ANALYSIS OF OPERATIONAL HAZARDS IN HEAVY FUEL OIL-BASED POWER PLANTS: A HYBRID MULTI-CRITERIA DECISION-MAKING APPROACH

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By

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CERTIFICATE OF APPROVAL

The project titled "**ANALYSIS OF OPERATIONAL HAZARDS IN HEAVY FUEL OIL-BASED POWER PLANTS: A HYBRID MULTI-CRITERIA DECISION-MAKING APPROACH**" submitted by Md. Tanvir Siraj, Student no: 0417082108 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Engineering in Advanced Engineering Management on September 14, 2022.

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CANDIDATES DECLARATION

It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

……………………………………

Md. Tanvir Siraj

Dedicated to

My parents Md. Sirajul Islam and Tahera Sultana,

and my beloved wife Nabila Taseen who always supported me in achieving this.

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Abstract

Hazard identification and prioritization practices are very important for power plants to continue their operations without disruption. Systematic operational hazard analysis is not a very common practice at the Heavy Fuel Oil (HFO) based power plants in Bangladesh. Hence, a structured hazard evaluation framework can greatly benefit them to ensure their operational safety. This study has been conducted to identify and prioritize the operational hazards of the HFO-based power plants through using a hybrid multi-criteria decision-making (MCDM) approach in a fuzzy environment, and then, to explore the appropriate mitigation methods for the top-ranked hazards and to find the interrelationships that exist among the mitigation methods. First, the most common hazards in HFO-based power plants have been identified from the expert feedbacks. Then, a fuzzy analytical hierarchy process (FAHP) method has been used to determine the weights of the evaluation criteria and a fuzzy technique for order performance by similarity to ideal solution (FTOPSIS) method, has been used for the final ranking of the potential hazards. Afterwards, mitigation methods for the top 25 hazards have been identified and interrelationship among those mitigation methods has been explored through using interpretive structural modelling (ISM) and a matriced impacts croisés multiplication appliquée à un classement (MICMAC) analysis. The study finds that 'explosion of high-pressure steam drum of the gas boiler', 'crankcase explosion and fire hazard due to oil pressure rise' and 'explosion of the compressed air reservoir' are the top three hazards in the hazard ranking. 'Standard operating procedure (SOP) and training' have been found to be the most driving mitigation methods for the top-ranked hazards based on the ISM-MICMAC analysis. The findings of this study are expected to provide the managers of power plants with valuable insights, which can help them to prepare sustainable operational strategies to ensure the least hazardous work environment.

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Thermal power plants are riskier than most other types of power plants since they employ a series of processes to generate electricity using highly combustible fossil fuel (Ahmad et al., 2016). Noteworthy operational hazards can occur in different types of thermal power plants. Fire hazards can occur from fossil fuel or other types of combustible material used in the plant; explosion hazard can result from the bursting of high-pressure steam boilers or compressed air reservoirs; chemical or electrical fires may originate from careless handling in the chemical store or malfunction in electric controls and circuitries; severe injury can occur if workers come into contact with high-speed rotating machineries. To ensure a safe operational environment in a thermal power plant, reducing operational risks to a minimal level is critical. Moreover, associated hazards must be identified and prioritised (Rathod et al., 2017).

Although engines that run on heavy fuel oil (HFO) are predominantly used in marine vessels, these engines are also used in several countries to generate electricity in small or medium-scale power plants (Guida et al., 2021). Due to the growing demand in electricity in a developing industrial country such as Bangladesh, the installation of an engine-based power plant is often a more expedient solution than building other types of large-scale and high-investment thermal power plants (Islam and Khan, 2017). Heavy fuel oil-based power plants have met the national electricity demand of Bangladesh for more than 24 years. Fifty-six such plants currently operating across the country and are capable of meeting more than 25% of the country’s total electricity demand (BPDB Power Station Statistics, 2022).

1.2 Rationale of the Study

Various studies address hazard identification and prioritisation in thermal or HFO-based power plants in different way. For instance, in most of the thermal plants in Bangladesh, a simple technique named decision matrix risk assessment (DMRA) is used, where the plant's management documents and prioritizes hazards using a simple two-criteria based matrix method. The two criteria evaluated in this method include severity and likelihood (Gul and Guneri, 2016). The main drawback of such a simple two criterion-based techniques is that it overlooks several additional key aspects of hazards that are often crucial for plant safety. Another shortcoming of the method is its inability to incorporate the evaluations and quantitative feedback of experts, rendering the technique less dynamic and proactive. To overcome these limitations, this study proposed employing a five criterion-based evaluation framework following the guidelines of the World Health Organisation (*Community emergency preparedness: a manual for managers and policymakers*, 1999). The five criteria considered in this study were severity, likelihood, manageability, extent, and time frame.

This study proposed identifying hazards and exploring appropriate mitigation methods in HFO-based thermal power plants using a hybrid multi-criteria decision-making (MCDM) method. Existing literature supports that hybrid MCDM methods are more efficient than single methods for decisions made in complex environments (Zavadskas et al., 2016; Moktadir et al., 2019; Saraswat and Digalwar, 2020). Moreover, this study utilised the fuzzy approach in this study to compensate for the vagueness and uncertainty of the human decision-making process. This study proposed an aggregation of the fuzzy analytical hierarchy process (FAHP) and fuzzy technique for order performance by similarity to ideal solution (FTOPSIS) method to prioritise and rank hazards of HFO-based thermal power plants. The FAHP was used in this study to identify the weights of the evaluation criteria. Criteria weights were then used as inputs to the FTOPSIS method to obtain a final hazard ranking.

After ranking hazards, decision-makers must focus on mitigation methods for the top-ranking hazards. Exploring the interrelationships between the mitigation methods based on their driving and dependency power is necessary to maximise the impact of the methods. Hence, appropriate mitigation methods were identified by expert opinion for the top-ranked 25 hazards in this study and were analysed using the interpretive structural modelling (ISM) and a matriced impacts croisés multiplication appliquée à un classement (MICMAC) approach. ISM method focuses on an expert opinion-based structural self-interaction matrix (SSIM), forms a reachability matrix from the SSIM and thus shows an interrelationship between the variables through level partitioning. The MICMAC analysis illustrates the graphical position of the variables from ISM to determine their driving and dependence power (Jawad and Ledwith, 2020).

