Journal of Advanced Research in Computing and Applications 40, Issue 1 (2025) 322-338

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Journal of Advanced Research in Computing and Applications

Journal homepage:
https://karyailham.com.my/index.php/arca/index
ISSN: 2462-1927

Risk Assessment Fuzzy-FMEA for the Prevention and Control of COVID-19 at Sarawak Longhouses

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ARTICLE INFO

Article history:
Received 20 October 2025
Received in revised form 25 November 2025
Accepted 3 December 2025
Available online 10 December 2025

Keywords:
COVID-19; FMEA; artificial intelligence; multi-criteria decision making; Mathematical programming; integrated approach

ABSTRACT

The COVID-19 outbreak causes great concern due to the high rates of infection and the large number of deaths worldwide. This paper presents a risk assessment Fuzzy-FMEA for the prevention and control of COVID-19 at Sarawak longhouses. The paper also provides a comprehensive review study on the transmission potentials, effects, and causes of COVID-19, which emphasize Artificial Intelligence (AI), Multi-Criteria Decision Making (MCDM), integrated approaches, and mathematical programming with Failure Mode and Effect Analysis (FMEA). The spreading of COVID-19 can be controlled and prevented by implementing the FMEA method by considering each failure mode's severity, occurrence, and detection rating via the Risk Priority Number (RPN) value. However, FMEA alone cannot provide a precise risk evaluation as the generated RPN might be unreliable in real-life applications. Recent research shows that the limitation of conventional FMEA can be tackled by aggregating it with other approaches. In conclusion, FMEA with a combination of fuzzy methods is a great integration in order to conduct a risk assessment to prevent and control infectious diseases, which in this paper is focused on COVID-19 incidences.

1. Introduction

Severe acute respiratory syndrome coronavirus (SARS-CoV-2) is a new RNA coronavirus from the same family as SARS-CoV discovered on 31st December 2019 and caused a pneumonia outbreak in Wuhan, Hubei Province's capital, China [1]. The most common symptoms of COVID-19 are fever and dry cough, with most patients showing bilateral pneumonia [2]. In addition, the severity of COVID-19 can be divided into three levels; mild, severe, and critical. Usually, patients will experience mild symptoms and then recover. However, there are cases where mild symptoms may further develop into critical, leading to fatalities. Although significant public health efforts in early detection, such as isolation, quarantine, treatment, contact tracing, and social-distancing measures to break the chain

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https://doi.org/10.37934/arca.40.1.322338

of transmission, the disease still persists, resulting in subsequent waves and the emergence of clusters [3]. This happened especially before the vaccination period. Due to this fact, there is a need to formulate a transmission-based risk analysis for the prevention and control of COVID-19 and other future infectious diseases.

With regard to this, the chain of infection model is adopted to explain the transmission of an infectious disease. A thorough understanding of the infection chain is crucial, as breaking a link anywhere along the chain can stop the transmission of the infectious agent. On the other hand, in conjunction with risk research, the recent trend focuses on the development of systematic methods and procedures for routinized risk analysis and risk management.

Therefore, the main objective of this paper is to present a risk assessment Fuzzy-FMEA for the prevention and control of COVID-19 at Sarawak longhouses, as well as a comprehensive review of various significant engineering risk tools known as Failure Mode Effect Analysis (FMEA) associated with Artificial Intelligence (AI), Multi-Criteria Decision Making (MCDM), integrated approaches, and mathematical programming for prevention and control of the spreading of COVID-19. Numerous research, both in China and globally, have provided predictions of the COVID-19 outbreak using various computer intelligence simulations [4–6]. However, previous studies mostly focused on compartmental models, such as the Susceptible-Exposed-Infectious-Recovered (SEIR) model, which was mainly beneficial in estimating disease dynamics and projecting future cases [7,8].

The breadth and depth of knowledge regarding COVID-19 and the enhancement of FMEA techniques are discussed in this paper. The basics of COVID-19 and different types of Coronaviruses are then discussed in Section 2, while risk analysis evaluation using conventional FMEA techniques is presented in Section III. The reliability improvement of FMEA using various computational tools is presented in Section IV. Finally, Section V summarises the conclusion and scope of future work.

2. FMEA to Control COVID-19

FMEA is a proactive qualitative and systematic risk analysis that identifies and classifies all possible problems (failure mode) and their consequences (effects analysis) in order to ensure the reliability and repeatability of a product or process [9]. In general, it is an analysis tool for the early detection of possible failures, and the data is used for continuous quality improvement. FMEA is commonly associated with hardware and processes. However, it can be applied to software analysis when examining the failure of a software function. While these methods originated in the manufacturing industry to identify and eliminate potential defects of a product, they are now utilized in both healthcare and industry [10].

