Contemporary Mathematics
https://ojs.wiserpub.com/index.php/CM/

Research Article

Integrated FRAM-FMEA based on PF-CRITIC and PF-WASPAS for Pandemic Disaster Risk Assessment

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Received: 9 June 2025; **Revised:** 1 July 2025; **Accepted:** 18 August 2025

Abstract: The utilization of trustworthy and optimistic risk evaluation methodologies is crucial in the continuously evolving context of global disasters and pandemics. This study has provided a summary of the suggested integrated methodology. The Functional Resonance Analysis Method (FRAM) and Failure Mode (FM) and Effect Analysis are combined in this article to present a novel hybrid approach that is further strengthened by the robustness of the Pythagorean Fuzzy-Criteria Importance Through Intercriteria Correlation (CRITIC) and Pythagorean Fuzzy-Weighted Aggregated Sum Product Assessment (WASPAS) method. In the first stage of the presented model, we determined the weight of the criteria by using Pythagorean Fuzzy Critic. In the second stage, we employed Pythagorean Fuzzy Waspas to rank failure modes. A case study was done to identify and evaluate the processes and hazards connected with fighting the COVID-19 virus in healthcare facilities. The use of this integrated approach in healthcare facilities has shown how effective it is at identifying complex risk variables and assisting in well-informed decision-making. Beyond conventional linear models, this integrated approach provides a comprehensive perspective that enables stakeholders to prioritize risks and put actions into place while having an improved understanding of systemic weaknesses. Considering changing worldwide challenges, this research lays the path for resilient and more adaptable risk management methods.

***Keywords*:** risk assessment, Functional Resonance Analysis Method (FRAM), Failure Mode and Effect Analysis (FMEA), Pythagorean Fuzzy sets, Criteria Importance Through Intercriteria Correlation (CRITIC), Weighted Aggregated Sum Product Assessment (WASPAS)

MSC: 03E72, 68M20, 90B25

1. Introduction

The twenty-first century has been defined by a worldwide health catastrophe of unprecedented scope and complexity: the COVID-19 pandemic. The SARS-CoV-2 virus, initially identified in late 2019 in Wuhan, China, rapidly disseminated globally, compelling health institutions to confront a crisis that adversely affected human lives and strained healthcare systems to their limits [1].

Institutional responses have ranged from mild to severe, addressing a wide range of issues such as emergency planning, patient care, clinical research, medical staff safety, and public health communication. These reactions have been

DOI: https://doi.org/10.37256/cm.6520257406

distinguished by both specific regional idiosyncrasies and collaborative global efforts, altering the pandemic's trajectory in complicated ways [2].

In the battle against the pandemic, health facilities play an active and significant role in the treatment of patients.

Health institutions, including hospitals, research organizations, public health agencies, and non-governmental entities, have become pivotal in combating this elusive adversary. Their contribution to the public health issue, as well as their attempts to increase scientific knowledge of the new coronavirus, is critical to the worldwide response [3].

Decision-making challenges in emergency response are frequently complex due to limited decision data and the possibility of emergency circumstances evolving. Therefore, selecting an effective reaction action at the preceding stage of an emergency is an essential study issue in emergency management [4].

1.1 *Purpose of the study*

The aim of the study is to introduce a novel approach for process-based risk management in disaster scenarios such as pandemics. This study intends to shed light on these health institutions' multifaceted battle against COVID-19, from their first reactions to the unique techniques they employed to the lessons learned in this global health crisis. In this study, FRAM-Failure Mode and Effect Analysis (FMEA) based Pythagorean Fuzzy-Criteria Importance Through Intercriteria Correlation (PF-CRITIC) Importance Through Intercriteria Correlation (CRITIC) & PF-Weighted Aggregated Sum Product Assessment (WASPAS) integrated approach is proposed. Multiple decision-makers can use this novel approach's optimization to reach the best decision. The proposed approach could be applied and developed as a guide for process analysis and risk management in possible disaster scenarios and complex systems.

1.2 *Motivation to study*

Disaster scenarios such as pandemics are becoming more common gradually. For this reason, the significance of risk assessment for disaster scenarios grows increasingly. Therefore, effective risk assessment and management approaches are critical for preventing or mitigating the harmful consequences of potential hazards and risks during a pandemic.

1.3 *Contributions to literature*

This study is, to the best of our knowledge, the first to integrate FRAM and FMEA within a PF-CRITIC & PF-WASPAS framework for pandemic scenarios. By unifying systemic process mapping (FRAM), failure mode diagnosis (FMEA) and fuzzy multi criteria ranking, the proposed model offers a single, coherent pipeline for quantifying and prioritizing complex risk factors in healthcare settings. The resulting strategy supports hospital administrators in designing targeted control actions that simultaneously protect staff, safeguard public health and optimize resource allocation.

2. Methodology

In this study, we presented FRAM and FMEA based a hybrid Critic & Waspas method under Pythagorean Fuzzy Sets environment to assess the risk for disaster scenarios like pandemics. First, the Pythagorean Fuzzy CRITIC method used for weighing the criteria and the second phase the alternatives are ranked by using Pythagorean Fuzzy Waspas method.

Diakoulaki [5] introduced the CRITIC method to quantify the relative importance of decision criteria, irrespective of potential inter criterion correlations. This approach's capacity to be used to both dependent and independent traits is one of its advantages. The benefits of the CRITIC method are numerous and may be summed up as follows. Instead of treating the cost and benefit criteria as distinct entities, the decision matrix is normalized in a way that considers both of their ideal values simultaneously. This method employs the correlation coefficient, derived from the values in the decision matrix, to assess the similarity among the criteria. Haktanir and Kahraman [6] propose that the relative importance of a criterion can be determined by calculating the standard deviation of the normalized values.

Combining the Weighted Product Model and the Weighted Sum Model yields the Weighted Aggregated Sum Product Assessment approach [7]. One of the main advantages of Weighted Sum Model (WSM) method is how easy it is to evaluate various options by using weighted sums. Conversely, Weighted Product Model (WPM) functions as a safeguard against low-value solutions. Utilizing the advantages of both approaches, the WASPAS method combines the WSM and WPM techniques [8]. Moreover, reference [9] reports that the WASPAS methodology has a higher degree of accuracy in comparison to the WPM and WSM methods. In addition, the WASPAS method has a number of benefits. First of all, it offers a series of concise and understandable procedures that make its application easier. Furthermore, it is beneficial for carrying out a thorough rating of options.

Maji et al. [10] presented an intuitionistic fuzzy soft set, however it can't handle situations where a parameter's total value of membership degree and non-membership degree surpasses 1. This restriction restricts the decision-making process and impacts the scope of potential applications. A distinctive version of the intuitionistic fuzzy set, the Pythagorean fuzzy set, is introduced to tackle this issue. This research aims to solve the problem of ambiguity that arises when the sum of the membership and non-membership values surpasses 1. It also makes sure that the values of membership (μ) and non-membership (v) satisfy the constraint $\mu 2 + v2 \leq 1$. By combining the characteristics of the Pythagorean fuzzy set with the parameterization and formal connections proposed by Alcantud [11] for soft sets, which were first presented by Molodtsov [12], Peng et al. [13] developed the idea of the Pythagorean Fuzzy Soft Set (PFSS). Pythagorean Fuzzy Numbers (PFNs) are the term used to refer to the parameters in the PFSS architecture. In this study, PF-CRITIC & PF-WASPAS is presented as a method for ranking and assessing alternative solutions. The proposed method incorporates the benefits of PFSs and integrates an expanded version of the CRITIC and WASPAS methodologies.

2.1 *Functional resonance analysis method*

Erik Hollnagel pioneered the Functional Resonance Analysis Method (FRAM) [14] in 2004. The FRAM was created in reaction to traditional safety analysis methodologies, which were frequently seen as insufficient in dealing with the intricacy and fluidity of current socio-technical systems. FRAM addresses safety from a systemic viewpoint, as opposed to traditional techniques that rely on a linear cause-effect perspective. It is based on the idea that failures in complex systems are caused by complex and unexpected interactions between different system functions rather than individual component failures [15].

A system is viewed as an assemblage of functions that interact with one another in FRAM, rather than as a collection of separate components. Input, Output, Preconditions, Resources, Control, and Time are the six characteristics that describe any function. The system's functional resonance is caused by the dynamic fluctuation in these features [16]. The method has shown to be a reliable and adaptable tool, offering a new viewpoint on system safety and resilience by shifting away from the old cause-effect paradigm and toward a more holistic and realistic view of complex socio-technical systems [17]. FRAM takes a fresh and novel approach to comprehending and managing complex socio-technical systems such as healthcare. FRAM gives essential insights into the factors that drive system safety and performance by concentrating on functional variability and its propensity to induce resonance.

FRAM is implemented in four steps as follows [15]:

Step 1. Defining and characterizing functions

Step 2. Identify performance variability using a checklist characterization.

Step 3. Aggregation of performance variability

Step 4. Identify barriers to variability and identify necessary respond to performance variability.

2.2 *Failure mode and effect analysis*

FMEA is a method for identifying possible failures in a product or process before they occur. It entails mapping out all possible failure modes, determining their impacts, and rating them in terms of severity, occurrence, and detection [17]. A failure mode in FMEA refers to the manner in which a product or process may fail. This may result from design deficiencies, human mistakes, process variability, or other unforeseen factors. The effects of these failures pertain to the potential consequences of these failures [18]. FMEA is an effective tool for problem prevention that integrates seamlessly with diverse engineering and reliability methodologies. FMEA facilitates successful risk management by comprehensively illustrating potential product or process failures and the corresponding planned solutions to these failures [19]. The Risk

Priority Number (RPN) is computed by multiplying the three ratings Severity (S), Occurrence (O), and Detection (D) for each failure mode.

$$\text{RPN} = (\text{Severity}) \times (\text{Occurrence}) \times (\text{Detection})$$

Decision makers assess these three elements on a scale of 1 to 10 based on universally agreed-upon assessment standards. The RPN serves as an indicator of failure risk, enabling the assessment of failures and the prioritization of measures. Actions will be prioritized based on the failure with the highest risk priority number. The following are the conventional FMEA steps:

Step 1. Establish the scale Severity, Occurrence, and Detection Table.

Step 2. Investigates a process's intent, purpose, goal, and objective. The interaction of process flow diagrams identifies it.

Step 3. Identify possible process failures, such as difficulties, concerns, and areas for improvement.

Step 4. Determine the impact of failures on other processes, operations, customers, and government regulations, among other things.

Step 5. Determine the root cause of possible failures.

Step 6. Severity rating: rate the severity of the impact of prospective failures.

Step 7. Occurrence rating: an estimate of the frequency of occurrence for a likely cause of failures.