1.3 Objectives of the Study

Specific study objectives are mentioned below. First, this study aimed to identify the five evaluation criteria and the major operational hazards associated with HFO-based power plants in Bangladesh. This work then sought to determine the weights of the evaluation criteria using the FAHP method. This study prioritised and ranked hazards using the FTOPSIS method, utilising criteria weights obtained from FAHP as inputs. This work subsequently identified appropriate mitigation methods from experts for the top-ranked hazards. Finally, this study explored the interrelationships between the mitigation methods by using the ISM-MICMAC approach. Doing so, this study attempted to answer the following questions:

1) What are the critical hazards that commonly occur in an HFO-based power plant?
2) What is the priority order of hazards? If management has limited resources to ensure

operational safety, which hazards should be addressed first?

3) What are the weights of the evaluation criteria according to which hazards will be ranked? Which criteria are more important?
4) What mitigation methods can be adopted to address the top-ranked hazards?
5) What are the interrelationships between the mitigation methods? How do these interrelationships impact the implementation of mitigation methods?

1.4 Arrangement of the Chapters

The rest of the chapters are as- a review of the relevant literature is presented in Section 2. Research methodologies are discussed in Section 3. Study results are discussed in Section 4, while managerial implications of the study are reviewed in Section 5. Finally, Section 6 provides study conclusions and suggests directions for future studies. Sample questionnaire to collect experts' opinion for this study can be found in the Appendix section.

CHAPTER 2

LITERATURE REVIEW

2.1 Review on Hazard Analysing

A hazard can be described as a phenomenon that causes damage to people and their surroundings. To minimise operational risks in any industry, managers must identify and prioritise hazards and explore appropriate mitigation methods. Diverse industries characterise and rank hazards associated with their own processes in different ways to maintain operational safety on the job site. DMRA method is one of the simplest methods still in wide use for hazard identification and risk analysis. This approach derives a Risk Priority Number (RPN) from two specific criteria: severity and likelihood. Hazards are then ranked based on the derived RPN (Ahmad et al., 2016; Gul and Guneri, 2016; Rathod et al., 2017). Hazard and Operability Study (HAZOP) is another familiar qualitative method that has been used in industrial safety studies (Othman et al., 2016; Marhavilas et al., 2020a, 2020b). Other common methods in the existing literature include fault tree analysis, event tree analysis, and failure modes and effect analysis (Alrifaey et al., 2019; Jokar et al., 2020).

2.2 Review on MCDM Techniques

If the criteria of hazard prioritisation cannot be described in terms of major aspects of the hazard, decision-makers may overlook some of the most critical issues. Various MCDM techniques are known to be employed for this purpose and can allow efficient prioritisation of multiple alternatives with multiple criteria and correlations (Singh and Malik, 2014; Stojčić et al., 2019, Krishnan et al., 2019). In recent safety studies, MCDM-based quantitative approaches have increasingly been used (Gul, 2018; Kazemi et al., 2020). Most frequently, researchers use a single MCDM method to fulfil the common objective of prioritising alternatives in a critical decision-making environment. On the other hand, hybrid MCDM methods involve merging two or more methods to achieve the decision-making objective. In such case, one method can be used for determining criteria weights and the other for determining the final rank of the alternatives using criteria weights (Zavadskas et al., 2016; Ayağ and Samanlioglu, 2020). The hybrid MCDM approach has been used in environmental risk assessment (Saffarian et al., 2020), risk assessment for occupational health and safety (Ilbahar et al., 2018; Gul, 2020; Karuppiah et al., 2020), manufacturing system selection (Mathew et al., 2020a), maintenance strategy selection (Mathew et al., 2020b), and many other related fields. To-date, operational hazards in thermal power plants have not been analysed using the hybrid MCDM approach, which can be identified as an unexplored research scope. Therefore, the hybrid FAHP-FTOPSIS method was used in this study to evaluate and prioritise hazards while the ISM-MICMAC method was utilised to explore appropriate mitigation methods.

2.3 Review on FAHP

Unlike the traditional analytical hierarchy process (AHP), fuzzy AHP or FAHP addresses the fuzziness of vague decisions by humans (Demirel et al., 2008). An effective approach to pair-wise comparison scale for FAHP involves using the triangular fuzzy number or TFN (Demirel et al., 2008). For risk assessment purposes, FAHP with TFN is considered a simpler and superior method over other types of membership functions (Shin et al., 2016). FAHP has been used by many researchers for risk assessment of projects (Shin et al., 2016; Ribas et al., 2019), operational risk evaluation (Yucesan and Kahraman, 2019), risk prioritisation in banking (Khalilzadeh et al., 2020), supply chain risk assesment (Tavana et al., 2021), outsourcing reverse logistics (Tavana et al., 2016) and so on. As a part of the hybrid method and coupled with other MCDM methods for calculating criteria weights, FAHP has been used for environmental risk assessment (Saffarian et al., 2020), fault tree analysis for fire and explosion hazards (Yazdi et al., 2020), risk assessment in process industries (Gul and Guneri, 2016), occupational health and safety risk assessment (Gul, 2020), the selection of maintenance strategies (Mathew et al., 2020b), and so on. However, FAHP has not yet been used for determining criteria weights for hazard analyses in power plants.

2.4 Review on FTOPSIS

TOPSIS is another classical MCDM method based on the concept that the selected alternative should be at a minimum distance from the positive ideal solution and at a maximum distance from the negative ideal solution (Sirisawat and Kiatcharoenpol, 2018). Fuzzy version of TOPSIS, FTOPSIS, can be utilised in a fuzzy environment. FTOPSIS is highly recommended in the field of construction and engineering management for selecting and ranking from multiple alternatives (Islam et al., 2017). The technique has also been used for project risk assessment (Valipour et al., 2018), failure mode and effect analysis (Song et al., 2013), supplier selection process (Ghosh et al., 2020), and so on. Furthermore, FTOPSIS has been coupled with other methods like AHP or FAHP as a hybrid approach in several previous studies, such as for the risk assessment of the process industry (Gul and Guneri, 2016), supply chain performance assessment (Tyagi et al., 2018), prioritising solutions for logistics barriers (Sirisawat and Kiatcharoenpol, 2018), project portfolio selection (Tavana et al., 2015), advanced manufacturing system selection (Mathew et al., 2020a), optimal maintenance strategy selection (Mathew et al., 2020b), and so on. However, the use of FAHP and FTOPSIS to analyse hazards in power plants has not been explored yet and can be considered a new scope for study related to hazard analysis.