In terms of the safety and health sector, FMEA has been applied to the emergency department of St. Paul's Hospital Millenium Medical College (SPHMMC) located on Swaziland St, Addis Ababa, Ethiopia. The primary goal is to pinpoint common failure modes, their potential causes, and the resulting effects on health services, all aimed at mitigating the transmission of COVID-19 originating from asymptomatic patients [11]. Teklewold *et al.*, [11] revealed a total of 22 failure modes, along with 89 associated causes and effects. Many of these failure modes are linked to the absence of or failure to adhere to standard transmission-based precautions, non-compliance, and the absence of a monitoring mechanism for precaution compliance, which contributed to the spread of SARS-CoV-2 (RPN=112) [11]. As an initial step in the FMEA process, a dedicated team of experts was assembled to systematically outline the infectious/transmission risk of SARS-CoV-2 [12]. Subsequently, the RPN was computed for each identified risk, taking into account its severity (S), occurrence (O), and detection (D), following the methodology outlined by Tay *et al.,* [13]:

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

Where S (severity) is the measure of the impacts of a failure, O (occurrence) is the likelihood of the failure mode and cause to take place, and D (detection) is the ability to identify potential failure causes before they appear, RPN (risk priority number) is the product of S, O, and D [11]. The maximum RPN that could be generated from the combination of S, O, and D was 125 (5 × 5 × 5), depending on the number of linguistic variables required. The higher the RPN value, the higher the priority should be given to the potential failure. First, the problems and their root causes are identified to reduce medical errors, then analyzed, and subsequently notified to the system to prevent future occurrences [10]. The steps involved in an FMEA process are depicted in Fig. 1. These steps are further explained as follows [13]:

i. Set the scale table for severity, occurrence, and detection.
ii. The intent, purpose, goal, and objective of a product or process are studied. These aspects are typically identified through an analysis of the process flow diagram, followed by a task analysis.
iii. Determine the possible failure of a product or process that includes problems, concerns, and enhancement opportunities.
iv. Describe the consequences of those potential failures to the following processes, design, system performance, and government regulations.
v. Discover what may be the source of these potential failure modes.
vi. List the existing and proposed methods or procedures for detecting and preventing product or process problems.
vii. Severity ranking: Using qualitative rankings, evaluate the hazard degree (severity) of the likely failure event.
viii. Occurrence ranking: Based on reliable statistics, determine the frequency of the potential failure mode.
ix. Detection ranking: Determine the efficiency of the process control to highlight a specific root cause of a potential failure mode.
x. Calculate the RPN value by multiplying three inputs rating of severity, occurrence, and detection.
xi. Identify if the correction is needed.
xii. If no correction is needed, the process is ended.

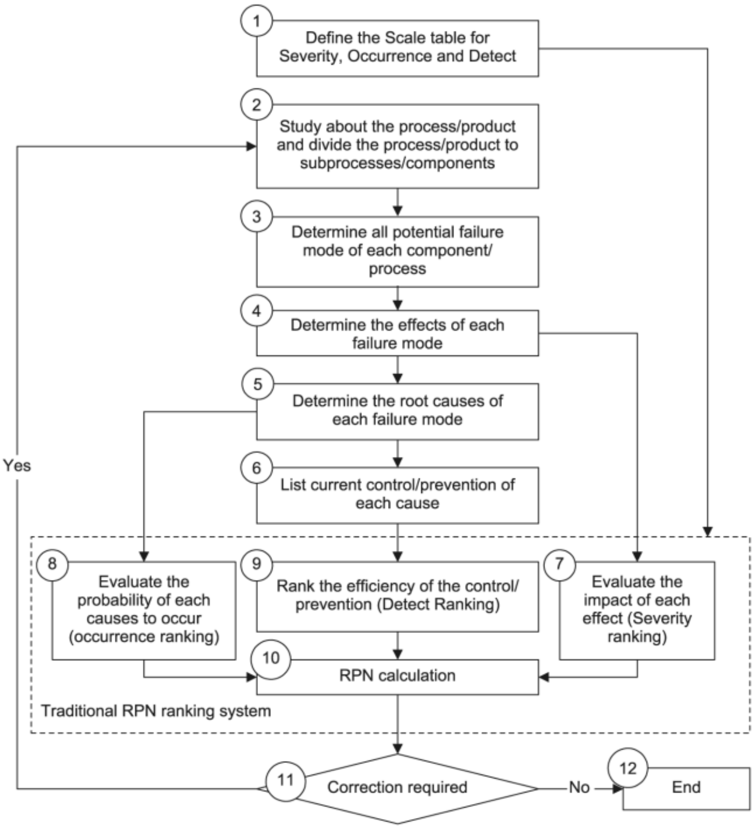

Fig. 1. Conventional FMEA procedure

The previous works related to the classification of risk assessment techniques in FMEA are reviewed. Academic journal papers published between 2010 and 2022 served as the study's sources. Also, this section only incorporated previous works that discuss a technique or procedure that particularly attempts to address some of the limitations of the conventional FMEA. This means that the previous works that only provide a description of the FMEA process or implement the conventional FMEA have not been included. Based on the FMEA's RPN value, this conventional method's efficiency scores are unreliable. This is due to the fact that the severity, occurrence, and detection values are the same, although their degree of significance may differ. Hence, the different combinations of these parameters may result in an RPN value being the same as others, while their impact on society might be different. Many studies have found that FMEA alone is insufficient and should be combined with other methods to overcome the above limitation.

Generally, the existing approaches to overcome the shortcomings of FMEA can be classified into four categories: artificial intelligence (AI), multi-criteria decision-making (MCDM), integrated approaches, and mathematical programming. Those methods are summarised with a description, and their strengths and limitations are discussed in the following subsections.