Step 8. Detection rating: the process control's chance of detecting a specific root cause of a failure.

Step 9. Risk Priority Number calculation: RPN = S × O × D.

2.3 *Background on fuzzy set extensions*

Fuzzy Sets (FS), Intuitionistic Fuzzy Sets (IFS), and Pythagorean Fuzzy Sets (PFS) are successive extensions in fuzzy set theory designed to better model uncertainty and vagueness. Table 1 outlines the characteristics of these three set types.

Table 1. Fundamental Distinctions and Modeling Autonomy

Set type	Membership condition	Modeling autonomy	References
FS	$\mu \in [0, 1]$	Only membership degree; no explicit non-membership	20, 21
IFS	$\mu + \nu \leq 1$	Membership and non-membership, but their sum is limited	21, 22
PFS	$\mu^2 + \nu^2 \leq 1$	Membership and non-membership can both be higher, as long as their squares sum to ≤ 1	21, 22, 23

In fuzzy sets, only the degree of membership is acknowledged, without an explicit value for non-membership [20, 21].

IFS defines both membership (μ) and non-membership (ν) degrees, constraining their sum to a maximum of 1, hence restricting the range of potential values [21, 22].

PFS extends IFS by permitting the sum of the squares of membership and non-membership degrees to total a maximum of 1, rather than only their sum. This indicates that both μ and ν can increase concurrently, offering greater flexibility in modeling scenarios characterized by robust support and opposition [21–23].

PFS can represent uncertainty with greater accuracy and flexibility in real-world contexts, particularly in decision-making and circumstances where IFS is very constraining [22–24].

PFS facilitates enhanced aggregation, ranking, and comparison in multi-attribute decision-making scenarios [22–24].

2.4 *Preliminaries of Pythagorean fuzzy sets*

Intuitionistic fuzzy set, proposed by Atanassov [25], have been employed by academics to address uncertainty [26]. The Pythagorean Fuzzy Set (PFS) is an extension of the conventional fuzzy set, utilized for representing uncertain data during the decision-making process [27]. These sets exhibit greater flexibility than intuitionistic fuzzy set in articulating uncertainty and fuzziness during the MCDM process [28]. Pythagorean fuzzy sets, an extension of intuitionistic fuzzy set, aim to enable decision-makers to circumvent the constraints of membership and non-membership, which must total no more than 1 [29]. For Pythagorean fuzzy sets, the squared sum of membership and non-membership degrees may exceed the unity bound of standard fuzzy sets yet remains limited by $\mu^2 + \nu^2 \leq 1$, extending the flexibility of intuitionistic fuzzy sets [29, 30].

Definition 1 Let X denote a finite, non-empty universe of discourse. Pythagorean fuzzy set $\widetilde{P}$ is an entity characterized by the form [31]:

$$\widetilde{P} \cong \left\{ \left\langle x,\ \mu_{\widetilde{P}}(x),\ \nu_{\widetilde{P}}(x) \right\rangle;\ x \in X \right\} \tag{1}$$

The degree of membership is determined by the function $\mu_{\widetilde{P}}(x) : X \mapsto [0,\ 1]$ and $\nu_{\widetilde{P}}(x) : X \mapsto [0,\ 1]$ expresses the degree of non-membership of the element $x \in X$ to P, respectively and for every $x \in X$, it holds:

$$0 \leq \mu_{\widetilde{A}}(x)^2 + \nu_{\widetilde{A}}(x)^2 \leq 1 \tag{2}$$

The degree of hesitation condition is as follows:

$$\pi_{\widetilde{P}}(x) = \sqrt{1 - \mu_{\widetilde{P}}(x)^2 - \nu_{\widetilde{P}}(x)^2} \tag{3}$$

Definition 2 Let $\widetilde{A} = \langle \mu_1,\ \nu_1 \rangle$, $\widetilde{B} = \langle \mu_2,\ \nu_2 \rangle$ be two PFNs, and $\lambda > 0$, then the definitions of the operations on these two PFNs are as follows [32]:

$$\widetilde{A} \oplus \widetilde{B} = \left(\sqrt{\mu_1^2 + \mu_2^2 - \mu_1^2 \mu_2^2},\ \nu_1 \nu_2 \right) \tag{4}$$

$$\widetilde{A} \otimes \widetilde{B} = \left(\mu_1 \mu_2,\ \sqrt{\nu_1^2 + \nu_2^2 - \nu_1^2 \nu_2^2} \right) \tag{5}$$

$$\lambda \widetilde{A} = \left(\sqrt{1 - (1 - \mu^2)^{\lambda}},\ \nu^{\lambda} \right) \tag{6}$$

$$\widetilde{A}^{\lambda} = \left(\mu^{\lambda},\ \sqrt{1 - (1 - \nu^2)^{\lambda}} \right) \tag{7}$$

Definition 3 Let $\widetilde{A}_i = \langle \mu_i,\ \nu_i \rangle$, $i = (1,\ 2,\ \ldots,\ n)$ be a collection of PFNs and $w = (w_1,\ w_2,\ \ldots,\ w_n)^T$ be the weight vector of $\widetilde{A}_i$, $i = (1,\ 2,\ \ldots,\ n)$ with $\sum_{i=1}^{n} w_i = 1$, then the Pythagorean Fuzzy Weighted Power Geometric (PFWPG) operator is [33]:

$$\text{PFWPG}\left(\widetilde{A}_1,\ \widetilde{A}_2,\ \ldots,\ \widetilde{A}_n \right) = \left(\left(1 - \prod_{i=1}^{n} (1 - \mu_i^2)^{w_i} \right)^{\frac{1}{2}},\ \left(1 - \prod_{i=1}^{n} (1 - \nu_i^2)^{w_i} \right)^{\frac{1}{2}} \right) \tag{8}$$

Definition 4 The Pythagorean Fuzzy Weighted Averaging operator (PFWA) with respect to $w = (w_1, w_2, \ldots, w_n)$; $\sum_{i=1}^{n} w_i = 1$ is defined as follows [33]:

$$\mathrm{PFWA}_w\left(\widetilde{A}_{s1}, \widetilde{A}_{s2}, \ldots, \widetilde{A}_{sn}\right) = w_1\widetilde{A}_{s1} + w_2\widetilde{A}_{s2} + \ldots + w_n\widetilde{A}_{sn} = \left(\left(1 - \prod_{i=1}^{n}(1-\mu_i^2)^{w_i}\right)^{\frac{1}{2}}, \prod_{i=1}^{n} v_i^{w_i}\right) \tag{9}$$

2.5 *The proposed FRAM and FMEA based PF-CRITIC & PF-WASPAS framework*

The presented hybrid methodology, FRAM and FMEA based PF-CRITIC & PF-WASPAS, includes sixteen steps, as demonstrated in Figure 1.

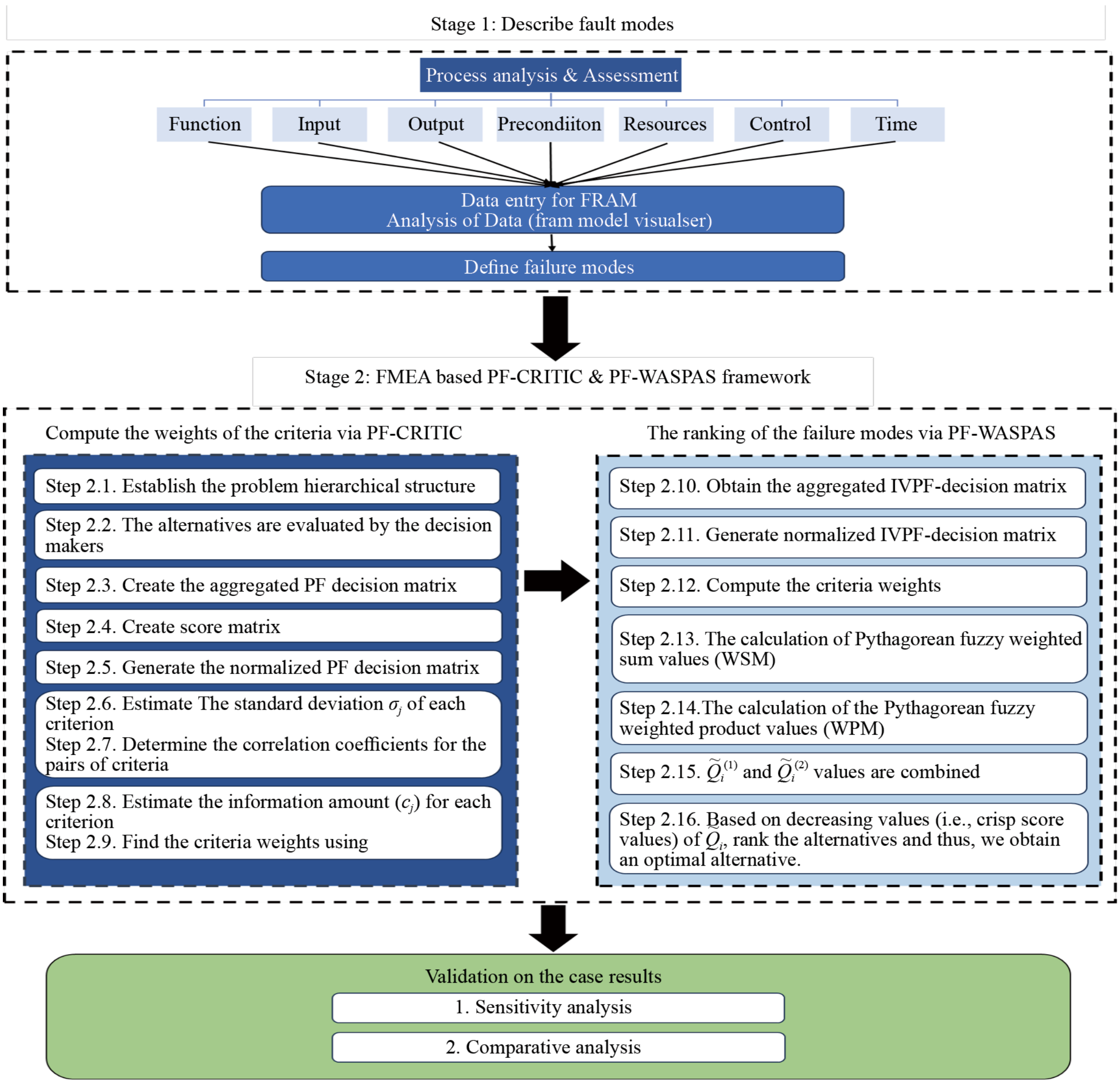

Figure 1. The main structure of the proposed approach

Stage 1. Determine failure modes via FRAM.