2.5 Review on Hazard Mitigation

Hazard mitigation involves measures usually taken to reduce the damage potentiality and impact of hazards in a cost-effective way (Hunter, 2017). While planning for a hazard mitigation strategy, the interrelationships among the mitigation methods can help decision-makers formulate proper action plan (Licitra et al., 2017). As hazard precursors are often not independent, mitigation methods must be designed based on their interrelationships (Rebello et al., 2019). In this study, based on the expert feedbacks, appropriate mitigation methods have been identified that can address the top-ranked hazards. These identified mitigation methods then have been analysed using ISM-MICMAC method, since the operational activities of power plants involve several discrete systems and accessories, for which the exploration of interrelationships based on driving and dependence power appears more appropriate.

2.6 Review on ISM-MICMAC

ISM is a renowned method for exploring relationships between variables based on their relative driving and dependence power, while MICMAC analysis is used to categorise variables as autonomous, dependent, linkage, and independent (Moktadir et al., 2019). ISM-MICMAC integrated approach, along with some sort of ranking method like AHP, best-worst method (BWM) etc., has been recently used by various researchers (Mukeshimana et al., 2021) for showing the ranking as well as the inter-dependencies among factors with in the same research. Such mixed or integrated methodologies has been used to analyse key factors behind energy-efficient supply-chains (Moktadir et al., 2019), analyse factors influencing the implementation of safety programs in the construction industries (Ibrahim and Mabrouk, 2021), risk assessment for thermal power plants (Li et al., 2019), evaluation strategies and drivers for renewable energy development (Anam et al. 2022), and barrier identification and analysis for implementing solar power plants (Nandal et al., 2019). However, to-date, hazard mitigation methods for power plants have not been explored using the both FAHP-FTOPSIS and ISM-MICMAC approach, which indicates a clear research gap.

2.7 Literature Review Summary

Some recently published closely related articles related to this research have been presented briefly in Table 1.

Table 1: Summary of recently published closely related studies

Author (s) and Year	**Applied Method**	**Application Area**	**Presented a Prioritization or Ranking?**	**Presented a hierarchical interrelationship?**
Anam et al. (2022)	BWM, ISM-MICMAC	Solar energy development	Yes	Yes
Lu et al. (2022)	AHP, FTOPSIS	Power transmission	Yes	No
Marhavilas et al. (2022)	AHP, HAZOP, DMRA	Petrochemical industry	Yes	No
Rehman et al. (2022)	FUCOM, VIKOR, QFD	Power generation	Yes	No
Shittu et al. (2022)	Relative Importance Index, Mean Item Score	Construction sites	Yes	No
Gul (2020)	Pythagorean fuzzy AHP and VIKOR	Safety in gun manufacturing industry	Yes	No
Saffarian et al. (2020)	FMEA and FAHP	Risk assessment in a gas power plant	Yes	No
Yazdi et al. (2020)	FAHP and FTOPSIS	Fire and explosion analysis in the process industries	Yes	No
Li et al. (2019)	ISM	Risk assessment for thermal power plants	No	Yes
Yucesan and Kahraman (2019)	Pythagorean fuzzy AHP	Risk factor analysis in hydro-electric power plant	Yes	No

CHAPTER 3

RESEARCH METHODOLOGY AND CALCULATIONS

3.1 Overview of Research Methodology

This study utilised FAHP, FTOPSIS, and ISM-MICMAC techniques for this research. Data were collected in multiple phases. At the initial stage, experts' responses were collected by an online survey to identify HFO-based power plants' operational hazards. The online survey was conducted using Google Forms. The initial questionnaire for gathering experts' responses was designed with 20 hazards, identified from the literature resources, and existing plant records. For the hazard identification, this study reviewed the closely related scholarly articles from Google Scholar and Scopus database, as there was no previous study on hazard analysis of HFO-based power plants directly. Then, the initial list was delivered to the experts via email to check the relevance of the identified hazards. The experts suggested adding 13 more operational hazards to the initial list during this data collection phase. However, they also removed three hazardous events from the primary list as the experts did not consider them to be very relevant in the case of HFO-based power plants. After gathering experts' responses, a total of 30 hazards were finally identified, which are shown in Table 4. Based on experts' responses in the final step of data collection (collected in a similar approach as identifying the hazards), the relevant mitigation methods were finalized and the interrelationships among them were examined as well.

In this study, a purposive or judgmental sampling method was carried out to select the experts (Belay et al., 2022). Purposive sampling is a non-probabilistic technique where the researcher's judgment is utilized to select the experts for gathering qualitative feedback to achieve the research objective, rather than using random sampling (Cash et al., 2022). In this study, a total of 21 industry experts, who have experience either in HFO-based power plant management or in marine engineering, were chosen purposively to collect responses. Inclusion criteria for experts included having a minimum educational qualification of a Bachelor's degree in mechanical, electrical, chemical or marine engineering, having at least ten years of working experience, and having knowledge of HFO-based power plant operation, maintenance, and safety. To maintain confidentiality, experts' names are not disclosed. A brief profile of the participating twenty-one experts' can be found in Table 2.

Table 2: Brief profile of the experts

Expert ID	**Title of the Expert**	**Experience (in years)**	**Education level**
E1	Executive Director and Head of the Plant	28	Post Graduate
E2	Assistant General Manager, Operations	19	Post Graduate
E3	Manager, Mechanical Maintenance	14	Post Graduate
E4	Senior Engineer, Mechanical Maintenance	10	Bachelor
E5	Manager, Electrical Maintenance	11	Post Graduate
E6	Manager, Health and Safety	15	Bachelor
E7	Senior Executive, Safety	10	Post Graduate
E8	Shift In-charge, Operations	12	Bachelor
E9	Shift In-charge, Electrical	11	Bachelor
E10	Shift In-charge, Mechanical	13	Post Graduate
E11	Shift In-charge, Chemical	10	Bachelor
E12	In-charge, Fuel Treatment	14	Bachelor
E13	Assistant General Manager, Mechanical	22	Post Graduate
E14	Deputy General Manager, Maintenance	13	Post Graduate
E15	Senior Manager, Electrical	12	Bachelor
E16	Senior Engineer, Electrical Maintenance	13	Bachelor
E17	Manager, Occupational Health and Safety	18	Post Graduate
E18	Assistant Manager, Chemical	10	Bachelor
E19	Executive Engineer, Mechanical	14	Bachelor
E20	Shift Engineer, Maintenance	10	Bachelor
E21	Shift Engineer, Operations	12	Post Graduate

The research methodology followed in this study is presented in Figure 1.