2.1 Artificial Intelligence

Fuzzy-Rule Based System (FRBS), Fuzzy Adaptive Resonance Theory (ART), and Fuzzy c-Means (FCM) are examples of AI categories that can be used for risk assessment. Prokopowicz *et al.*, [14] described fuzzy sets theory as primarily motivated by the need to simulate real-world events, which are by their very nature uncertain and ambiguous [14]. This implies that the fuzzy system was originally introduced to provide a formal tool for the representation of mathematical linguistics and processing of the given information. As stated by Feigenbaum and Mermin [15], any intellectual job may benefit from AI. It covered a wide range of fields, from the broad (learning and perception) to the narrow (task-specific).

Obtaining rules from experts to create a fuzzy IF-THEN rule base is a time-consuming and complex procedure, as the fuzzy RPN usually requires a high number of rules. In FMEA, the rules can exceed 125, depending on the proposed linguistic scales. Dinmohammadi and Shafiee introduced a fuzzy rule base approach using IF-THEN rules and grey relation theory for offshore wind turbine risk analysis [16]. In this study, the fuzzy rule base gathered from experts was reduced by assuming that all risk factors (S, O, and D) have the same relative importance. Subsequently, all risk factors were weighted using grey theory approaches, providing a method to quantify and examine relations between discrete quantitative and qualitative series. The priority of risk can be ranked in order from weaker to stronger degrees of relation, as a smaller degree of relation has a larger effect from the cause. Meanwhile, Tay and Lim argue that not all rules are necessary for conducting fuzzy analysis [17]. They proposed a Guided Rules Reduction System (GRRS) to assist the user in identifying which rules are needed and which should be removed. Their findings are particularly beneficial for users dealing with massive amounts of rules in real-world problems.

In the context of COVID-19 risk management, Jin *et al*., [18] introduced a hybrid approach combining fuzzy FMEA with the Analytic Hierarchy Process (AHP) to assess the failure of the logistics system during the COVID-19 pandemic [18]. The authors highlight the importance of the fuzzy method as a crucial theory for handling information breakdowns. Risk index factors such as severity (S), occurrence (O), and detection (D) are fuzzified using Gaussian membership functions. This method relies on expert knowledge and can be developed with the assistance of expert input and decision-making through the creation of fuzzy IF-THEN rules. By incorporating expert knowledge, more accurate and appropriate knowledge-based models can be constructed. Finally, the fuzzy consequences are transformed into a precise value known as the RPN. The study's findings suggest that enterprises could reduce operating costs during the COVID-19 pandemic by maximizing work efficiency.

Chang proposed a novel emergency risk evaluation method by combining FMEA with spherical fuzzy-sets methods to prevent secondary COVID-19 transmissions in hospitals [19]. A spherical fuzzy set represents an advancement in fuzzy sets wherein membership degrees are assigned to elements based on their distance from a center point or core. The author contends that spherical fuzzy sets can offer more detailed information, as they fully consider the membership degree (MD), indeterminacy degree, non-membership degree (NMD), and refusal degree of failure modes. A summary of different calculation methods for risk ranking using FMEA and fuzzy sets is presented in Table I. The drawback of the proposed method lies in the utilization of distance-based membership functions in spherical fuzzy sets, which may demand more computational resources compared to traditional fuzzy sets, especially for large datasets or high-dimensional spaces.

Table 1
Different calculation methods for RPN

Calculation methods	References	Use of information	Information extraction
Traditional RPN	[12]	Semantic information	None
Fuzzy set	[18]	Fuzzy information	MD
Intuitionistic fuzzy set	[20]	Intuitionistic fuzzy	MD and NMD
Spherical fuzzy set	[19]	Spherical fuzzy information	MD, indeterminacy degree, NMD, and refusal degree

2.2 Multi-Criteria Decision Making

In recent years, there has been a growing interest in integrating multi-criteria decision-making (MCDM) methods into the FMEA process. MCDM-based FMEA combines the strengths of both FMEA and MCDM, offering a more comprehensive and systematic approach to risk assessment. In MCDM-based FMEA, multiple criteria, such as severity, occurrence, and detectability, are taken into account when assessing the potential risk associated with a failure mode. This approach allows for a more nuanced and evidence-based assessment of risk, moving beyond reliance solely on subjective judgment. The outcomes of MCDM-based FMEA can be utilized to prioritize risk mitigation activities and allocate resources more effectively. Several Multi-Criteria Decision Making (MCDM) methods have been employed in the FMEA process. Among these are the Analytic Hierarchy Process (AHP), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Simple Additive Weighting (SAW). These methodologies provide diverse perspectives on assessing criteria and establishing the comprehensive risk score for each identified failure mode.

Lo *et al*., [21] introduced a hybrid approach based on Multi-Criteria Decision-Making (MCDM) for enhancing FMEA in the manufacturing industry. This FMEA model is designed to be more comprehensive by initially integrating estimated expenditures and environmental protection indicators [21]. Subsequently, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) approach is applied to precisely identify critical components and generate a network relationship map of risk factors. In order to rank the failure modes, the integrated MCDM approaches make use of the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) concept. The four MCDMs utilized in this process include Simple Additive Weighting (SAW), VIse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR), Grey Relational Analysis (GRA), and Complex Proportional Assessment of Alternatives (CORPAS).

