and Q were calculated and then sorted in increasing order. The failure modes were ranked according to the questionnaires, answered by the experts. The failure modes' final ranks were determined by the fuzzy VIKOR method. The aggregated scores given to the failure modes according to the three risk factors of O, S, and D are presented in Tables 7-9, respectively. Top ten failure modes are shown in Table 10. As shown in Table 6, the risk factor occurrence has the greatest relative weight value. Hence, the occurrence of failure modes is the most important risk factor in decision making. Furthermore, results shown in Table 10 suggest that 'absence of manual and guideline on angiography procedure' (FM 16) is the most important failure mode with the highest impact on the angiography process. 'Inadequate training of personnel' (FM 11) and 'exhaustion' (FM 21) have the second and the third ranks, respectively.

Table 3: The profile of respondents

	Age	Gender	Experience	Expertise
1	42	Female	12	Angiography specialist
2	48	Female	15	Angiography specialist
3	56	Male	18	Cardiac anesthesia fellowship
4	35	Female	10	Nurse Supervisor
5	47	Male	14	Cardiac surgeon
6	43	Male	13	Cath Lab manager

Table 4: The disruptions in the angiography process, identified as the failure modes in the FMEA method

Failure Modes			
Organizational failure modes	Personnel	FM 1	Delayed patient reception by Cath lab personnel
		FM 2	Medical team members' tardiness
	Human resource shortage	FM 3	Nurse
		FM 4	Staff
		FM 5	Stretcher-bearer
	Communication and teamwork	FM 6	Unrelated conversation
		FM 7	Vocal problems
		FM 8	Using unscientific language
		FM 9	Feeling isolated
		FM 10	Low morale in the medial team
	Education and training	FM 11	Inadequate training of personnel
		FM 12	Lack of knowledge of group activities
	Planning	FM 13	Changes and instability in the angiography procedure
		FM 14	Improper management and lack of coordination between different sections
	Instructions	FM 15	Unclear instructions and organizational tasks
		FM 16	Absence of manual and guideline on angiography procedure
	Medical records	FM 17	Deficiency in medical records
Patient related failure modes		FM 18	Patient's entourage crowding behind the operations room's door and no proper accountability to them
		FM 19	Patient anxiety and disquiet
		FM 20	Insufficient information given to the patient
Individual failure modes		FM 21	Exhaustion
		FM 22	Forgetfulness
		FM 23	Drowsiness
		FM 24	Individual motivation
		FM 25	Individual skills
		FM 26	Work ethic
		FM 27	Pecuniary incentives
		FM 28	Short temper
		FM 29	Excessive confidence
		FM 30	Multi-tasking
Technical failure modes	Facilities	FM 31	Insufficient space in recovery room
		FM 32	Insufficient space in operation room
		FM 33	Insufficient laboratory facilities
		FM 34	Insufficient number of stretchers
	Cath lab	FM 35	Beep sound
		FM 36	Sounds from the control room
		FM 37	Outside noises
		FM 38	Loud music
		FM 39	Unreasonable roaming inside and around Cath lab
		FM 40	Improper temperature
		FM 41	Improper lighting
		FM 42	Improper equipment layout
		FM 43	Equipment failure
		FM 44	Power outage
		FM 45	False settings entered for angiography equipment
		FM 46	Absence of appropriate size of balloon
		FM 47	Absence of appropriate size of balloon stent
		FM 48	Absence of appropriate size of wire
		FM 49	Absence of another angiography equipment
		FM 50	Reporting method

Table 5: Pairwise comparison of Risk Factors

Risk Factor	Occurrence	Severity	Detectability
Occurrence	(1,1,1)	(1,1.134,1.634)	(0.887,1.082,1.512)
Severity	(0.622,0.910,1)	(1,1,1)	(0.670,0.977,1.201)
Detectability	(0.711,1.010,1.226)	(0.899,1.12,1.587)	(1,1,1)

Table 6: Normalized weight of the FMEA risk factors calculated by fuzzy AHP method

Risk Factor	Normalized weight
Occurrence	0.374
Severity	0.283
Detectability	0.342