Stage 2. FMEA based PF-CRITIC & PF-WASPAS Framework.

Estimate criterion weights via Pythagorean fuzzy CRITIC:

The CRITIC approach was devised to determine the objective weights of criteria by using the standard deviation and correlation coefficient [5]. The implementation of the PF-CRITIC procedure is included in the subsequent references [34–36].

Step 2.1. Establish the hierarchical structure of the problem.

Step 2.2. The decision makers assess alternatives against the criteria using the Pythagorean fuzzy linguistic terms concepts presented in Table 2.

$$\widetilde{D_p} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} C1 & C1 & & Cm \end{array} \\ \begin{bmatrix} \tilde{r}_{11}^P & \tilde{r}_{12}^P & & \tilde{r}_{1m}^P \\ \tilde{r}_{21}^P & \tilde{r}_{22}^P & \cdots & \tilde{r}_{2m}^P \\ \vdots & & \ddots & \vdots \\ \tilde{r}_{n1}^P & \tilde{r}_{n2}^P & \cdots & \tilde{r}_{nm}^P \end{bmatrix} \end{array}, \text{ and} \tag{10}$$

$$\widetilde{W}_P = \left(\widetilde{w}_1^P,\ \widetilde{w}_2^P,\ \cdots,\ \widetilde{w}_m^P\right)$$

where $\widetilde{r}_{ij}^P = (\mu_r,\ v_r)$ is the rating of i^{th} alternative, $i = \{1,\ \ldots,\ N\}$, for the j^{th} criterion, $j = \{1,\ \ldots,\ M\}$, as evaluated by the p^{th} Decision Maker (DM), $p = \{1,\ \ldots,\ P\}$. Additionally, $\widetilde{w}_j^P = (\mu_w,\ v_w)$ is the weight of jth criterion assigned by the pth DM. μ_r and v_r are the membership and non-membership degrees for the ith alternative and jth criterion, in turn.

Table 2. Linguistic scale for PFSs for criteria [37]

Linguistic terms	$(\mu,\ v)$
Very Low (VL)	(0.15, 0.85)
Low (L)	(0.25, 0.75)
Medium Low (ML)	(0.35, 0.65)
Medium (M)	(0.50, 0.45)
Medium High (MH)	(0.65, 0.35)
High (H)	(0.75, 0.25)
Very High (VH)	(0.85, 0.15)

Step 2.3. Create the aggregated PF decision matrix by deploying PFWA operator in Equations (9).

$$\text{PFWA}_w(\widetilde{A}_{s1},\ \widetilde{A}_{s2},\ \ldots,\ \widetilde{A}_{sn}) = \left(\left(1 - \prod_{i=1}^{n}(1-\mu_i^2)^{w_i}\right)^{\frac{1}{2}},\ \prod_{i=1}^{n} v_i^{w_i}\right) \tag{11}$$

Step 2.4. Create score matrix $S = (x_{ij})_{mxn}$ with Equation (12).

$$x_{ij} = \mu_{ij}^2 - v_{ij}^2 \tag{12}$$

Step 2.5. Generate the normalized PF decision matrix $\widetilde{S} = (\widetilde{x}_{ij})_{mxn}$ where

$$\widetilde{x_{ij}^{-}} = \begin{cases} \dfrac{x_{ij} - x_j^-}{x_j^+ - x_j^-}, & j \in \text{benefit} \\ \\ \dfrac{x_j^+ - x_{ij}}{x_j^+ - x_j^-}, & j \in \text{cost} \end{cases} \tag{13}$$

where $x_j^+ = \max_i x_{ij}$ and $x_j^- = \min_i x_{ij}$.

Step 2.6. The standard deviation σ_j for each criterion is estimated as specified in the Equation (14).

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m} (\widetilde{x}_{ij} - \overline{x}_j)^2}{m}}, \quad \text{where} \quad \overline{x}_j = \frac{\sum_{i=1}^{m} \widetilde{x}_{ij}}{m} \tag{14}$$

Step 2.7. Calculate the correlation coefficients for the criterion pairings utilizing Equation (15).

$$r_{jt} = \frac{\sum_{i=1}^{m} (\widetilde{x}_{ij} - \overline{x}_j)(\widetilde{x}_{it} - \overline{x}_t)}{\sqrt{\sum_{i=1}^{m} (\widetilde{x}_{ij} - \overline{x}_j)^2 \sum_{i=1}^{m} (\widetilde{x}_{it} - \overline{x}_t)^2}} \tag{15}$$

Step 2.8. Calculate the information quantity (c_j) for each criterion using the Equation (16).

$$c_j = \sigma_j \sum_{t=1}^{n} (1 - r_{jt}) \tag{16}$$

Step 2.9. Determine the criteria weights utilizing the Equation (17).

$$w_j = \frac{c_j}{\sum_{j=1}^{n} c_j} \tag{17}$$

The Evaluation of the alternatives Using PF-WASPAS:

The WASPAS method introduced by Zavadskas et al. [38]. The Interval-Valued Pythagorean Fuzzy WASPAS (IVPF-WASPAS) integrates Pythagorean fuzzy sets with the WASPAS approach. Decision-makers assess options based on multiple criteria using a linguistic scale. The steps of the IVPF-WASPAS architecture are defined below [39].

Step 2.10. Obtain the aggregated IVPF-decision matrix by using Eq. (18). Decision makers provide their assessments in linguistic form, which are subsequently converted into Interval-Valued Pythagorean Fuzzy Numbers (IVPFNs) according to the scale outlined in Table 3.

Table 3. An IVPFN scale for evaluating options based on criteria [40]

Linguistic terms	μ_L	μ_U	v_L	v_U
Very Very Bad (VVB)	0.03	0.18	0.75	0.90
Very Bad (VB)	0.12	0.27	0.66	0.81
VVB	0.03	0.18	0.75	0.90
Bad (B)	0.21	0.36	0.57	0.72
Medium Bad (MB)	0.30	0.45	0.48	0.63
Fair (F)	0.39	0.54	0.39	0.54
Medium Good (MG)	0.48	0.63	0.30	0.45
Good (G)	0.57	0.72	0.21	0.35
Very Good (VG)	0.66	0.81	0.12	0.27
Very Very Good (VVG)	0.75	0.90	0.03	0.18

Then, Eq. (18) utilizes to aggregate of decision makers judgments.

$$\text{IVPFWA} = \left(\left[\sum_{i=1}^{n} w_i \mu_i^L, \ \sum_{i=1}^{n} w_i \mu_i^U \right], \ \left[\sum_{i=1}^{n} w_i v_i^L, \ \sum_{i=1}^{n} w_i v_i^U \right] \right) \tag{18}$$

Step 2.11. Generate normalized IVPF-decision matrix $\widetilde{S} = (\widetilde{x}_{ij})_{mxn}$ where.

$$\widetilde{r}_{ij} = \begin{cases} \dfrac{\widetilde{x}_{ij}}{\max_i p_{ij}}, & j \in \text{benefit} \\ \\ \dfrac{\min_i p_{ij}}{\widetilde{x}_{ij}}, & j \in \text{cost} \end{cases} \tag{19}$$

Step 2.12. Compute the criteria weights. Criteria weights are obtained in Stage 2 by using PF-CRITIC.

Step 2.13. The computation of Pythagorean fuzzy Weighted Summation Numbers (WSM), $\widetilde{Q}_i^{(1)}$, for each alternative, which as

$$\widetilde{Q}_i^{(1)} = \sum_{j=1}^{n} \widetilde{r}_{ij} \widetilde{w}_{ij} \tag{20}$$

Step 2.14. The calculation of the Pythagorean fuzzy Weighted Product Model (WPM), $\widetilde{Q}_i^{(2)}$, for each alternative, which as

$$\widetilde{Q}_i^{(2)} = \prod_{j=1}^{n} \widetilde{r}_{ij}^{w_j} \tag{21}$$

Step 2.15. $\widetilde{Q}_i^{(1)}$ and $\widetilde{Q}_i^{(2)}$ values are combined through Eqs. (22):

$$\widetilde{Q}_i = \lambda \widetilde{Q}_i^{(1)} + (1-\lambda)\widetilde{Q}_i^{(2)}, \quad \lambda \in [0,\ 1] \tag{22}$$

where λ represents the aggregating coefficient of a decision-making method. The objective was to evaluate the precision of WASPAS based on the accuracy of initial criteria, specifically when $\vartheta \in [0,\ 1]$, where $\vartheta = 0$ and $\vartheta = 1$ correspond to the transformations of WASPAS into WSM and WPM, respectively. The accuracy of the aggregating methods was determined to be more suitable and accurate than that of the individual methods.

Step 2.16. Rank the alternatives based on the decreasing values of $\widetilde{Q}_i$, to identify the ideal alternative.

3. Case study

A case study was conducted in the City Hospital to identify and analyze the processes and hazards associated with fighting the Covid-19 virus in healthcare facilities.

Stage 1. The Functional Resonance Analysis Method given in [15] is used for Step 1, Phase 1 of the suggested comprehensive methodology. The process map impacting the transmission and spread of Covid-19 virus in healthcare infrastructure was obtained by FRAM analysis [41] and shown in Figure 2.

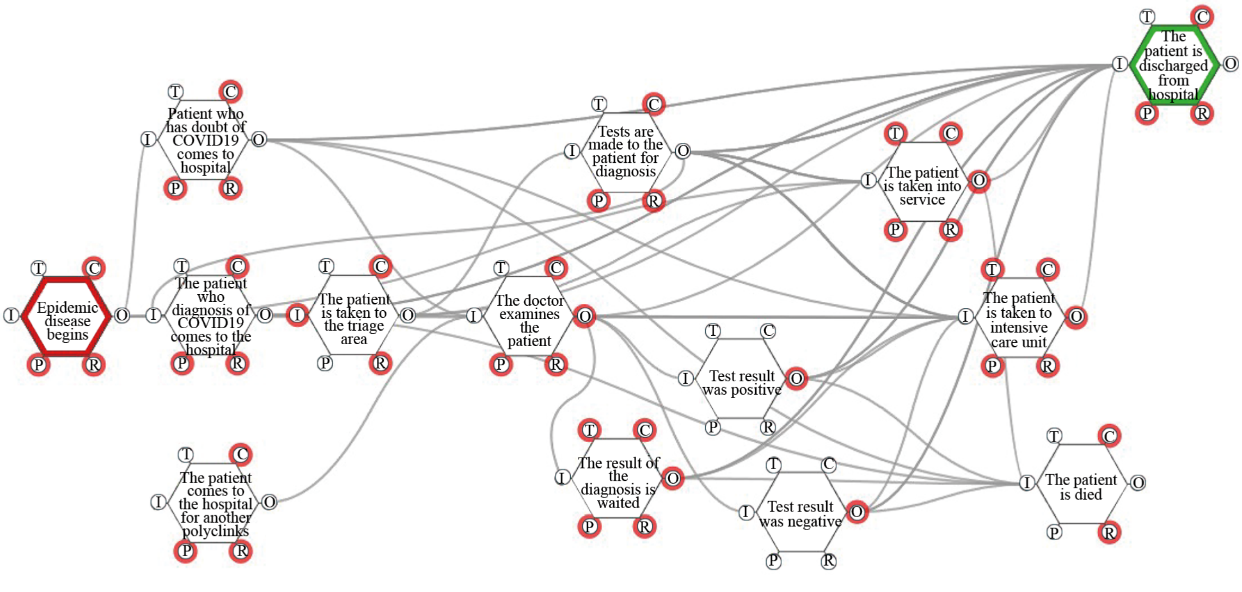

Figure 2. Process map for pandemic management in healthcare institutions [41]

This case study comprises three decision makers and twenty-five failure modes/hazard. Failure modes were identified by brainstorming with healthcare professionals within the context of the interactive process map [41]. Table 4 shows the list of failure modes for Stage 1. DM1, DM2, and DM3 are the designations for these decision makers. Decision makers were formed by the teams of the Triage Department, Public Health Department and Microbiology Department, which have an effective and critical role in healthcare facilities during the pandemic. Each team was moderated by the director of the department and consisted of a specialist doctor and a chief nurse.