Nie *et al.,* [22] utilized the best-worst method (BWM) in MCDM-based FMEA for the supercritical water gasification (SCWG) system [22]. BWM is formed based on the analytic hierarchy process (AHP), which can provide weights to the risk factors. The key difference between BWM and AHP is that BWM does not require too much information and computation quantity to determine the weightage. Moreover, asking too many questions from the experts, which occurs in the case of a full matrix (within the AHP technique), might contribute to the confusion and inconsistency of the experts. The author also tested the consistency of the comparisons from FMEA team members via consistency ratio (CR) and obtained CR values ranging from 0.5 to 0. A CR value that is closer to 0 indicates that the comparisons are more consistent with one another. Meanwhile, Yazdi *et al.* claimed that fuzzy BWM might provide a better consistency ratio compared to conventional BWM [23]. Thus, they proposed a new risk analysis approach that combines the BWM with the consideration of decision-making style (democratic or autocratic) via a fuzzy logic system. The method aims to increase the reliability of risk analysis by accounting for the effect of decision-making style on the decision-making process. The democratic-autocratic dimension is used to categorize decision-makers into two groups, and the best-worst method is used to rank the alternatives based on the opinions of both groups.

In the context of COVID-19 applications, there is currently no existing research attempting to review the utilization of Multi-Criteria Decision-Making (MCDM) in COVID-19 risk management. However, a review has been conducted on a hybrid technique incorporating MCDM for COVID-19 management. Nguyen *et al*. conducted a theoretical analysis of MCDM methods for evaluating intervention strategies to combat the spread of COVID-19 in Vietnam [24]. The study initially identified and examined crucial factors, such as total estimated cost, ease of implementation, high acceptance among residents, efficacy in curbing the spread of COVID-19, and the irreplaceability of other measures, through expert interviews and literature reviews. Subsequently, 15 strategies were assessed and compared using MCDM techniques. To aid stakeholders like governors and policymakers in prioritizing governmental interventions, the study proposed a novel hybrid Spherical Fuzzy Analytic Hierarchy Process (SF-AHP) and Fuzzy Weighted Aggregated Sum Product Assessment (WASPAS-F) model. The WASPAS-F method evaluated intervention choices, while the SF-AHP assessed the importance of criteria. Fig. 2. illustrates the final ranks of the options based on the comparison study, providing a clear depiction of rank changes for each option in different models. The study highlights that various methodologies may yield slightly different ranking outcomes, possibly due to varying weighted sums, weighted product values, and assumptions. However, it's important to note that the study does not consider various decision-makers from other categories that play critical roles in the decision-making process.

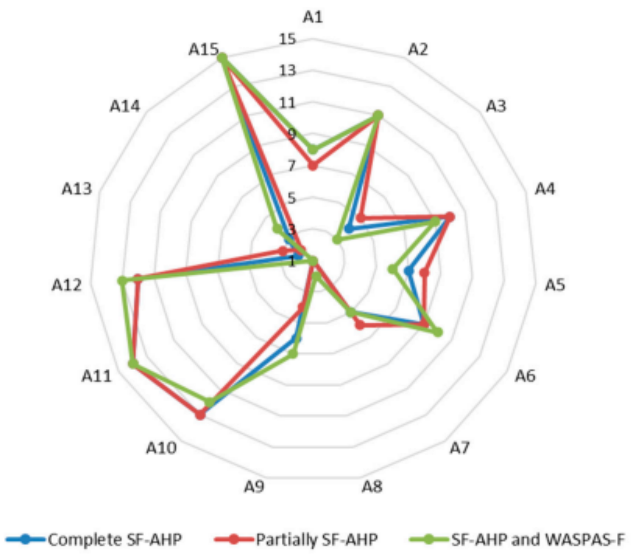

Fig. 2. Radar plot for comparative analysis of various models to address the expansion of COVID-19

2.3 Integrated Approach

Integrated or hybrid approaches operate by aggregating two or more methods to obtain the benefits from different methods. These approaches aim to enhance the effectiveness and efficiency of FMEA by combining it with other risk assessment methods, such as Hazard and Operability Studies (HAZOP), Fault Tree Analysis (FTA), and Reliability Block Diagrams (RBD). The goal of integrated approaches is to provide a comprehensive and systematic approach to risk assessment by considering various factors such as system components, operational scenarios, and external factors. However, due to its complexity and time consumption to build expert knowledge, these approaches are difficult to implement for theoretical analysis for the potential transmission analysis.

Chang and Cheng present an integrated risk assessment approach that combines two methodologies: the Fuzzy Order Weighted Average (OWA) method and the Decision Making Trial and Evaluation Laboratory (DEMATEL) method [25]. The Fuzzy OWA method is employed to evaluate the significance of individual risk factors, utilizing a set of weighting factors to assign scores to each risk factor. Simultaneously, the DEMATEL method is utilized to identify the interrelationships between these risk factors by constructing a causality matrix, representing the influence of one risk factor on another. The authors apply this combined approach to assess the risk of failure in the production of thin-film transistor liquid crystal display (TFT-LCD) and demonstrate that the results align with expert opinions.