Table 7: The aggregated scores given to the O factor by the experts

	Fuzzy number of O				Fuzzy number of O		
	a	b	c		a	b	c
FM1	0.675	2.35	4.35	FM26	0.972	1.71	3.03
FM2	0.603	1.74	3.47	FM27	0.836	2.31	4.13
FM3	1.529	3.2	4.78	FM28	1.399	2.89	4.53
FM4	1.315	3.04	4.68	FM29	1.058	2.74	4.55
FM5	1.891	3.57	4.96	FM30	0.662	2.19	4.05
FM6	1.362	3.36	5.18	FM31	2.776	4.6	5.84
FM7	0.449	1.9	3.9	FM32	1.941	3.25	4.48
FM8	1.347	2.66	4.07	FM33	2.4	4.22	5.66
FM9	0.382	1.76	3.76	FM34	3.63	5.25	6.07
FM10	0.402	1.53	3.33	FM35	0.811	2.12	3.81
FM11	2.81	4.54	5.64	FM36	0.812	2.25	4.06
FM12	1.119	2.5	4.17	FM37	0.611	2.03	3.85
FM13	2.615	4.28	5.4	FM38	0.481	1.83	3.69
FM14	1.938	3.74	5.27	FM39	1.71	3.52	5.07
FM15	1.961	3.71	5.1	FM40	1.376	3.38	5.19
FM16	2.088	4.09	5.68	FM41	1.67	3.3	4.87
FM17	1.807	3.33	4.78	FM42	2.122	3.75	5.1
FM18	1.077	2.75	4.55	FM43	2.31	4.13	5.47
FM19	2.901	4.38	5.36	FM44	1.992	3.74	5.25
FM20	1.498	3.09	4.73	FM45	1.082	2.67	4.42
FM21	2.216	4.22	5.61	FM46	2.206	3.77	5.07
FM22	1.399	2.89	4.53	FM47	1.216	2.74	4.42
FM23	0.811	1.94	3.43	FM48	1.404	3.11	4.8
FM24	1.107	2.66	4.3	FM49	1.716	3.46	5.15
FM25	2.549	4.23	5.39	FM50	1.172	2.83	4.58

Table 8: The aggregated scores given to the S factor by the experts

	Fuzzy number of S				Fuzzy number of S		
	a	b	c		a	b	c
FM1	1.81	3.59	5.2	FM26	2.19	3.96	5.39
FM2	1.78	3.15	4.46	FM27	0.39	1.77	3.77
FM3	2.6	4.6	5.94	FM28	0.75	2.13	3.95
FM4	0.82	2.64	4.64	FM29	0.68	1.9	3.72
FM5	1.17	2.99	4.81	FM30	2.03	3.84	5.46
FM6	1.15	2.92	4.74	FM31	2.26	4.06	5.47
FM7	0.59	2.19	4.19	FM32	2.41	4.41	5.84
FM8	1.4	2.98	4.71	FM33	3.35	4.97	5.93
FM9	0.54	1.5	3.09	FM34	2.89	4.69	5.88
FM10	1.6	3.42	5.17	FM35	0.59	2.17	4.17
FM11	4.46	6	6.41	FM36	0.43	1.86	3.86
FM12	2.68	4.62	5.91	FM37	1.45	3.25	5.06
FM13	2.39	4.19	5.49	FM38	1.22	2.8	4.61
FM14	2.86	4.48	5.59	FM39	2.55	4.55	5.91
FM15	2.07	4.01	5.44	FM40	1.49	3.3	5.1
FM16	1.83	3.83	5.41	FM41	2.55	4.55	5.91
FM17	2.03	3.79	5.24	FM42	3.4	5.2	6.14
FM18	1.63	3.44	5.03	FM43	4.78	6.16	6.41
FM19	3.45	5.23	6.14	FM44	4.82	6.19	6.41
FM20	0.77	2.55	4.55	FM45	1.9	3.9	5.45
FM21	2.41	4.41	5.84	FM46	2.86	4.36	5.46
FM22	1.79	3.56	5.19	FM47	3.17	4.91	5.96
FM23	1.79	3.56	5.19	FM48	3.54	5.27	6.14
FM24	1.66	3.59	5.37	FM49	3.54	5.27	6.14
FM25	3.55	5.55	6.41	FM50	0.93	2.73	4.67

Table 9: The aggregated scores given to the D factor by the experts

	Fuzzy number of D				Fuzzy number of D		
	a	b	c		a	b	c
FM1	2.5	4.43	5.68	FM26	1.05	2.6	4.37
FM2	2.87	4.87	6.07	FM27	0.66	1.62	3.19
FM3	2.46	4.28	5.59	FM28	1.63	3.44	5.03
FM4	1.85	3.85	5.43	FM29	1.65	3.65	5.46
FM5	1.85	3.85	5.43	FM30	1.92	3.74	5.33
FM6	0.87	2.46	4.46	FM31	2.46	4.46	5.87
FM7	0.59	2.01	3.82	FM32	1.94	3.75	5.33
FM8	2.07	3.89	5.39	FM33	3.04	5.04	6.16
FM9	0.18	1.14	2.91	FM34	3.72	5.29	6.07
FM10	1.51	3.51	5.26	FM35	1.42	2.97	4.56
FM11	2.54	4.09	5.37	FM36	1.45	3.45	5.23
FM12	2.1	4.03	5.48	FM37	2.1	4.1	5.69
FM13	3.49	5.11	5.86	FM38	2.01	4.01	5.64
FM14	3.04	4.84	5.96	FM39	3.36	5.18	6.14
FM15	2.06	3.81	5.25	FM40	2.18	3.95	5.5
FM16	0.59	2.01	3.82	FM41	2.6	4.6	5.94
FM17	2.4	4.33	5.74	FM42	2.62	4.62	5.95
FM18	2.54	4.31	5.68	FM43	3.85	5.43	6.14
FM19	3.45	5.23	6.14	FM44	3.99	5.49	6.14
FM20	1.79	3.56	5.19	FM45	2.71	4.49	5.77
FM21	2.15	3.74	5.19	FM46	3.45	4.59	5.23
FM22	1.22	2.81	4.63	FM47	3.45	4.77	5.59
FM23	1.81	3.44	5.08	FM48	3.63	5.13	5.96
FM24	0.52	1.81	3.59	FM49	3.63	5.13	5.96
FM25	2.6	4.6	5.94	FM50	1	2.59	4.53