Table 4. Description of failure modes

Failure modes	Description of the failure modes/hazard
FM1	Failure to provide HES code control at hospital entrances and exits
FM2	Patients are not wearing masks
FM3	Health workers not wearing masks and personal protective equipment
FM4	Referral of the patient with suspected/carried C-19 to other outpatient clinics and wards
FM5	Lack of separate and special areas and roads for combating the pandemic in the hospital
FM6	Incomplete and inadequate signaling, placards, etc. and guidance in the fight against the pandemic
FM7	Social distancing and non-compliance with hygiene rules
FM8	Failure to provide necessary and sufficient training to healthcare professionals in the fight against the pandemic
FM9	Failure to provide necessary and sufficient PPE to healthcare workers in the fight against the pandemic
FM10	Failure to organize an emergency action plan and work plan in the fight against the pandemic
FM11	Failure to organize accommodation, transportation and food for health workers
FM12	Lack of proper ventilation system
FM13	Uncontrolled discharge of garbage and waste
FM14	The presence of health professionals other than the health personnel in charge in the relevant units
FM15	Insufficient number of test kits and medical supplies
FM16	Failure to store test kits and materials under appropriate conditions and in isolation
FM17	Failure to ensure follow-up, control and coordination of the tested patient by the filiation team
FM18	Lack of sufficient capacity of services
FM19	Emergency services do not have sufficient capacity
FM20	Failure to follow the instructions and rules for the acceptance of patient companions and visitors
FM21	Discharging the patient/patients without reporting and recording
FM22	If the patient has passed away, not to be taken to the mortuary within the instructions and rules
FM23	Failure of mortuary workers to wear masks and personal protective equipment
FM24	Failure of the patient's relatives to comply with the instructions and rules for burial and burial procedures
FM25	All health personnel working in the fight against the pandemic are not subject to regular testing

All failure modes were identified through expert brainstorming; Refer to Table 4 for specifics.

Ethical approval was granted by the Istanbul Medeniyet University Science and Engineering Research and Publication Ethics Committee under decision number 2022/02.

Stage 2: FMEA based PF-CRITIC & PF-WASPAS Framework.

Estimate criterion weights via Pythagorean fuzzy CRITIC:

Step 2.1. Establish the problem hierarchical structure. The list of failure modes/hazard are given in Table 4, whereas Figure 3 demonstrates the hierarchical structure consists of three criteria and 25 failure modes/hazard.

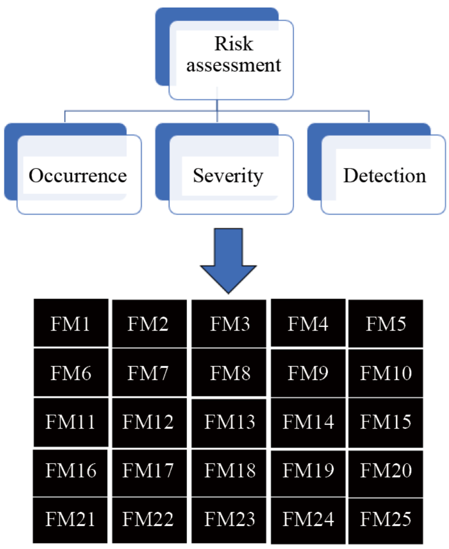

Figure 3. Hierarchical structure of the risk assessment for disaster scenarios like pandemic

Step 2.2. The Failure Modes are evaluated as given Table 5 by the three decision makers with respect to the Pythagorean fuzzy linguistic terms as given in Table 2.

Table 5. Evaluation ratings of alternatives of three DMs via Pythagorean fuzzy linguistic terms

	Occurrence	Severity	Detection
FM1	(VL, L, VL)	(H, H, VH)	(L, L, L)
FM2	(VL, L, L)	(VH, H, H)	(ML, ML, L)
FM3	(VL, VL, VL)	(VH, H, VH)	(L, L, VL)
FM4	(H, MH, M)	(H, H, H)	(ML, ML, L)
FM5	(VL, VL, VL)	(VH, H, H)	(VL, VL, L)
FM6	(VL, VL, VL)	(VH, H, H)	(VL, VL, L)
FM7	(ML, M, ML)	(H, H, H)	(L, L, ML)
FM8	(VL, VL, VL)	(VH, H, H)	(VL, VL, VL)
FM9	(VL, VL, VL)	(VH, H, H)	(VL, VL, VL)
FM10	(ML, L, ML)	(VH, H, H)	(VL, VL, L)
FM11	(ML, M, M)	(MH, H, H)	(ML, L, L)
FM12	(ML, L, ML)	(H, H, H)	(L, M, ML)
FM13	(VL, ML, MH)	(VH, M, MH)	(ML, ML, ML)
FM14	(ML, M, ML)	(ML, ML, ML)	(MH, M, ML)
FM15	(VL, L, L)	(H, H, VH)	(VL, VL, L)
FM16	(VL, ML, L)	(VH, H, VH)	(VL, VL, VL)
FM17	(L, ML, L)	(VH, VH, VH)	(L, L, L)
FM18	(MH, MH, MH)	(H, VH, H)	(L, VL, VL)
FM19	(MH, MH, MH)	(VH, VH, VH)	(VL, VL, VL)
FM20	(MH, MH, M)	(H, H, MH)	(L, ML, L)
FM21	(VL, VL, VL)	(VH, VH, VH)	(VL, VL, VL)
FM22	(VL, VL, VL)	(VH, H, H)	(VL, VL, L)
FM23	(VL, VL, VL)	(VH, H, H)	(VL, VL, L)
FM24	(M, M, M)	(M, MH, H)	(ML, ML, L)
FM25	(VL, VL, VL)	(H, H, VH)	(VL, L, L)

Table 6. Evaluation ratings of alternatives of three DMs

	Occurrence						Severity						Detection					
	DM1		DM2		DM3		DM1		DM2		DM3		DM1		DM2		DM3	
FM1	0.15	0.85	0.25	0.75	0.15	0.85	0.75	0.25	0.75	0.25	0.85	0.15	0.25	0.75	0.25	0.75	0.25	0.75
FM2	0.15	0.85	0.25	0.75	0.25	0.75	0.85	0.15	0.75	0.25	0.75	0.25	0.35	0.65	0.35	0.65	0.25	0.75
FM3	0.15	0.85	0.15	0.85	0.15	0.85	0.85	0.15	0.75	0.25	0.85	0.15	0.25	0.75	0.25	0.75	0.15	0.85
FM4	0.75	0.25	0.65	0.35	0.5	0.45	0.75	0.25	0.75	0.25	0.75	0.25	0.35	0.65	0.35	0.65	0.25	0.75
FM5	0.15	0.85	0.15	0.85	0.15	0.85	0.85	0.15	0.75	0.25	0.75	0.25	0.15	0.85	0.15	0.85	0.25	0.75
FM6	0.15	0.85	0.15	0.85	0.15	0.85	0.85	0.15	0.75	0.25	0.75	0.25	0.15	0.85	0.15	0.85	0.25	0.75
FM7	0.35	0.65	0.5	0.45	0.35	0.65	0.75	0.25	0.75	0.25	0.75	0.25	0.25	0.75	0.25	0.75	0.35	0.65
FM8	0.15	0.85	0.15	0.85	0.15	0.85	0.85	0.15	0.75	0.25	0.75	0.25	0.15	0.85	0.15	0.85	0.15	0.85
FM9	0.15	0.85	0.15	0.85	0.15	0.85	0.85	0.15	0.75	0.25	0.75	0.25	0.15	0.85	0.15	0.85	0.15	0.85
FM10	0.35	0.65	0.25	0.75	0.35	0.65	0.85	0.15	0.85	0.15	0.85	0.15	0.15	0.85	0.15	0.85	0.25	0.75
FM11	0.5	0.45	0.5	0.45	0.5	0.45	0.65	0.35	0.75	0.25	0.75	0.25	0.35	0.65	0.25	0.75	0.25	0.75
FM12	0.5	0.45	0.25	0.75	0.35	0.65	0.75	0.25	0.75	0.25	0.75	0.25	0.25	0.75	0.5	0.45	0.35	0.65
FM13	0.15	0.85	0.35	0.65	0.35	0.65	0.85	0.15	0.5	0.45	0.65	0.35	0.35	0.65	0.35	0.65	0.35	0.65
FM14	0.5	0.45	0.5	0.45	0.35	0.65	0.35	0.65	0.35	0.65	0.35	0.65	0.65	0.35	0.5	0.45	0.35	0.65
FM15	0.15	0.85	0.25	0.75	0.25	0.75	0.75	0.25	0.75	0.25	0.85	0.15	0.15	0.85	0.15	0.85	0.25	0.75
FM16	0.15	0.85	0.15	0.85	0.25	0.75	0.85	0.15	0.75	0.25	0.85	0.15	0.15	0.85	0.15	0.85	0.15	0.85
FM17	0.25	0.75	0.35	0.65	0.25	0.75	0.85	0.15	0.85	0.15	0.85	0.15	0.25	0.75	0.25	0.75	0.25	0.75
FM18	0.65	0.35	0.65	0.35	0.65	0.35	0.75	0.25	0.85	0.15	0.75	0.25	0.25	0.75	0.15	0.85	0.15	0.85
FM19	0.65	0.35	0.65	0.35	0.65	0.35	0.85	0.15	0.85	0.15	0.85	0.15	0.15	0.85	0.15	0.85	0.15	0.85
FM20	0.65	0.35	0.65	0.35	0.5	0.45	0.75	0.25	0.75	0.25	0.65	0.35	0.25	0.75	0.35	0.65	0.25	0.75
FM21	0.15	0.85	0.15	0.85	0.15	0.85	0.85	0.15	0.85	0.15	0.85	0.15	0.15	0.85	0.15	0.85	0.15	0.85
FM22	0.15	0.85	0.15	0.85	0.15	0.85	0.85	0.15	0.75	0.25	0.75	0.25	0.15	0.85	0.15	0.85	0.25	0.75
FM23	0.15	0.85	0.15	0.85	0.15	0.85	0.85	0.15	0.75	0.25	0.75	0.25	0.15	0.85	0.15	0.85	0.25	0.75
FM24	0.5	0.45	0.5	0.45	0.5	0.45	0.5	0.45	0.65	0.35	0.75	0.25	0.35	0.65	0.35	0.65	0.25	0.75
FM25	0.15	0.85	0.15	0.85	0.15	0.85	0.75	0.25	0.75	0.25	0.85	0.15	0.15	0.85	0.25	0.75	0.25	0.75