Liu *et al.,* [26] used FER and BRB for performing fuzzy FMEA to identify the potential failure of a fishing vessel in a marine industry [26]. FER utilizes a combination of fuzzy logic and evidential reasoning to handle uncertainty and incomplete information in FFMEA. This allows for a more flexible and adaptable approach to the analysis of complex systems. Meanwhile, BRB uses a rule-based system to represent knowledge and perform reasoning in fuzzy FMEA. A collection of information from experts in BRB represents the functional mappings between antecedents and consequents, which include uncertainty. This means it can provide better information with a realistic scheme compared to basic IF-THEN rule-based representation. Meanwhile, Liu *et al.,* [26] adopted FER and grey theory to address the uncertainty and imprecision associated with the failure data and make the analysis more reliable [27]. The grey theory generates the comparative series in the form of a matrix from the de-fuzzified membership function of linguistic terms and fuzzy interval grades set. As for the standard series, the risk factors are generated by identifying the ideal amount of each risk component for the failure modes in the FMEA. Once comparative and standard series have been identified, the grey relational coefficient and grey relational degree can be computed. The higher the grey relational degree, the lower the effect of the potential failure.

In the context of COVID-19, Asadi *et al*., [28] applied the Decision Making Trial and Evaluation Laboratory (DEMATEL) method to examine the relationships among factors influencing the prevention of the spread of COVID-19 infection in Malaysia [28]. Subsequently, they utilized the Fuzzy Rule-Based System (FRBS) approach to underscore the critical and significant influencing factors, emphasizing the importance of determining factors based on the model inputs [28]. The DEMATEL analysis revealed six factors that influence the response to COVID-19 in Malaysia: social media sharing, cancellation of mass gatherings, movement control order, international travel restrictions, distance learning, and economic stimulation package.

2.4 Mathematical Programming

Integrated Mathematical programming is another method that can be used to enhance the FMEA [29–31]. Garcia *et al*. proposed the fuzzy DEA, which can consider linguistic variables from expert opinion and consider the uncertainties related to these variables. In spite of its ability to tackle the shortcomings of conventional FMEA, this approach cannot fully discriminate against all DMUs, leading to inaccurate priority ranking.

Khalilzadeh *et al.* explored the use of mathematical programming to mitigate the risks of oil and gas projects [32]. The best risk response techniques were found using the enhanced Epsilon-constraint approach once the potential failure had been identified. The use of the Epsilon-constraint method to identify risk response strategies can assist decision-makers in selecting options that are more desirable in terms of each project objective. By reviewing the literature and historical data and consulting with experts, many techniques for addressing the primary risks that were discovered were obtained. The mathematical programming model was then enhanced to choose the optimal solutions. The results of the study show that the proposed model is able to solve complex problems that involve the optimization of multiple objectives and constraints.

In the context of COVID-19 risk management, a study conducted by Tavana *et al.* utilized linear programming to identify and prioritize vulnerable populations and rationalize the COVID-19 vaccine allocation process [33]. The mixed-integer linear programming (MILP) model is presented for COVID-19 vaccine distribution by grouping them into cold, very cold, and ultra-cold categories where a particular temperature is required for their storage and distribution. Although the proposed model does not directly contribute to the COVID-19 prevention measures, it does assist developing countries in monitoring which manufacturer the vaccine should be ordered from, how much should be ordered, what is the waiting time for each manufacturer, and the storage process of the vaccines. In other words, this study is significant to manage COVID-19 vaccines efficiently and thus contributes to better control of the pandemic.

The identified approaches against COVID-19 by utilizing AI, MCDM, integrated approaches, and mathematical programming have been summarized in Table II. Based on these journal articles, some observations are made in the following subsections.

Table 2
Different risk evaluation methods for COVID-19

Risk evaluation method	Authors	Application area	Description	Research contribution
Artificial intelligence	Jin *et al.,* [18]	field of logistics and supply chain management during pandemic	fuzzy membership functions were assigned to each criterion to reflect the uncertainty and imprecision associated with the data	Ensures that resources were allocated to the most critical failure modes, leading to a more effective and efficient logistics system
Multi-Criteria Decision Making	Nguyen *et al.,* [24]	Governmental intervention strategies on COVID-19 (case study in Vietnam)	A comprehensive and flexible approach prioritized COVID-19 intervention strategies for decision-makers based on multiple criteria	15 criteria were identified for prioritizing COVID-19 governmental interventions; "vaccinations" was found to be an as optimal strategy
Integrated approach	Asadi *et al.,* [28]	Governmental intervention strategies on COVID-19 (case study in Malaysia)	DEMATEL analyzed interrelationships, and fuzzy logic provided expert output for identified factors	Key pandemic response factors were identified: public health, healthcare capacity, economy, and social factors. Successfully prioritized for effective resource allocation.
Mathematical programming	Tavana *et al.,* [33]	for policymakers and public health officials to allocate COVID-19 vaccines	Mixed-integer linear programming model was utilized to consider the location-inventory problem	Assisted the decision-makers in developing evidence-based vaccine distribution strategies that are both equitable and efficient

3. Proposed Fuzzy-FMEA Approach for Prevention and Control of COVID-19 at Sarawak Longhouses

This section introduces an artificial intelligence approach that employs fuzzy IF-THEN rules and Gaussian fuzzy numbers to analyze the transmission potential of COVID-19. To implement this proposed model, a team of three decision-makers was assembled for FMEA to assess potential failure modes at the Sarawak longhouse. Key potential failure modes were identified by a team of experts from the Faculty of Medicine and Health, along with input from local residents in the longhouse.

These failure modes encompass various areas, including the ruai (area 1), veranda (area 2), living room (area 3), bedroom (area 4), balcony (area 5), kitchen (area 6), and washroom (area 7).