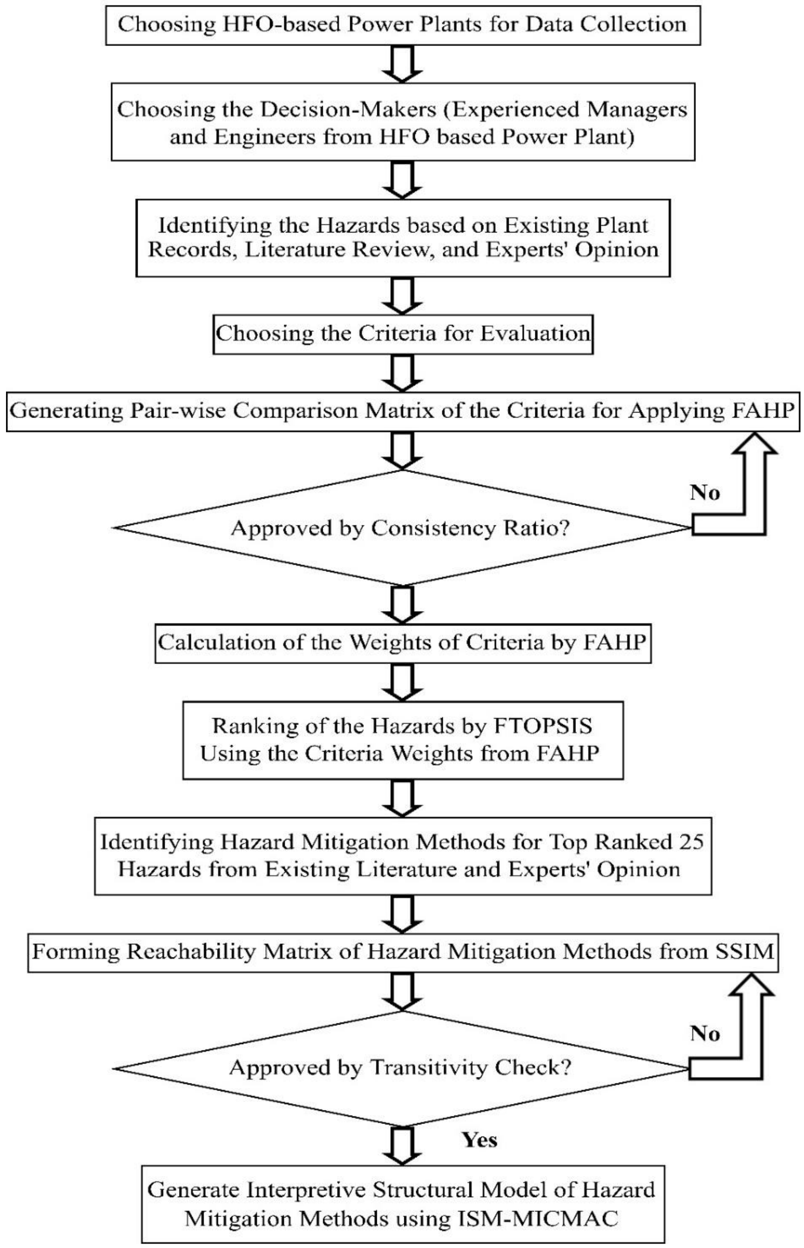

Figure 1: Research Methodology

3.2 Description of the Methodology

Step 1: Hazards have been identified from the experts' opinions who working in different HFO-based power plants of Bangladesh.

Step 2: Five criteria for hazard prioritization and ranking have been selected with the help of existing literatures.

Step 3: Hybrid Fuzzy AHP and Fuzzy TOPSIS methodology has been applied to prioritize and rank the hazards.

3.2.1 Hybrid Fuzzy AHP and Fuzzy TOPSIS Methodology

Fuzzy AHP:

- ***Step A:*** A scale with 9 linguistic variables based on Triangular Fuzzy Number (l, m, u) have been used to collect decision-makers' opinions to generate pair-wise comparison matrices of the criteria.
- ***Step B:*** Consistency of each of the pair-wise comparison matrix has been confirmed with maintaining Consistency Ratio less than or equal to 0.1.
- ***Step C:*** All the fuzzy pair-wise comparison matrices have been aggregated into a single fuzzy pair-wise comparison matrix using geometric mean approach.
- ***Step D:*** Fuzzy weights of criteria have been determined through geometric mean method and fuzzy operations.
- ***Step E:*** Fuzzy criteria weights have been de-fuzzified with simple centroid formula.

Fuzzy TOPSIS:

- ***Step F:*** A 5-point Likert scale with linguistic variable have been modified based on Triangular Fuzzy Number for the five criteria to collect decision-makers' opinions to generate Fuzzy Decision Matrices with the identified hazards.
- ***Step G:*** The Fuzzy Decision Matrices have been aggregated into a single Fuzzy Decision Matrix using minimum, mean, maximum approach.

- ***Step H:*** All the criteria have been determined as Benefit Criteria, hence, maximum 'u' value of TFN (l, m, u) among all the values for each of the criterion has been determined from the decision matrix.
- ***Step I:*** All the values of each criterion of the decision matrix have been divided by the associated value of that criterion achieved from *Step H* to normalize the matrix.
- ***Step J:*** All the values of the normalized matrix have been multiplied by the criteria weights achieved from *Step E* to get the Aggregated Weighted Normalized Decision Matrix.
- ***Step K:*** Fuzzy Positive Ideal Solution (FPIS) have been determined by finding the maximum and Fuzzy Negative Ideal Solution (FNIS) have been determined by finding the minimum fuzzy value for each of the criteria of the matrix achieved from *Step J.*
- ***Step L:*** Distances from FPIS and FNIS of each value of the matrix achieved from *Step J* have been calculated to find the Closeness Coefficient.
- ***Step M:*** Final ranking of the hazard has been achieved from the descending order of the Closeness Coefficient values of the hazards.

Step 4: Find mitigation methods for 25 top ranked hazards by literature review and expert opinion.

Step 5: Apply ISM MICMAC analysis for finding interpretive structural model of the mitigation methods.