Step 2.3. We obtain the aggregated PF decision matrix by utilizing PFWA operator in Equations (9) as given in Table 8. In risk assessment, varying weights are assigned for every decider. The decision makers are assigned using the computing approach described in [42]. Each decision maker is assigned a weight ($w_{dm} > 0$ and $\sum w_{dm} = 1$). The weights allocated are 0.4, 0.3, and 0.3, respectively. Table 7 shows the list of decision makers consulted for the study.

Table 7. The list of decision makers consulted for the study

	Experience (degree)	Position
DM 1	4	Triage department
DM 2	3	Public health department
DM 3	3	Microbiology department

Table 8. The consolidated PF decision matrix

	Occurrence		Severity		Detection	
	u	*v*	*u*	*v*	*u*	*v*
FM1	0.175	0.819	0.779	0.214	0.250	0.750
FM2	0.204	0.789	0.789	0.204	0.316	0.679
FM3	0.150	0.850	0.819	0.175	0.214	0.779
FM4	0.636	0.330	0.750	0.250	0.316	0.679
FM5	0.150	0.850	0.789	0.204	0.175	0.819
FM6	0.150	0.850	0.789	0.204	0.175	0.819
FM7	0.390	0.582	0.750	0.250	0.277	0.718
FM8	0.150	0.850	0.789	0.204	0.150	0.850
FM9	0.150	0.850	0.789	0.204	0.150	0.850
FM10	0.316	0.679	0.850	0.150	0.175	0.819
FM11	0.500	0.450	0.708	0.286	0.286	0.708
FM12	0.365	0.586	0.750	0.250	0.340	0.616
FM13	0.249	0.724	0.669	0.269	0.350	0.650
FM14	0.449	0.502	0.350	0.650	0.499	0.454
FM15	0.204	0.789	0.779	0.214	0.175	0.819
FM16	0.175	0.819	0.819	0.175	0.150	0.850
FM17	0.277	0.718	0.850	0.150	0.250	0.750
FM18	0.650	0.350	0.779	0.214	0.184	0.808
FM19	0.650	0.350	0.850	0.150	0.150	0.850
FM20	0.601	0.377	0.718	0.277	0.277	0.718
FM21	0.150	0.850	0.850	0.150	0.150	0.850
FM22	0.150	0.850	0.789	0.204	0.175	0.819
FM23	0.150	0.850	0.789	0.204	0.175	0.819
FM24	0.500	0.450	0.611	0.350	0.316	0.679
FM25	0.150	0.850	0.779	0.214	0.204	0.789

Step 2.4-2.5. The Score matrix and standard decision matrix are computed using Eq. (12) and Eq. (13).

Step 2.6-2.9. Furthermore, using equations (14)-(16), the Standard Deviation (SD) Correlation Coefficient(r) (CRC) and amount of information of each challenge are estimated. Lastly, criteria weights are computed using Eq. (17) and shown in Table 9.

Table 9. The standard PF-matrix SD, criteria weights

	Occurrence	Severity	Detection
FM1	0.0302	0.8163	0.2032
FM2	0.0665	0.8407	0.3787
FM3	0.0000	0.9173	0.1279
FM4	0.9701	0.7462	0.3787
FM5	0.0000	0.8407	0.0481
FM6	0.0000	0.8407	0.0481
FM7	0.3853	0.7462	0.2724
FM8	0.0000	0.8407	0.0000
FM9	0.0000	0.8407	0.0000
FM10	0.2377	1.0000	0.0481
FM11	0.6314	0.6505	0.2974
FM12	0.3474	0.7462	0.4765
FM13	0.1398	0.5731	0.4714
FM14	0.5176	0.0000	1.0000
FM15	0.0665	0.8163	0.0481
FM16	0.0302	0.9173	0.0000
FM17	0.1710	1.0000	0.2032
FM18	1.0000	0.8163	0.0662
FM19	1.0000	1.0000	0.0000
FM20	0.8713	0.6735	0.2724
FM21	0.0000	1.0000	0.0000
FM22	0.0000	0.8407	0.0481
FM23	0.0000	0.8407	0.0481
FM24	0.6314	0.4508	0.3787
FM25	0.0000	0.8163	0.1060
σ_j	0.3542	0.2053	0.2259
C_j	0.7001	0.6478	0.5747
W_j	0.3641	0.3369	0.2989

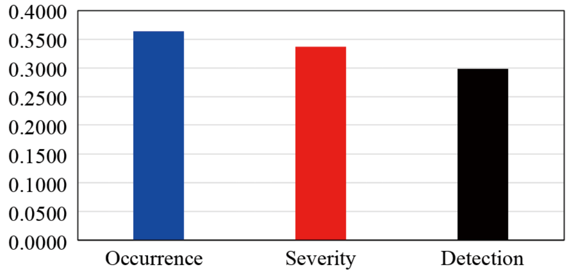

Figure 4. Weights of criteria using the PF-CRITIC technique

From Table 9 and Figure 4, while Occurrence is the most significant factor with a weight of 0.3641, severity is the second significant factor with a weight of 0.3369. And detection is the third significant factor with a weight of 0.2989.

The Evaluation of the alternatives Using PF-WASPAS:

Step 2.10. Linguistic The language assessments of the decision-makers were converted into interval-valued Pythagorean fuzzy numbers according to the scale specified in Table 3. The aggregated IVPF-decision matrix is calculated using Eq. (18), as seen in Table 10.

Step 2.11. Generate normalized IVPF-decision matrix by using Eq. (19) as Table 11.

Table 10. The aggregated pairwise evaluation matrix for main criteria

	Occurrence				Severity				Detection			
	ML	MU	VL	VU	ML	MU	VL	VU	ML	MU	VL	VU
FM1	0.153	0.300	0.632	0.782	0.600	0.751	0.178	0.324	0.210	0.360	0.570	0.720
FM2	0.180	0.328	0.604	0.755	0.610	0.761	0.168	0.315	0.277	0.426	0.505	0.656
FM3	0.120	0.270	0.660	0.810	0.636	0.787	0.142	0.292	0.188	0.336	0.596	0.746
FM4	0.498	0.649	0.281	0.430	0.570	0.720	0.210	0.350	0.277	0.426	0.505	0.656
FM5	0.120	0.270	0.660	0.810	0.610	0.761	0.168	0.315	0.153	0.300	0.632	0.782
FM6	0.120	0.270	0.660	0.810	0.610	0.761	0.168	0.315	0.153	0.300	0.632	0.782
FM7	0.330	0.480	0.451	0.602	0.570	0.720	0.210	0.350	0.241	0.390	0.541	0.692
FM8	0.120	0.270	0.660	0.810	0.610	0.761	0.168	0.315	0.120	0.270	0.660	0.810
FM9	0.120	0.270	0.660	0.810	0.610	0.761	0.168	0.315	0.120	0.270	0.660	0.810
FM10	0.277	0.426	0.505	0.656	0.610	0.761	0.168	0.315	0.153	0.300	0.632	0.782
FM11	0.357	0.507	0.424	0.574	0.537	0.688	0.242	0.387	0.250	0.399	0.532	0.683
FM12	0.277	0.426	0.505	0.656	0.570	0.720	0.210	0.350	0.302	0.450	0.483	0.635
FM13	0.326	0.470	0.474	0.630	0.548	0.703	0.225	0.387	0.300	0.450	0.480	0.630
FM14	0.330	0.480	0.451	0.602	0.300	0.450	0.480	0.630	0.408	0.558	0.374	0.526
FM15	0.180	0.328	0.604	0.755	0.600	0.751	0.178	0.324	0.153	0.300	0.632	0.782
FM16	0.216	0.361	0.574	0.725	0.636	0.787	0.142	0.292	0.120	0.270	0.660	0.810
FM17	0.241	0.390	0.541	0.692	0.660	0.810	0.120	0.270	0.210	0.360	0.570	0.720
FM18	0.480	0.630	0.300	0.450	0.600	0.751	0.178	0.324	0.162	0.310	0.622	0.773
FM19	0.480	0.630	0.300	0.450	0.660	0.810	0.120	0.270	0.120	0.270	0.660	0.810
FM20	0.456	0.606	0.325	0.475	0.546	0.696	0.234	0.377	0.241	0.390	0.541	0.692
FM21	0.120	0.270	0.660	0.810	0.660	0.810	0.120	0.270	0.120	0.270	0.660	0.810
FM22	0.120	0.270	0.660	0.810	0.610	0.761	0.168	0.315	0.153	0.300	0.632	0.782
FM23	0.120	0.270	0.660	0.810	0.610	0.761	0.168	0.315	0.153	0.300	0.632	0.782
FM24	0.390	0.540	0.390	0.540	0.480	0.631	0.299	0.449	0.277	0.426	0.505	0.656
FM25	0.120	0.270	0.660	0.810	0.600	0.751	0.178	0.324	0.180	0.328	0.604	0.755