The three decision-makers are required to evaluate the FMEA form, as depicted in Table VI, using the scale provided in Table III, Table IV, and Table V. The subsequent sub-section will delve into the development of fuzzy numbers derived from the numerical scale table. These fuzzy numbers will serve as inputs for the decision-making process aimed at determining the ranking of potential COVID-19 failures.

3.1 Membership Function for Severity, Occurrence, and Detection

The severity, occurrence, and detection scale tables were developed through discussions with the three experts, represented in Table III, Table IV, and Table V. Each scale table includes columns for "Ranking," "Linguistic term," and "Descriptions," with scores provided within the columns. These scale tables encompass a scale ranging from 1 to 10, defining the maximum and minimum limits of the scale.

Table 3
Scale table for severity

Ranking	Linguistic term	Descriptions
1	Negligible	• Inhabitants adhere to health routines and follow standard precautions • Every resident has received complete vaccination • Routinely sanitizing and disinfecting surfaces and objects that are frequently touched
2-3	Marginal	• Inhabitants uphold health practices and adhere to standard precautions • Every resident has been fully vaccinated • Periodically cleaning and disinfecting surfaces and objects that are frequently touched
4-6	Moderate	• Inhabitants intermittently follow health practices and standard precautions • The majority of residents have completed their vaccinations • Periodically cleaning and disinfecting surfaces and objects that come into contact
7-8	Critical	• Residents seldom adhere to health practices and standard precautions • A minority of residents have received full vaccination • Infrequently cleaning and disinfecting surfaces and objects that are touched
9-10	Catastrophic	• Residents neglect health practices and standard precautions • None of the residents have been vaccinated Cleaning and disinfecting surfaces and objects only takes place when deemed necessary

Table 4
Scale table for occurrence

Ranking	Linguistic term	Descriptions
1	Very low	• There is a high level of assurance that all individuals are not infected • There is a high level of confidence that objects or surfaces are free from contamination • Close communication can be circumvented with confidence
2-4	Low	• There is a high degree of certainty that all individuals are not infected • There is a high level of confidence that objects or surfaces are free from contamination • It is challenging to entirely avoid close communication
5-6	Medium	• Low confidence that all humans are not infected • Low confidence that objects or surfaces are not contaminated • Close communication is hardly to be avoided
7-8	High	• There is low confidence that all individuals are not infected • It is difficult to completely avoid contamination of objects or surfaces • Avoiding close communication is challenging
9-10	Very high	• Confidence is low that all individuals are not infected • It is challenging to entirely prevent contamination of objects or surfaces This applies especially in crowded places, close-contact settings, and confined or enclosed spaces

Table 5
Scale table for detection

Ranking	Linguistic term	Descriptions
1-2	Very high	There is an extremely high likelihood of detecting the transmission of COVID-19
3-5	High	There is a significant likelihood that the transmission of COVID-19 will be detected
6-8	Medium	There is a moderate likelihood that the transmission of COVID-19 will be detected
9	Low	There is a low likelihood that the transmission of COVID-19 will be detected
10	Very low	There is a very low or zero probability that the transmission of COVID-19 will be detected

From Table III, Table IV, and Table V, the Gaussian fuzzy membership functions can be derived using the MATLAB Fuzzy Logic Toolbox, as displayed in Fig. 3, Fig. 4, and Fig. 5, respectively. For instance, in Fig. 3 representing the severity scale, the fuzzy membership function for "Moderate" exhibits the widest distribution, aligning with their score intervals in Table III. Following this, the widths of the fuzzy membership functions for "Marginal," "Critical," and "Catastrophic" are consistent. Lastly, the fuzzy membership functions for "Negligible" showcase the smallest score intervals.