3.2.2 ISM MICMAC Methodology

- ***Step N:*** Taking experts' opinion through questionnaire to form pairwise comparison based on driving and dependence power of the mitigation methods.
- ***Step O:*** From the pairwise comparison, a Structural Self-Interaction Matrix (SSIM) has been formed. SSIM shows the influence of one variable over another variable with a symbol of any of the four letters V, A, X, and O. If two variables are denoted with I

and j, then the interrelation among these two variables shall fall in any one of the following four conditions:

V: I influences j, but j does not influence i

A: j influences I, but I does not influence j

X: I influences j, and j influences i

O: I does not influence j, and j does not influence i

- ***Step P:*** The SSIM is converted into a Reachability Matrix (RM) by substituting the four symbols (i.e., V, A, X or O) of SSIM by 1s or 0s.

Table 3: Rules for substituting SSIM symbols

Entry in SSIM	Value of (I, j) entry in RM	Value of (j, i) entry in RM
V	1	0
A	0	1
X	1	1
O	0	0

Following the substitution rules shown in Table 3, the initial reachability matrix is prepared. The matrix is then checked for transitivity and 1* entries are included to fill any gap in the SSIM. After incorporating the transitivity, the final reachability matrix is formed.

- ***Step Q:*** Reachability, Antecedents and Intersection sets were formed for level partitioning.
- ***Step R:*** After all the iteration have been completed, interpretive structural model of the hazard mitigation methods has been built.
- ***Step S:*** MICMAC analysis has been done by graphical presentation of the driving and dependence power of the mitigation methods in 4 different groups: Autonomous, Dependent, Linkage, Independent.

Step 6: Managerial insights and limitations of the findings have been discussed to support future decision-makers.

3.2.3 The Basics of Fuzzy Logic

Fuzzy logic involves approximate reasoning rather than precision and is therefore capable of handling uncertainty. Let, Ã (a_{ij}) be a fuzzy judgement matrix that can be expressed mathematically as in matrix (1).

$$\begin{bmatrix} (1,1,1) & \tilde{a}_{12} & .. & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & .. & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & .. & (1,1,1) \end{bmatrix} \quad (1)$$

Here, $\tilde{a}_{ji} = \tilde{a}_{ij}{}^{-1}$ and all $\tilde{a}_{ij}$ are TFN. The TFN is a very popular fuzzy number type, among several others. $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ A TFN with a lower limit l_{ij} and an upper limit $u_{ij} \cdot m_{ij}$ is the point where$\mu(x) = 1$. A graphical presentation of TFN is shown in Figure 2.

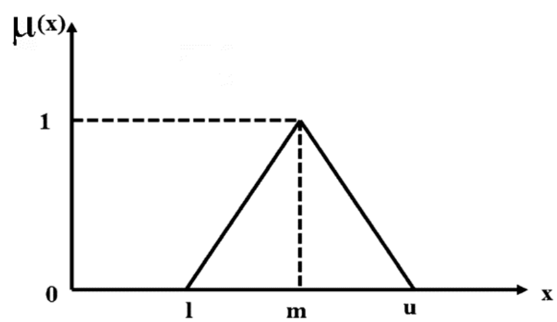

Figure 2: The membership function of TFN

The membership function $\mu(x)$ of TFN as described by Chang (1996) is shown in equation (2).

$$\mu(x) = \begin{cases} \frac{x-l}{m-l}, & x\epsilon[l,m] \\ \frac{u-x}{u-m}, & x\epsilon[m,u] \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

Where $l_{ij} \leq m_{\mathrm{ij}} \leq u_{\mathrm{ij}}$. If $l_{\mathrm{ij}} = m_{\mathrm{ij}} = u_{\mathrm{ij}}$, the fuzzy number becomes a crisp number.

Assuming $\tilde{M}_1$ and $\tilde{M}_2$ are two TFNs, where $\tilde{M}_1 = (l_1, m_1, u_1)$ and$\tilde{M}_2 = (l_2, m_2, u_2)$, some basic operations of TFN are as follows:

$$\tilde{M}_1 \oplus \tilde{M}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (3)$$
$$\tilde{M}_1 \otimes \tilde{M}_2 = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (4)$$
$$\tilde{M}_1^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \quad (5)$$

3.3 Identification of Potential Hazards

An HFO-based power plant consists of several hazard-prone areas such as the fuel treatment plant and tank yard, the engine hall and control room, the boiler and stack area, the compressor room, the sub-station, the water treatment and chemical plant, the general plant area, etc. These areas are particularly prone to potential hazards and if not properly maintained, many dangers can befall these areas.

Twenty-one experienced personnel (directors, managers, and engineers) from HFO-based power plants across Bangladesh participated as study experts in hazard identification and determination of criteria weights. Subsequently, the eleven most experienced of the twenty-one experts participated again in the ISM-MICMAC study. Sample questionnaires sent to experts by email as Google Forms, which are provided in **Appendix section**. Hazardous activities identified through the literature and through feedback from experts were aggregated in a single generalised hazard list, as shown in Table 4.

Table 4: Identified hazards

Code	Hazard Description	Relevant Literature/Source
H1	Contact with high-speed rotating machines during operation	(Li et al., 2019)
H2	Falling from height during operation and maintenance at higher places	(Rathod et al., 2017); (Bussier et al., 2020)
H3	Falling of heavy equipment during overhead crane operation	(Yucesan and Kahraman, 2019)
H4	Fire from the presence of hot combustible material	(Yucesan and Kahraman, 2019); (Li et al., 2019)
H5	Long term contact with spilled HFO and hazardous chemicals	Expert Opinion
H6	Spillage of oil during valve operation and maintenance	(Li et al., 2019); (Marhavilas et al., 2020b)
H7	Burning by high temperature HFO, steam and condensed line	(Rathod et al., 2017); (Li et al., 2019)
H8	Crankcase explosion and fire hazard due to oil mist pressure rise	(Marhavilas et al., 2020b)
H9	Failure of Permit to Work system	(Alrifaey et al., 2019); (Illankoon et al., 2019)
H10	Lack of oxygen due to improper ventilation	(Chow and Walker, 2019)
H11	Leakage of hot substance while starting engine	Expert Opinion
H12	Explosion of compressed air reservoir	(Yucesan and Kahraman, 2019)
H13	Poor earthing connection of electrical equipment	Expert Opinion
H14	Explosion of circuit breaker during operation at switchgear	Expert Opinion
H15	Fire from heat build-up in high voltage equipment	Expert Opinion
H16	Maintenance work without de-energizing the system	(Zhao et al., 2015); (Illankoon et al., 2019)
H17	Contact or near approach to live high voltage overhead lines	Expert Opinion
H18	Electrocution while isolating and switching high voltage distribution line	Expert Opinion
H19	Induced voltage during work on isolated equipment	(Illankoon et al., 2019)
H20	Unauthorized entry in restricted area	Expert Opinion
H21	Explosion from steam hammering at high pressure	Expert Opinion
H22	Explosion of high-pressure steam drum of exhaust gas boiler	(Rathod et al., 2017)
H23	Fire hazard due to dirty heat surface of EGB	Expert Opinion
H24	Inhalation and ingestion of heavy toxic particles during soot blowing	(Li et al., 2019)
H25	Explosion in chemical store	(Marhavilas et al., 2020a)
H26	Fire hazard from flammable chemical in chemical store	(Marhavilas et al., 2020a)
H27	Inhalation and ingestion of HFO or other toxic fumes	(Ezrahovich et al., 2017)
H28	Injury by sharp metal chips while working in workshop	Expert Opinion
H29	Fire hazard from hot work	Expert Opinion
H30	Contact with buried electric cables while excavating	Expert Opinion