Table 10: values of S, R and Q for the top ten failure modes

Failure mode	S	R	Q	Rank
FM 16	0.209	0.115	0.021	1
FM 11	0.200	0.148	0.056	2
FM 21	0.269	0.131	0.065	3
FM 32	0.320	0.132	0.087	4
FM 15	0.316	0.138	0.093	5
FM 24	0.290	0.157	0.104	6
FM 25	0.261	0.157	0.107	7
FM 22	0.327	0.148	0.109	8
FM 31	0.290	0.164	0.111	9
FM 6	0.314	0.156	0.112	10

Discussion:

In this paper, a new hybrid method based on fuzzy FMEA is presented in order to identify and prioritize the disruptions in the angiography process in the Kowsar hospital, Semnan, Iran. The cardiology section's patients for angiography were studied for six months and a total of fifty failure modes was identified in the process. A fuzzy AHP and fuzzy VIKOR combination is used to evaluate the failure modes in the angiography process using the FMEA method.

Results show that among the three FMEA risk factors, the occurrence of failure modes has the most relative importance. The top three failure modes, ranked by the proposed approach, are 'absence of manual and guideline on angiography procedure', 'inadequate training of personnel' and 'exhaustion', respectively.

The absence of a uniform and clear instruction which explains all procedures needed to be followed in the angiography process and inadequate training of the personnel lead to the personnel's confusion. Therefore, a huge proportion of the staff's time would be wasted on doing unessential or incorrect tasks and this would increase the time spent on each angiography procedure, as well as the patients' waiting time, and reduce the quality of the service they are given. This is exactly what has been observed during the study, and the results of the implemented method also suggest this fact. Exhaustion is another commonly observed failure mode in the angiography process during the study. Several angiography procedures in one working day lead to the personnel's exhaustion which significantly reduces their productivity in doing their tasks.

The rankings were presented to the FMEA team in order to ask their opinion regarding the failure modes, selected as the most important ones. The experts confirmed the failure mode ranking list obtained by the proposed method and the failure modes in the top of the ranking list were verified by the experts as the ones with the most serious impacts on the angiography process. The efficiency and applicability of the proposed method and the rankings are validated by the experts.

The approach proposed in this study is based on the fuzzy FMEA method which is a well-known method and has proved to be useful for risk analysis in different research areas and particularly in healthcare. The three criteria in FMEA method, occurrence, severity, and detectability are suitable for analyzing the disruptions in the angiography process; as any disruption might severely affect the process, despite the number of times they occur during the process. Taking benefit from the fuzzy numbers, this method is also able to deal with the ambiguity and uncertainty in the experts' judgments, leading to more reliable decisions. In order to determine the FMEA criteria's importance, the fuzzy AHP method is selected because it is suitable for dealing with a few numbers of criteria. Also, it performs pairwise comparisons among the criteria which interact which each other. This method simplifies the decision-making process by integrating multiple decision-makers' opinions [32]. Furthermore, since the VIKOR method is suitable for selecting the best alternative among a large number of alternatives; it is selected to be used to determine the most important disruption among all fifty alternatives defined in this study. However, there are some shortcomings regarding using this method in healthcare, which are worth mentioning. For instance, the risk factors in the FMEA method are originated from research areas other than healthcare. Therefore, using risk factors specialized for healthcare industry might be beneficial.

Conclusion:

Regarding the growing number of patients with cardiovascular diseases, which leads to an increasing need for angiography, it is necessary to identify the disruptions in the angiography process and avoid these disruptions, in order to increase the customer satisfaction, as well as the service quality. The results of this research may help hospital managers and practitioners evaluate risk factors during the angiography process and take necessary actions, in advance, to prevent the incidence of disruptions in the process. Although the proposed method in this study is applied in the angiography process in a Kowsar hospital in Iran, it is applicable on other sections and other hospitals to identify the disruptions in other medical services as well. For further research, the method proposed in this paper might be used in order to analyze failure modes in other healthcare areas. Furthermore, other MCDM methods such as TOPSIS, ELECTERE, and Entropy could be utilized to weight the risk factors and prioritize the failure modes.

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