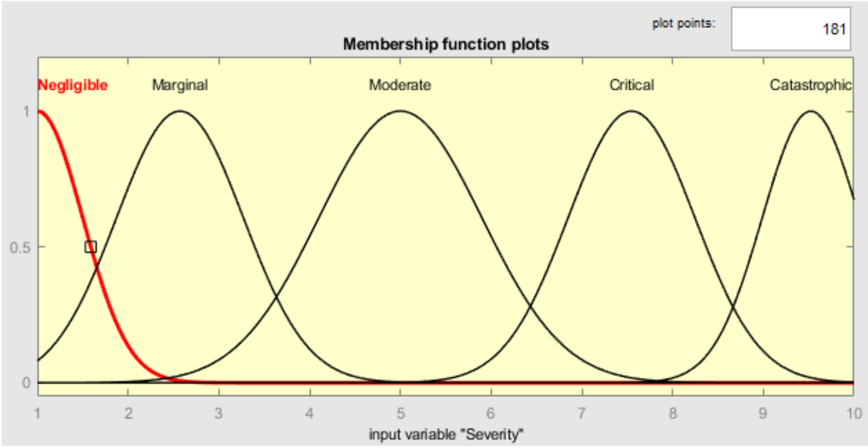

Fig. 3. Gaussian membership function for severity

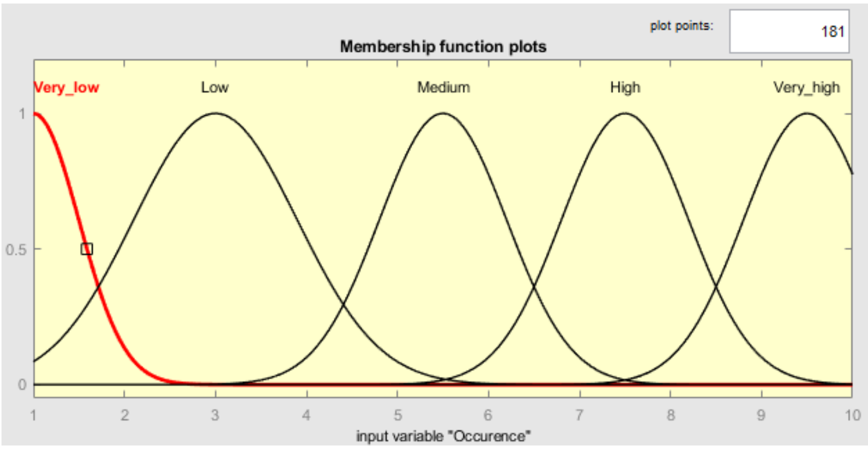

Fig. 4. Gaussian membership function for occurrence

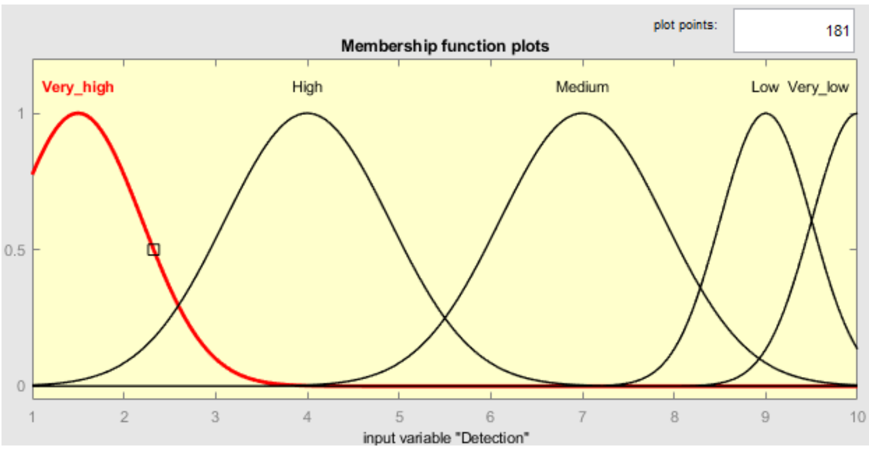

Fig. 5. Gaussian membership function for detection

3.2 Fuzzy IF-THEN Rules

Fuzzy IF-THEN rules involve employing fuzzy logic to establish a mapping from a given input to an output. This mapping serves as a foundation for decision-making or trend identification [34]. In the realm of fuzzy logic systems, the Fuzzy Inference System (FIS) plays a central role, with decision-making being a critical component of this system. FIS operates on principles derived from fuzzy IF-THEN rules, fuzzy set theory, and fuzzy reasoning. To formulate analytical decision rules, FIS utilizes "IF... THEN..." statements, typically connected by "OR" or "AND" connectors [34].

As stated by An *et al.*, [35], FIS is made up of the following components: a fuzzy rule base, a database, fuzzification, a decision-making unit, and defuzzification. A FIS depicted in Fig.6. consists of four functional blocks. A fuzzy rule base elucidates the system's criticality level for each combination of input variables [35,36]. Combinations of input variables are formulated using rule-based logic, such as "IF-THEN" or "OR-ELSE" rules [36]. Additionally, a database defining fuzzy set membership functions is utilized within these rules. Fuzzification involves the conversion of crisp input values into corresponding degrees of membership functions for specific variables. Subsequently, a fuzzy inference engine or decision-making unit executes the inference operations based on the established rules. Finally, defuzzification transforms the fuzzy results into a crisp output [35].

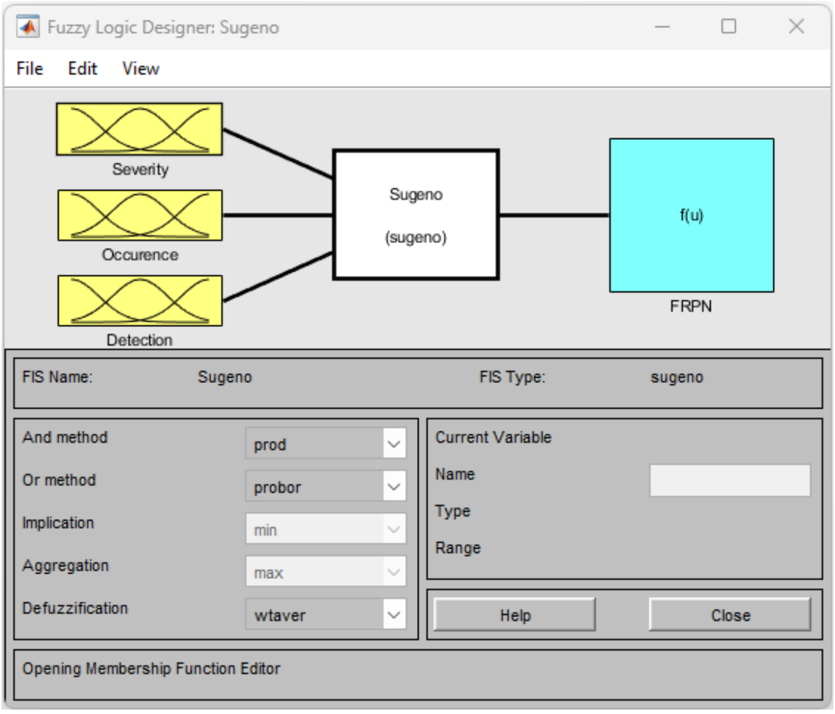

Fig. 6. FIS editor from MATLAB

In this study, the Takagi-Sugeno model is chosen for the decision-making process. This choice is attributed to its strong approximation capabilities and suitability for these specific applications. Additionally, the Sugeno model's consequent part is structured as singletons, enabling easy human interpretation of each rule consequent during the collection phase for the fuzzy rule base [37].