3.4 Calculation of Criteria Weights Using FAHP

Hazards were prioritised in this study based on five criteria: severity (a function of the magnitude of the associated risk), likelihood (a function of frequency of occurrence in a given time interval), extent (a function of the scale or range of the area affected by the hazard), time frame (a function of warning time, length, and duration of emergency operation), and manageability (a function of the capability to improve, manage, and maintain risky processes) (Community emergency preparedness: a manual for managers and policy-makers, 1999).

Chang's TFN-based FAHP using Buckley's geometric mean method (Meixner, 2009) was used to determine criteria weights. Twenty-one fuzzified and pairwise comparison matrices were formed with the responses of each of the 21 experts. A sample questionnaire to gather experts opinion can for FAHP can be found in **Appendix A**. Linguistic variables and TFNs for criteria ratings are shown in Table 5 (Kannan et al., 2013). Based on this scale, fuzzy pairwise comparison matrices were formed from the linguistic responses of experts.

Table 5: Linguistic variables for pairwise comparison

Linguistic variable	Fuzzy Numbers
Extremely strong	(9,9,9)
Intermediate	(7,8,9)
Very strong	(6,7,8)
Intermediate	(5,6,7)
Strong	(4,5,6)
Intermediate	(3,4,5)
Moderately strong	(2,3,4)
Intermediate	(1,2,3)
Equally strong	(1,1,1)

Consistency index (CI) and consistency ratio (CR) value for each of the de-fuzzified comparison matrices were calculated to ensure decision quality using equations (6) and (7). The random consistency (RC) for a 5 by 5 matrix is 1.11, and the consistency ratio (CR) should not exceed 0.1 for a matrix larger than 4 by 4 (Saaty, 1990; Meixner, 2009).

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{6}$$

$$CR = \frac{CI}{RC} \leq 0.1 \tag{7}$$

The process for generating pairwise comparisons was repeated until the consistency ratio of a specific matrix was more than 0.1 (Saaty, 1990; Pant et al., 2022).

3.4.1 Consistency of Comparison Checking for FAHP

In this research, consistency of comparison has been checked for the FAHP method. Consistency of each of the pair-wise comparison matrices has been confirmed by maintaining a consistency ratio less than or equal to 0.1, following the rules of AHP or FAHP (Saaty, 1990; Meixner, 2009; Pant et al., 2022). Tables 6 to 9 show how **consistency index (CI)** and then **consistency ratio (CR)** was calculated for **expert 1 (E1)** as an example.

Table 6: Fuzzified sample response from E1 for pair-wise comparison

	Severity			**Likelihood**			**Extent**			**Time Frame**			**Manageability**		
Severity	1.0	1.0	1.0	1.0	2.0	3.0	6.0	7.0	8.0	4.0	5.0	6.0	2.0	3.0	4.0
Likelihood	0.3	0.5	1.0	1.0	1.0	1.0	4.0	5.0	6.0	3.0	4.0	5.0	1.0	2.0	3.0
Extent	0.1	0.1	0.2	0.2	0.2	0.3	1.0	1.0	1.0	0.3	0.3	0.5	0.2	0.3	0.3
Time Frame	0.2	0.2	0.3	0.2	0.3	0.3	2.0	3.0	4.0	1.0	1.0	1.0	0.3	0.3	0.5
Manageability	0.3	0.3	0.5	0.3	0.5	1.0	3.0	4.0	5.0	2.0	3.0	4.0	1.0	1.0	1.0

Table 7: Non-fuzzified sample response from E1 for pair-wise comparison

	Severity	**Likelihood**	**Extent**	**Time Frame**	**Manageability**
Severity	1.000	2.000	7.000	5.000	3.000
Likelihood	0.583	1.000	5.000	4.000	2.000
Extent	0.144	0.204	1.000	0.354	0.258
Time Frame	0.204	0.258	3.000	1.000	0.354
Manageability	0.354	0.583	4.000	3.000	1.000
Sum=	2.286	4.046	20.000	13.354	6.613

Table 8: Normalized matrix

	Severity	Likelihood	Extent	Time Frame	Manageability	Weights
Severity	0.437	0.494	0.350	0.374	0.454	**0.422**
Likelihood	0.255	0.247	0.250	0.300	0.302	**0.271**
Extent	0.063	0.050	0.050	0.027	0.039	**0.046**
Time Frame	0.089	0.064	0.150	0.075	0.054	**0.086**
Manageability	0.155	0.144	0.200	0.225	0.151	**0.175**

Table 9: Weighted matrix

	Severity	Likelihood	Extent	Time Frame	Manageability	Weighted Sum Value		λ_{max}
Severity	0.422	0.542	0.321	0.432	0.525	2.241	5.311	**5.245**
Likelihood	0.246	0.271	0.229	0.345	0.350	1.441	5.322	
Extent	0.061	0.055	0.046	0.031	0.045	0.238	5.188	
Time Frame	0.086	0.070	0.138	0.086	0.062	0.442	5.120	
Manageability	0.149	0.158	0.183	0.259	0.175	0.925	5.284	

By using equations (6) and (7), the calculated CI and CR value for expert 1 is thus 0.061 and 0.055 respectively. Notice that the CR value is less than 0.1 here, which is ok according to the AHP or FAHP protocol (Saaty, 1990; Pant et al., 2022). CR values for all 21 experts have been calculated similarly to make sure none of them exceeds 0.1. In this research, none were more than 0.1. However, suppose there was any such expert feedback for which CR value is greater than 0.1. In that case, the protocol is to repeat the pairwise comparison process for that certain expert again and again until a CR value less than 0.1 is achieved.