Table 11. Normalized IVPF-decision matrix

	Occurrence				Severity				Detection			
	ML	MU	VL	VU	ML	MU	VL	VU	ML	MU	VL	VU
FM1	0.119	0.235	0.759	0.863	0.532	0.680	0.354	0.508	0.152	0.264	0.713	0.821
FM2	0.140	0.257	0.739	0.844	0.541	0.690	0.342	0.500	0.202	0.315	0.664	0.776
FM3	0.093	0.211	0.779	0.881	0.566	0.717	0.310	0.477	0.136	0.246	0.733	0.839
FM4	0.397	0.529	0.467	0.602	0.504	0.648	0.392	0.532	0.202	0.315	0.664	0.776
FM5	0.093	0.211	0.779	0.881	0.541	0.690	0.342	0.500	0.111	0.219	0.759	0.863
FM6	0.093	0.211	0.779	0.881	0.541	0.690	0.342	0.500	0.111	0.219	0.759	0.863
FM7	0.259	0.381	0.620	0.737	0.504	0.648	0.392	0.532	0.175	0.287	0.692	0.801
FM8	0.093	0.211	0.779	0.881	0.541	0.690	0.342	0.500	0.087	0.197	0.779	0.881
FM9	0.093	0.211	0.779	0.881	0.541	0.690	0.342	0.500	0.087	0.197	0.779	0.881
FM10	0.216	0.336	0.664	0.776	0.541	0.690	0.342	0.500	0.111	0.219	0.759	0.863
FM11	0.281	0.404	0.597	0.717	0.474	0.616	0.427	0.565	0.182	0.294	0.685	0.795
FM12	0.216	0.336	0.664	0.776	0.504	0.648	0.392	0.532	0.221	0.334	0.646	0.761
FM13	0.256	0.373	0.638	0.757	0.483	0.631	0.408	0.566	0.219	0.334	0.643	0.758
FM14	0.259	0.381	0.620	0.737	0.261	0.394	0.643	0.758	0.301	0.421	0.554	0.680
FM15	0.140	0.257	0.739	0.844	0.532	0.680	0.354	0.508	0.111	0.219	0.759	0.863
FM16	0.168	0.284	0.717	0.824	0.566	0.717	0.310	0.477	0.087	0.197	0.779	0.881
FM17	0.188	0.307	0.692	0.801	0.589	0.741	0.280	0.455	0.152	0.264	0.713	0.821
FM18	0.382	0.512	0.485	0.619	0.532	0.680	0.354	0.508	0.118	0.226	0.752	0.857
FM19	0.382	0.512	0.485	0.619	0.589	0.741	0.280	0.455	0.087	0.197	0.779	0.881
FM20	0.361	0.490	0.509	0.640	0.481	0.625	0.418	0.557	0.175	0.287	0.692	0.801
FM21	0.093	0.211	0.779	0.881	0.589	0.741	0.280	0.455	0.087	0.197	0.779	0.881
FM22	0.093	0.211	0.779	0.881	0.541	0.690	0.342	0.500	0.111	0.219	0.759	0.863
FM23	0.093	0.211	0.779	0.881	0.541	0.690	0.342	0.500	0.111	0.219	0.759	0.863
FM24	0.307	0.432	0.568	0.691	0.422	0.562	0.485	0.618	0.202	0.315	0.664	0.776
FM25	0.093	0.211	0.779	0.881	0.532	0.680	0.354	0.508	0.130	0.240	0.739	0.844

Step 2.12. Calculate the criteria weights. Criteria weights are derived in stage 2 by the application of PF-CRITIC.

Step 2.13. The computation of Pythagorean fuzzy Weighted Summation Numbers (WSM), $\widetilde{Q}_i^{(1)}$, for each alternative, as in Table 12.

Step 2.14. The computation of the Pythagorean fuzzy weighted results (WPM), $\widetilde{Q}_i^{(2)}$, for each alternative, as in Table 13.

Table 12. Pythagorean fuzzy weighted sum values

	Occurrence				Severity				Detection			
	ML	MU	VL	VU	ML	MU	VL	VU	ML	MU	VL	VU
FM1	0.072	0.143	0.904	0.948	0.326	0.434	0.705	0.796	0.084	0.146	0.904	0.943
FM2	0.085	0.157	0.896	0.940	0.332	0.442	0.697	0.792	0.111	0.175	0.885	0.927
FM3	0.056	0.128	0.913	0.955	0.349	0.464	0.674	0.779	0.075	0.136	0.911	0.949
FM4	0.246	0.336	0.758	0.831	0.307	0.410	0.729	0.809	0.111	0.175	0.885	0.927
FM5	0.056	0.128	0.913	0.955	0.332	0.442	0.697	0.792	0.061	0.121	0.921	0.957
FM6	0.056	0.128	0.913	0.955	0.332	0.442	0.697	0.792	0.061	0.121	0.921	0.957
FM7	0.158	0.236	0.840	0.895	0.307	0.410	0.729	0.809	0.096	0.159	0.896	0.936
FM8	0.056	0.128	0.913	0.955	0.332	0.442	0.697	0.792	0.048	0.108	0.928	0.963
FM9	0.056	0.128	0.913	0.955	0.332	0.442	0.697	0.792	0.048	0.108	0.928	0.963
FM10	0.131	0.207	0.861	0.912	0.332	0.442	0.697	0.792	0.061	0.121	0.921	0.957
FM11	0.172	0.251	0.829	0.886	0.286	0.386	0.751	0.825	0.100	0.163	0.893	0.934
FM12	0.131	0.207	0.861	0.912	0.307	0.410	0.729	0.809	0.122	0.186	0.878	0.922
FM13	0.156	0.231	0.849	0.904	0.293	0.397	0.739	0.825	0.121	0.186	0.877	0.920
FM14	0.158	0.236	0.840	0.895	0.153	0.235	0.862	0.911	0.167	0.238	0.838	0.891
FM15	0.085	0.157	0.896	0.940	0.326	0.434	0.705	0.796	0.061	0.121	0.921	0.957
FM16	0.102	0.174	0.886	0.932	0.349	0.464	0.674	0.779	0.048	0.108	0.928	0.963
FM17	0.114	0.188	0.874	0.923	0.366	0.485	0.651	0.767	0.084	0.146	0.904	0.943
FM18	0.236	0.324	0.769	0.840	0.326	0.434	0.705	0.796	0.064	0.125	0.918	0.955
FM19	0.236	0.324	0.769	0.840	0.366	0.485	0.651	0.767	0.048	0.108	0.928	0.963
FM20	0.223	0.309	0.782	0.850	0.292	0.392	0.745	0.821	0.096	0.159	0.896	0.936
FM21	0.056	0.128	0.913	0.955	0.366	0.485	0.651	0.767	0.048	0.108	0.928	0.963
FM22	0.056	0.128	0.913	0.955	0.332	0.442	0.697	0.792	0.061	0.121	0.921	0.957
FM23	0.056	0.128	0.913	0.955	0.332	0.442	0.697	0.792	0.061	0.121	0.921	0.957
FM24	0.188	0.269	0.814	0.874	0.253	0.346	0.783	0.850	0.111	0.175	0.885	0.927
FM25	0.056	0.128	0.913	0.955	0.326	0.434	0.705	0.796	0.071	0.132	0.914	0.951

Table 13. Pythagorean fuzzy weighted product model (WPM)

	Occurrence				Severity				Detection			
	ML	MU	VL	VU	ML	MU	VL	VU	ML	MU	VL	VU
FM1	0.460	0.590	0.518	0.625	0.809	0.878	0.210	0.309	0.570	0.672	0.438	0.534
FM2	0.488	0.610	0.500	0.604	0.813	0.882	0.203	0.304	0.619	0.708	0.399	0.491
FM3	0.421	0.567	0.537	0.648	0.826	0.894	0.183	0.289	0.551	0.658	0.453	0.552
FM4	0.714	0.793	0.293	0.389	0.794	0.864	0.234	0.326	0.619	0.708	0.399	0.491
FM5	0.421	0.567	0.537	0.648	0.813	0.882	0.203	0.304	0.518	0.635	0.476	0.578
FM6	0.421	0.567	0.537	0.648	0.813	0.882	0.203	0.304	0.518	0.635	0.476	0.578
FM7	0.611	0.704	0.402	0.498	0.794	0.864	0.234	0.326	0.594	0.689	0.421	0.514
FM8	0.421	0.567	0.537	0.648	0.813	0.882	0.203	0.304	0.482	0.615	0.494	0.601
FM9	0.421	0.567	0.537	0.648	0.813	0.882	0.203	0.304	0.482	0.615	0.494	0.601
FM10	0.572	0.673	0.437	0.534	0.813	0.882	0.203	0.304	0.518	0.635	0.476	0.578
FM11	0.630	0.719	0.385	0.480	0.777	0.850	0.256	0.349	0.601	0.694	0.415	0.508
FM12	0.572	0.673	0.437	0.534	0.794	0.864	0.234	0.326	0.637	0.720	0.386	0.477
FM13	0.609	0.699	0.416	0.517	0.783	0.856	0.244	0.349	0.635	0.720	0.384	0.475
FM14	0.611	0.704	0.402	0.498	0.636	0.731	0.406	0.500	0.699	0.772	0.322	0.411
FM15	0.488	0.610	0.500	0.604	0.809	0.878	0.210	0.309	0.518	0.635	0.476	0.578
FM16	0.522	0.632	0.480	0.583	0.826	0.894	0.183	0.289	0.482	0.615	0.494	0.601
FM17	0.544	0.651	0.459	0.559	0.837	0.904	0.165	0.274	0.570	0.672	0.438	0.534
FM18	0.704	0.784	0.305	0.402	0.809	0.878	0.210	0.309	0.527	0.641	0.470	0.572
FM19	0.704	0.784	0.305	0.402	0.837	0.904	0.165	0.274	0.482	0.615	0.494	0.601
FM20	0.690	0.771	0.321	0.418	0.782	0.853	0.250	0.343	0.594	0.689	0.421	0.514
FM21	0.421	0.567	0.537	0.648	0.837	0.904	0.165	0.274	0.482	0.615	0.494	0.601
FM22	0.421	0.567	0.537	0.648	0.813	0.882	0.203	0.304	0.518	0.635	0.476	0.578
FM23	0.421	0.567	0.537	0.648	0.813	0.882	0.203	0.304	0.518	0.635	0.476	0.578
FM24	0.651	0.737	0.364	0.459	0.747	0.823	0.294	0.387	0.619	0.708	0.399	0.491
FM25	0.421	0.567	0.537	0.648	0.809	0.878	0.210	0.309	0.544	0.652	0.459	0.558

Step 2.15-2.16. $\widetilde{Q}_i^{(1)}$ and $\widetilde{Q}_i^{(2)}$ values are combined through Eqs. (22). The alternatives are ranked based on the decreasing amounts of $\widetilde{Q}_i$, and an optimal alternative is subsequently obtained.