3.3 Result and Discussion

The RPN and fuzzy RPN (FRPN) value for the analyzed transmission potential is shown in Table VI. The ranking of RPN values of the failure mode is F 3.1 > F 4.2 > F 4.3 > F 5.2 > F 1.1 > F 2.1 > F 1.3 > F 2.2 > F 5.1 = F 6.1 = F 7.1 > F 3.2 > F 1.2 > F 2.3 > F 4.1 > F 6.2 > F 1.5. These were obtained by the product of risk-indexed parameters such as severity, occurrence, and detection in the conventional FMEA approach. Meanwhile, the ranking for FRPN values of the failure mode is F 3.1 > F 4.2 > F 1.1 >

F 4.3 > F 5.2 > F 1.2 = F 1.3 > F 2.2 = F 2.3 > F 1.4 = F 2.1 = F 4.1 = F 5.1 > F 6.1 = F 7.1 > F 6.2 > F 1.5. FRPN values were obtained directly from the fuzzy interface from MATLAB.

Table 6
Fuzzy-FMEA table for COVID-19 transmission at Sarawak Longhouses

Area	ID	Transmission potentials	S	O	D	RPN	FRPN
Ruai	F 1.1	Social interaction at a close distance. Special events. i.e Gawai, Christmas, Wedding and Engagement Reception, Funeral, etc.	7	6	5	210	666
	F 1.2	Sharing of traditional instruments	6	6	4	144	515
	F 1.3	Passing drinks and food during events	6	6	5	180	515
	F 1.4	Area contamination with infectious agents (eg, ruai floor, ruai wall and etc.	4	5	6	120	485
	F 1.5	Common access entry to the ruai area (share side entrances also known as tempuan)	3	4	6	72	201
Veranda	F 2.1	Social interaction at close distance, which involves 2 and more peoples	4	7	7	196	485
	F 2.2	Contamination of the area with infectious agents (staircase handle, door handle of the entrances, etc.	5	5	7	175	500
	F 2.3	Infected non-residents/outsiders using the same entrances	5	5	5	125	500
Living room	F 3.1	Social interaction at a close distance. Special events. i.e Gawai, Christmas, Wedding, and Engagement Reception.	8	8	8	512	836
	F 3.2	Contamination of the area with infectious agents (furniture, etc)	5	6	5	150	500
Bedroom	F 4.1	Contamination of the area with infectious agents (i.e. door handles, bedroom furniture)	4	5	6	120	485
	F 4.2	Poor ventilation	7	7	8	392	807
	F 4.3	Sharing of bedroom/ No personal bedroom	6	7	7	294	528
Family room	F 5.1	Contamination of the area with infectious agents (furniture, remote TV, etc)	4	6	7	168	485
	F 5.2	Social interactions at a close distance	6	6	8	288	519
Kitchen	F 6.1	Sharing of cooking equipment	3	7	8	168	343
	F 6.2	Potential contamination of the tableware and kitchenware with infectious agents	2	6	8	96	314
Washroom	F 7.1	Contamination of the area with infectious agents (door handle and faucet handle)	3	7	8	168	343

5. Conclusion

Amidst the ongoing COVID-19 pandemic, various FMEA methods, evaluation, and development categories are presented together to ease the challenges posed by unclear decision-making processes. This paper provides an in-depth exploration of the integration between FMEA and COVID-19, examining its taxonomy and categorizing the reviewed literature into evaluation-based and development-based approaches for the first time. The integration of FMEA with AI, MCDM, integrated approach, and mathematical programming has the potential to enhance the effectiveness and efficiency of risk assessment and management in the context of COVID-19. These advanced techniques can provide a more sophisticated analysis of the complex and dynamic risks posed by the pandemic.

Artificial intelligence can help automate and streamline the FMEA process while also enabling more accurate and timely prediction of failure modes and their impacts. MCDM and hybrid approaches can incorporate multiple criteria and factors in decision-making while also considering the trade-offs and uncertainties involved. Mathematical programming can optimize resource allocation and intervention strategies while also considering constraints and priorities.

In conclusion, FMEA, with the integration of AI, MCDM, integrated approach, and mathematical programming, can enhance the capability to perform the risk assessment for COVID-19 or any infectious diseases.

Acknowledgement
This work was supported by Ministry of Higher Education, Malaysia through Fundamental Research Grant Scheme (FRGS) under Project ID FRGS/1/2022/TK08/UNIMAS/02/11. The authors thank Universiti Malaysia Sarawak (UNIMAS) for the research support with Project ID NAT/F02/FRGS/85440/20222021.

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