Table 10: Aggregated fuzzified pairwise comparison matrix through geometric mean

	Severity			Likelihood			Extent			Time Frame			Manageability		
Severity	1.00	1.00	1.00	2.06	3.15	4.20	4.75	5.78	6.80	3.92	4.83	5.82	0.96	1.46	2.10
Likelihood	0.24	0.32	0.49	1.00	1.00	1.00	2.08	3.18	4.23	2.13	2.95	3.79	0.40	0.55	0.79
Extent	0.15	0.17	0.21	0.24	0.32	0.48	1.00	1.00	1.00	0.26	0.36	0.53	0.17	0.21	0.27
Time Frame	0.17	0.21	0.26	0.26	0.34	0.47	1.87	2.79	3.78	1.00	1.00	1.00	0.24	0.32	0.45
Manageability	0.48	0.68	1.05	1.27	1.81	2.51	3.73	4.77	5.79	2.21	3.16	4.18	1.00	1.00	1.00

Using equation (8), the 21 matrices were subsequently aggregated into a single fuzzified pairwise comparison matrix, as shown in Table 10.

$$l_{ij} = \left(\prod_{k=1}^{k} l_{ijk}\right)^{1/k}, m_{ij} = \left(\prod_{k=1}^{k} m_{ijk}\right)^{1/k}, u_{ij} = \left(\prod_{k=1}^{k} u_{ijk}\right)^{1/k} \tag{8}$$

The fuzzy ratings of criteria were calculated through the geometric means method with equation (9) and fuzzy weights were calculated with equation (10).

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{P}_{ij}\right)^{1/n} \tag{9}$$

$$\tilde{w}_i = \tilde{r}_i \otimes \left(\sum_{i=1}^{n} \tilde{r}_i\right)^{-1}, i = 1,2,\dots,n \tag{10}$$

Table 11: Fuzzy geometric mean value and criteria weight

	Fuzzy Geometric Mean Value, r			Fuzzy Weight of Criteria, w		
Severity	2.0554	2.6417	3.2261	0.4103	0.4097	0.3976
Likelihood	0.8408	1.1043	1.4364	0.1679	0.1713	0.1770
Extent	0.2756	0.3330	0.4289	0.0550	0.0516	0.0529
Time Frame	0.4586	0.5733	0.7285	0.0916	0.0889	0.0898
Manageability	1.3787	1.7958	2.2940	0.2752	0.2785	0.2827

Table 11 shows fuzzy geometric mean values and the fuzzy weights of criteria. Further de-fuzzification was conducted by using a simple centroid method; resulting criteria weights are illustrated in Table 12.

Table 12: Criteria weights

Criteria	Calculated Weights
Severity	0.40587
Likelihood	0.17204
Extent	0.05316
Time Frame	0.09008
Manageability	0.27882

3.5 Ranking of Hazards Using FTOPSIS

This study used FTOPSIS to determine the final hazard ranking using the criteria weights identified by the FAHP method in section 3.4. This work used the TFN-based 5-point Likert scale to collect expert opinion, which is shown in Table 13.

Table 13: TFN-based 5-point Likert scale for ranking of alternatives

Linguistic Variable	Fuzzy Numbers
Very Low	(1,1,3)
Low	(1,3,5)
Average	(3,5,7)
High	(5,7,9)
Very High	(7,9,9)

A scale based on these five points was designed and modified for the study. The modified scale is shown in Table 14. Identified hazards were evaluated based on five criteria with the modified fuzzy scale. The same 21 experts participated in a simple questionnaire-based the response for the hazard evaluation.

Table 14: Modified 5-point scale to collect experts' opinion for FTOPSIS.

Severity	Very Low	First Aid Only	1,1,3
	Low	Medical Treatment	1,3,5
	Average	Partial Disability	3,5,7
	High	Permanent Disability	5,7,9
	Very High	Death	7,9,9
Likelihood	Very Low	Very Unlikely	1,1,3
	Low	Unlikely	1,3,5
	Average	Possible	3,5,7
	High	Probable	5,7,9
	Very High	Multiple	7,9,9
Extent	Very Low	Negligible	1,1,3
	Low	Low	1,3,5
	Average	Medium	3,5,7
	High	High	5,7,9
	Very High	Extreme	7,9,9
Time Frame	Very Low	Very Short Term	1,1,3
	Low	Short Term	1,3,5
	Average	Medium Term	3,5,7
	High	Long Term	5,7,9
	Very High	Very Long Term	7,9,9
Manageability	Very Low	Personal Protective Equipment	1,1,3
	Low	Administrative Control	1,3,5
	Average	Engineering Control	3,5,7
	High	Replacement	5,7,9
	Very High	Elimination	7,9,9

The questionnaire format with a sample response is included in **Appendix B**. An individual decision matrix was obtained from each expert opinion, with a total of 21 decision matrices formed. A sample matrix can be found in Table 15.

Table 15: Sample fuzzy decision matrix based on expert opinion (from expert 1)

Code	Severity			Likelihood			Extent			Time Frame			Manageability		
H1	5	7	9	1	3	5	1	3	5	1	3	5	3	5	7
H2	7	9	9	1	3	5	1	3	5	1	3	5	3	5	7
H3	5	7	9	1	3	5	1	3	5	1	3	5	3	5	7
H4	3	5	7	1	3	5	5	7	9	3	5	7	7	9	9
H5	5	7	9	5	7	9	3	5	7	3	5	7	1	3	5
H6	3	5	7	5	7	9	5	7	9	3	5	7	3	5	7
H7	3	5	7	7	9	9	3	5	7	3	5	7	1	1	3
H8	7	9	9	1	3	5	7	9	9	5	7	9	5	7	9
H9	5	7	9	3	5	7	7	9	9	7	9	9	7	9	9
H10	3	5	7	3	5	7	3	5	7	3	5	7	3	5	7
H11	3	5	7	1	3	5	1	3	5	1	3	5	1	1	3
H12	7	9	9	1	3	5	5	7	9	5	7	9	5	7	9
H13	3	5	7	5	7	9	3	5	7	3	5	7	3	5	7
H14	7	9	9	1	3	5	5	7	9	5	7	9	5	7	9
H15	5	7	9	1	3	5	7	9	9	7	9	9	3	5	7
H16	7	9	9	1	3	5	7	9	9	7	9	9	3	5	7
H17	7	9	9	3	5	7	7	9	9	5	7	9	1	3	5
H18	5	7	9	5	7	9	5	7	9	5	7	9	3	5	7
H19	5	7	9	3	5	7	1	3	5	3	5	7	1	1	3
H20	3	5	7	1	3	5	5	7	9	5	7	9	1	3	5
H21	5	7	9	1	3	5	5	7	9	5	7	9	3	5	7
H22	7	9	9	3	5	7	7	9	9	7	9	9	5	7	9
H23	3	5	7	1	3	5	5	7	9	5	7	9	3	5	7
H24	7	9	9	5	7	9	5	7	9	3	5	7	1	1	3
H25	7	9	9	3	5	7	7	9	9	5	7	9	7	9	9
H26	7	9	9	3	5	7	5	7	9	5	7	9	7	9	9
H27	7	9	9	3	5	7	1	3	5	1	3	5	1	3	5
H28	5	7	9	7	9	9	3	5	7	3	5	7	1	1	3
H29	5	7	9	7	9	9	7	9	9	7	9	9	3	5	7
H30	7	9	9	5	7	9	7	9	9	7	9	9	1	3	5