Table 14. Final score and rank of each failure mode

Alternatifler	SCORE $(\widetilde{Q}_i)$	RANK
FM1	0.37346	15
FM2	0.39926	11
FM3	0.37244	16
FM4	0.47556	1
FM5	0.35404	20
FM6	0.35404	21
FM7	0.41923	7
FM8	0.34658	24
FM9	0.34658	25
FM10	0.39754	12
FM11	0.41759	9
FM12	0.41788	8
FM13	0.42236	5
FM14	0.37376	14
FM15	0.36748	17
FM16	0.38240	13
FM17	0.42186	6
FM18	0.45140	3
FM19	0.46132	2
FM20	0.44614	4
FM21	0.36647	18
FM22	0.35404	22
FM23	0.35404	23
FM24	0.41451	10
FM25	0.35673	19

According to Figure 5, the most three important failure modes FM4 (Referral of the patient with suspected/carried C-19 to other outpatient clinics and wards) (0.47556), FM18 (Lack of sufficient capacity of services) (0.45140), and FM19 (Emergency services do not have sufficient capacity) (0.46132).

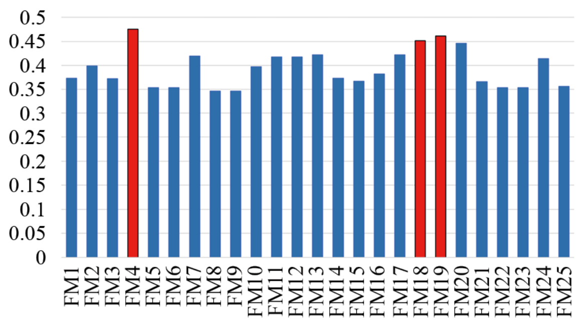

Figure 5. Final score of each failure mode

3.1 *The validation test*

In this section, a validation test was conducted, which encompassed sensitivity analysis and comparative analysis of the presented framework.

3.1.1 *Sensitivity analysis*

This section presents a sensitivity analysis to assess the robustness of the proposed methodology in response to variations. In order to analyze the impact of criterion weights on the ranking process, we incorporated the S, O, and D weights from three relevant publications in the literature that conducted risk assessments similar to our own study, as illustrated in Table 15.

Table 15. The cases for Weight of risk parameters

Cases	Risk parameters		
	S	O	P
This study	0.337	0.364	0.299
Case 1: Zhao et al. [43]	0.274	0.400	0.326
Case 2: Fattahi [44]	0.387	0.330	0.283
Case 3: Mete [45]	0.440	0.378	0.182

These weights are deployed in PF-WASPAS process to rank failure modes. The findings are presented in Table 16 and Figure 6.

Table 16. Ranking orders of the RPN

Failure mode	Our Study		Case 1		Case 2		Case 3	
	Ranking	SCORE $\left(\tilde{Q}_i\right)$	Ranking	SCORE $\left(\tilde{Q}_i\right)$	Ranking	SCORE $\left(\tilde{Q}_i\right)$	Ranking	SCORE $\left(\tilde{Q}_i\right)$
FM1	0.37346	15	0.40322	15	0.36725	15	0.38209	15
FM2	0.39926	11	0.42889	10	0.39292	12	0.40608	12
FM3	0.37244	16	0.40525	14	0.36580	16	0.38431	14
FM4	0.47556	1	0.48327	1	0.47388	1	0.47759	1
FM5	0.35404	20	0.38513	19	0.34774	20	0.36527	19
FM6	0.35404	21	0.38513	20	0.34774	21	0.36527	20
FM7	0.41923	7	0.43742	8	0.41531	7	0.42364	6
FM8	0.34658	24	0.37716	24	0.34047	24	0.35869	23
FM9	0.34658	25	0.37716	25	0.34047	25	0.35869	24
FM10	0.39754	12	0.41990	12	0.39314	11	0.40782	11
FM11	0.41759	9	0.43239	9	0.41425	8	0.41925	9
FM12	0.41788	8	0.44009	7	0.41287	9	0.42038	8
FM13	0.42236	5	0.44090	6	0.41806	5	0.42306	7
FM14	0.37376	14	0.37908	23	0.37072	14	0.35198	25
FM15	0.36748	17	0.39493	17	0.36191	17	0.37775	17
FM16	0.38240	13	0.40925	13	0.37719	13	0.39558	13
FM17	0.42186	6	0.44968	5	0.41632	6	0.43379	5
FM18	0.45140	3	0.46092	3	0.44981	3	0.45941	3
FM19	0.46132	2	0.47374	2	0.45945	2	0.47431	2
FM20	0.44614	4	0.45495	4	0.44420	4	0.44808	4
FM21	0.36647	18	0.39930	16	0.36007	18	0.38160	16
FM22	0.35404	22	0.38513	21	0.34774	22	0.36527	21
FM23	0.35404	23	0.38513	22	0.34774	23	0.36527	22
FM24	0.41451	10	0.42428	11	0.41192	10	0.41109	10
FM25	0.35673	19	0.38776	18	0.35035	19	0.36658	18

Table 16 demonstrates that the most serious four failure modes in all cases are FM4 (Referral of the patient with suspected/carried C-19 to other outpatient clinics and wards), FM19 (Emergency services do not have sufficient capacity), FM18 (Lack of sufficient capacity of services), and FM20 (Failure to follow the instructions and rules for the acceptance of patient companions and visitors).

According to different cases in terms of the weights as shown in Figure 6, Hence, the ranks of all cases are stable. The ranking orders of dangers in the current study are largely consistent with those in other cases, exhibiting only minor variations and no significant deviations. The sensitivity analysis results demonstrate the model's considerable robustness and reliability.

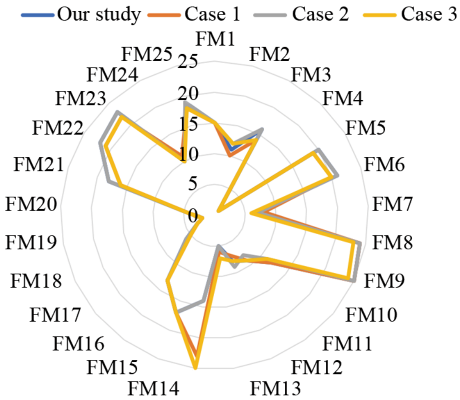

Figure 6. Ranking orders and Qa values of hazards for different cases

Secondly, we applied an algorithm suggested Görçün et al. [46] because the advantage of this approach is that it examines the effects of the change in all criteria weights respectively and can capture all possible conditions concerning of detecting the change in the ranking results. Hundred additional criterion importance scenarios were simulated by reducing the importance of the most significant criterion (criteria C) by a rate of 1% while altering the relevance of the other two criteria. New criteria values are computed for each case by applying Eqs. (23)-(25), accordingly.

$$w_{nv} = w_{pv} - (w_{pv} \cdot \%\alpha_v) \tag{23}$$

$$w'_{nv} = \frac{(1 - w_{nv})}{m-1} + w'_{pv} \tag{24}$$

$$w_{nv} + \sum w'_{nv} = 1 \tag{25}$$

Here, w_{nv} represents the new value of the changed weight of the jth factor w_{pv} denotes the previous amounts of the criterion, and $\%\alpha_v$ represents the proportional variation in weight. In addition, w'_{nv} represents the novel amounts of the residual criteria, m represents the number of factors, and w'_{pv} represents the previous values of the remaining criteria. We calculated novel criterion weights for each scenario using Equations (23)-(25) and determined the current ranking performances of the possible workplace risks for each scenario. The effect of variations in criterion importance on the results (Figures 6-7).

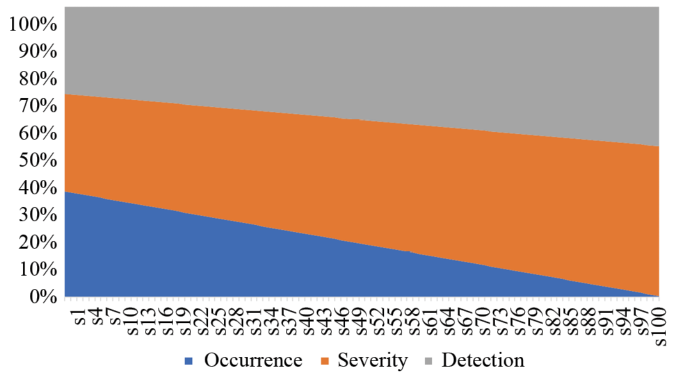

Figure 7. The simulated criteria importance scenarios

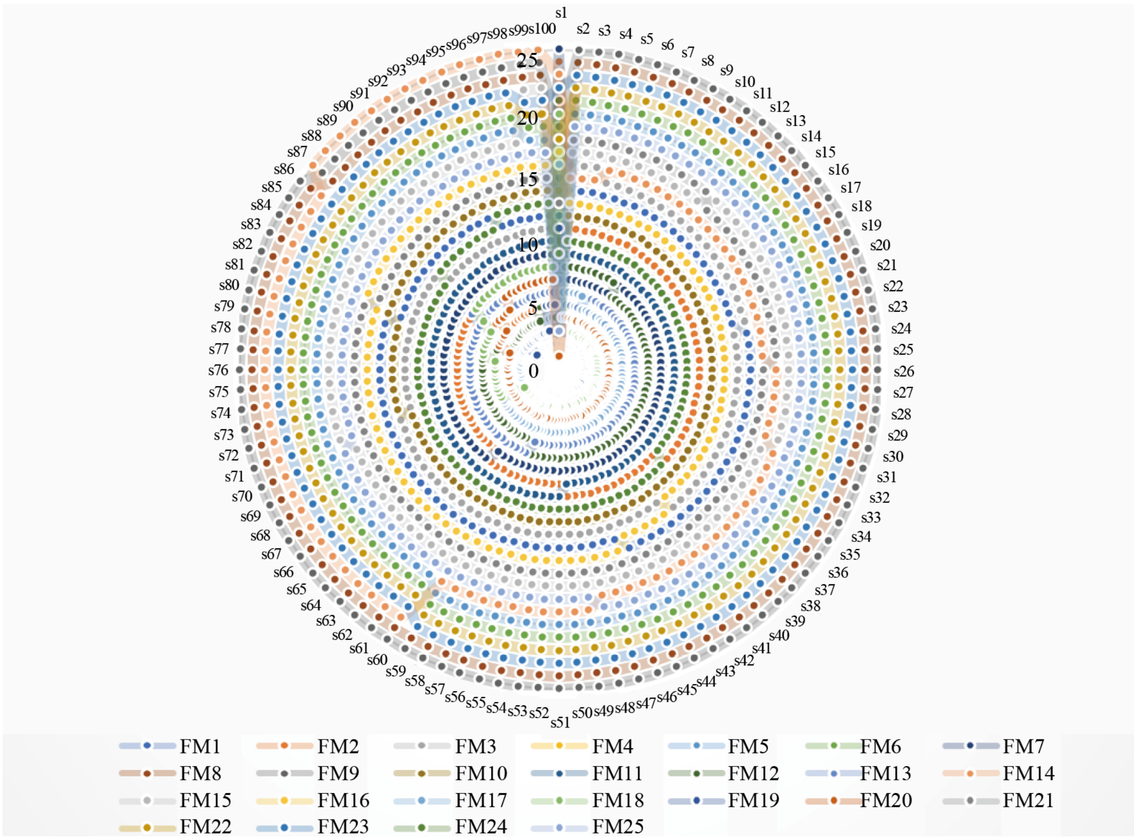

Figure 8. Impact of alterations in FMEA risk parameter weights on the ranking efficacy of risks across 100 scenarios

Evaluation of the findings depicted in Figure 8 reveals that variations in the weight value of the criterion do not influence the robustness and consistency of the proposed model.

3.1.2 *Comparative analysis*

This section presents a comparison investigation to validate the efficacy and robustness of the PF-CRITIC and PF-WASPAS models. To achieve this objective, we compared the Single-Valued Fuzzy CRITIC (SF-CRITIC) and Single-Valued Fuzzy VIKOR (SF-VIKOR) methods with the PF-CRITIC and PF-WASPAS methods to elucidate the impact of the ranking methodology on the scores of the alternatives. From Table 17, it is apparent that the ranking orders obtained by these two methods slightly differ. Using the presented PF-CRITIC & PF-WASPAS and SF-CRITIC & SF-VIKOR methods, the first Failure Mode (FM4) is the same.

Table 17. Comparison of combinations of different ranking methods

	PF-CRITIC & PF-WASPAS		PF-CRITIC & PF-VIKOR	
FM	SCORE	RANK	SCORE	RANK
FM1	0.373	15	0.744	15
FM2	0.399	11	0.594	12
FM3	0.372	16	0.877	17
FM4	0.476	1	0.0	1
FM5	0.354	20	0.940	20
FM6	0.354	21	0.940	20
FM7	0.419	7	0.251	6
FM8	0.347	24	1.0	22
FM9	0.347	25	0.969	21
FM10	0.398	12	0.521	11
FM11	0.418	9	0.228	5
FM12	0.418	8	0.159	3
FM13	0.422	5	0.431	10
FM14	0.374	14	0.660	13
FM15	0.367	17	0.714	14
FM16	0.382	13	0.841	16
FM17	0.422	6	0.393	8
FM18	0.451	3	0.365	7
FM19	0.461	2	0.418	9
FM20	0.446	4	0.128	2
FM21	0.366	18	0.913	19
FM22	0.354	22	0.940	20
FM23	0.354	23	0.940	20
FM24	0.415	10	0.227	4
FM25	0.357	19	0.903	18

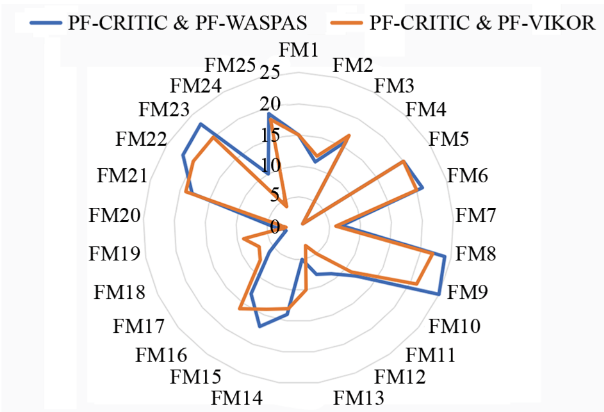

Figure 9. Evaluation of outcomes using various ranking methodologies

Multiple analysis and methodologies have been used to compare and validate the novel integrated approach that has been proposed. As illustrated in Table 17 and Figure 9, there is no dramatic difference in ranking and scores as a result of the compared methods. The outcomes are very constant and identical.

A secondary comparison study is conducted with regards to the methodology employed for assigning weights. In order to achieve this objective, we utilized the PF-AHP approach to ascertain the weights of the criteria. The outcomes of the PF-AHP method were employed to prioritize the failure modes in the PF-WASPAS method. Thus, in this study, we conducted a comparison between the PF-AHP & PF-WASPAS and PF-CRITIC & PF-WASPAS methodologies to investigate the impact of the chosen weight determination method on the obtained findings. As can be seen from Table 18 and Figure 10, the ranking orders obtained by these two methods differ slightly. Using the presented PF-WASPAS & PF-CRITIC and PF-WASPAS & PF-AHP methods, the first four failure mode (FM4) is the same; FM4, FM19, FM18, FM20, respectively.

Table 18. Analysis of various combinations of ranking methodologies

	PF-CRITIC & PF-WASPAS		PF-CRITIC & PF-VIKOR	
FM	SCORE	RANK	SCORE	RANK
FM1	0.373	15	0.389	15
FM2	0.399	11	0.413	12
FM3	0.372	16	0.390	14
FM4	0.476	1	0.493	1
FM5	0.354	20	0.372	19
FM6	0.354	21	0.372	20
FM7	0.419	7	0.436	6
FM8	0.347	24	0.367	24
FM9	0.347	25	0.367	25
FM10	0.398	12	0.420	11
FM11	0.418	9	0.433	8
FM12	0.418	8	0.431	9
FM13	0.422	5	0.435	7
FM14	0.374	14	0.372	23
FM15	0.367	17	0.387	17
FM16	0.382	13	0.406	13
FM17	0.422	6	0.442	5
FM18	0.451	3	0.477	3
FM19	0.461	2	0.493	2
FM20	0.446	4	0.464	4
FM21	0.366	18	0.388	16
FM22	0.354	22	0.372	21
FM23	0.354	23	0.372	22
FM24	0.415	10	0.427	10
FM25	0.357	19	0.373	18

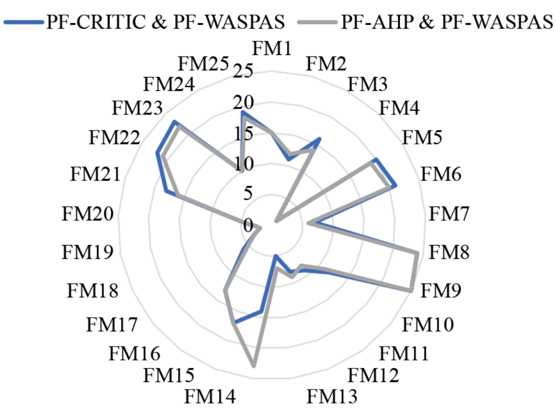

Figure 10. Comparison of outcomes using various ranking methodologies

4. Managerial implications

The findings of the proposed integrated approach show that while FM4 is the riskiest hazard, FM19 and FM18 are the second and third riskiest hazards. However, the lowest risk is likewise identified as FM9, whereas FM8 and FM23 are the second and third lowest risk hazards respectively.

These findings indicate that the riskiest hazard to identify in healthcare facilities is when a patient suspected of having Covid-19 leaves one ward and enters another. The precondition, input, output, and control parameters of FM4 are connected to FM1, FM5, and FM6 in the interactive process map created using FRAM. The risk of FM4 will be decreased by the actions taken for FM5 and FM6.

On the other hand, the finding that FM9 and FM8 posed the lowest risks indicates that healthcare professionals had received necessary and sufficient PPE and the essential and enough training to combat the pandemic.

The proposed integrated approach optimizes the risk priority number, which is significant for control and preventative strategies. As a result of this prioritization, control and precautionary activities are determined. For instance, to reduce and control the impact of FM4; "Disaster and outbreak management scenario and agencies are established. Signaling and direction indicators offer guidance. The healthcare facilities offer the pandemic of separate dedicated places, roadways, services, and equipment. It makes use of entrance-exit zones, floor layout, roadways, lifts, etc. that are isolated and segregated from other units".

Current pandemic-risk research generally employs only one of the three methodologies outlined in our framework: FRAM for system-level variability mapping [41–47], FMEA for prospective failure-mode assessment [48], or fuzzy MCDM ranking devoid of a systemic phase [49, 50].

No prior research has concurrently integrated FRAM and FMEA into a PF-CRITIC and PF-WASPAS weighted and ranking framework. Our study provides a comprehensive decision support system for risk analysis and assessment that:

• Provides comprehensive process analysis and identifies emergent functional couplings (FRAM),

• Assesses failure modes/hazards using Risk Priority Numbers (FMEA), and

• Optimizes the resolution of profound uncertainties using Pythagorean memberships (PF-CRITIC → PF-WASPAS) in the computation of risk scores, ranks, and priority for the decision support system.

This approach allows decision-makers to see the system, quantify uncertainty, and respond based on a clear, data-driven hierarchy of risks.

The approach has been compared and validated with multiple analyses and methods. The consistency of the findings is tested by simulating 100 different scenarios. The findings indicate that the suggested novel strategy is highly resilient and consistent. Sensitivity and comparative studies are provided to illustrate the effectiveness of the proposed integrated method of FMEA-FRAM-based PF-CRITIC and PF-WASPAS. When the results of all models are examined, it is discovered that there are extremely little rank differences between them.

For disaster scenarios such as pandemics and complex systems, the suggested model offers a novel and multidimensional optimistic approach to risk assessment.

5. Conclusion

The proposed integrated approach has been outlined in this study. A novel approach for risk assessment FRAM-FMEA based PF-CRITIC & PF-WASPAS integrated method is presented in this research.

FRAM is an effective method for comprehending and examining a system's processes and the connections between those activities. FRAM enables critical paths to be found by examining the interrelationship and holistic interaction of processes.

In decision-making, particularly with several criteria, methodical evaluation methods are essential. Two such methodologies, CRITIC and WASPAS, offer unique pathways to make sense of complex decision-making scenarios. The PF-CRITIC & PF-WASPAS is used to optimize decision makers' assessments to establish the risk priority in FMEA analysis. With the suggested integrated approach, effective control and preventative actions may be identified as a consequence of risk prioritization to lessen the effects of risks.

Multiple-criteria decision methods like PF-CRITIC and PF-WASPAS showcase the diversity of tools available to decision-makers. Their unique methodologies and applications ensure that they remain valuable, especially in an era of increasing data and decision complexity.

During disaster scenarios like pandemics, this strategy was utilized to prioritize hazards and their related processes for healthcare institutions. This study demonstrates the viability of the proposed integrated approach for a variety of complex systems and demonstrates its applicability to disaster scenarios like pandemic.

Epidemics are anticipated to be unavoidable in our daily existence in many ways in the future. As a result, it is vital to regulate these hazards and maintain safe circumstances. Future studies could be expanded to include FMEA-FRAM-based PF-CRITIC & PF-WASPAS implementation.

Conflict of interest

The authors declare no competing financial interest.

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