Table 16: Fuzzy aggregated decision matrix (min, mean, max)

Code	Severity			Likelihood			Extent			Time Frame			Manageability		
H1	5.000	7.000	9.000	1.000	3.857	9.000	1.000	3.857	9.000	1.000	3.667	9.000	3.000	5.000	7.000
H2	7.000	9.000	9.000	1.000	3.571	9.000	1.000	3.286	9.000	1.000	3.762	9.000	1.000	4.619	7.000
H3	5.000	8.905	9.000	1.000	3.762	9.000	1.000	3.571	9.000	1.000	3.571	9.000	3.000	5.000	7.000
H4	3.000	5.476	9.000	1.000	3.667	9.000	5.000	7.381	9.000	3.000	5.762	9.000	7.000	9.000	9.000
H5	3.000	6.810	9.000	3.000	6.905	9.000	1.000	5.000	9.000	3.000	5.095	9.000	1.000	2.810	5.000
H6	3.000	5.000	7.000	5.000	7.000	9.000	5.000	7.000	9.000	3.000	5.190	9.000	3.000	5.000	7.000
H7	3.000	6.905	9.000	3.000	7.000	9.000	3.000	6.905	9.000	1.000	6.714	9.000	1.000	2.048	7.000
H8	7.000	9.000	9.000	1.000	3.381	7.000	7.000	9.000	9.000	5.000	7.476	9.000	5.000	7.381	9.000
H9	5.000	7.000	9.000	1.000	4.905	7.000	5.000	8.048	9.000	3.000	7.190	9.000	1.000	6.143	9.000
H10	3.000	5.952	9.000	3.000	5.000	7.000	3.000	5.857	9.000	3.000	5.000	7.000	1.000	4.905	7.000
H11	3.000	5.000	7.000	1.000	3.000	5.000	1.000	3.952	7.000	1.000	3.000	5.000	1.000	4.048	9.000
H12	7.000	9.000	9.000	1.000	3.000	5.000	5.000	7.000	9.000	5.000	7.000	9.000	5.000	7.000	9.000
H13	3.000	6.333	9.000	3.000	6.905	9.000	3.000	6.238	9.000	1.000	6.143	9.000	3.000	5.000	7.000
H14	5.000	8.905	9.000	1.000	3.476	7.000	5.000	7.762	9.000	5.000	7.000	9.000	5.000	7.000	9.000
H15	5.000	8.143	9.000	1.000	4.143	7.000	7.000	9.000	9.000	5.000	8.429	9.000	3.000	6.143	9.000
H16	7.000	9.000	9.000	1.000	3.000	5.000	5.000	7.667	9.000	5.000	7.667	9.000	1.000	4.714	7.000
H17	5.000	8.905	9.000	3.000	5.190	9.000	5.000	7.952	9.000	5.000	7.000	9.000	1.000	3.952	7.000
H18	5.000	8.810	9.000	5.000	7.000	9.000	5.000	7.000	9.000	5.000	7.000	9.000	3.000	5.000	7.000
H19	5.000	8.429	9.000	3.000	6.524	9.000	1.000	6.143	9.000	3.000	7.381	9.000	1.000	5.857	9.000
H20	3.000	7.476	9.000	1.000	1.381	5.000	1.000	4.333	9.000	1.000	3.762	9.000	1.000	3.000	5.000
H21	5.000	7.190	9.000	1.000	5.286	9.000	5.000	7.190	9.000	5.000	7.190	9.000	3.000	5.857	9.000
H22	7.000	9.000	9.000	3.000	5.952	9.000	5.000	8.619	9.000	5.000	8.619	9.000	3.000	7.190	9.000
H23	3.000	6.714	9.000	1.000	5.857	9.000	3.000	7.000	9.000	3.000	6.619	9.000	1.000	5.381	9.000
H24	5.000	8.714	9.000	3.000	6.905	9.000	5.000	7.190	9.000	3.000	6.333	9.000	1.000	1.762	7.000
H25	5.000	8.810	9.000	1.000	5.952	9.000	3.000	7.952	9.000	5.000	7.762	9.000	5.000	7.381	9.000
H26	5.000	8.810	9.000	3.000	6.143	9.000	3.000	7.000	9.000	3.000	7.095	9.000	3.000	7.667	9.000
H27	7.000	9.000	9.000	1.000	4.905	9.000	1.000	5.857	9.000	1.000	5.857	9.000	1.000	5.190	9.000
H28	1.000	5.381	9.000	1.000	5.952	9.000	1.000	4.143	9.000	1.000	3.762	7.000	1.000	2.905	9.000
H29	5.000	8.524	9.000	5.000	7.476	9.000	5.000	7.762	9.000	1.000	7.190	9.000	3.000	7.000	9.000
H30	5.000	8.619	9.000	3.000	7.095	9.000	3.000	7.571	9.000	3.000	7.381	9.000	1.000	6.143	9.000

Table 17: Normalized decision matrix

Code	Severity			Likelihood			Extent			Time Frame			Manageability		
H1	0.556	0.778	1.000	0.111	0.429	1.000	0.111	0.429	1.000	0.111	0.407	1.000	0.333	0.556	0.778
H2	0.778	1.000	1.000	0.111	0.397	1.000	0.111	0.365	1.000	0.111	0.418	1.000	0.111	0.513	0.778
H3	0.556	0.989	1.000	0.111	0.418	1.000	0.111	0.397	1.000	0.111	0.397	1.000	0.333	0.556	0.778
H4	0.333	0.608	1.000	0.111	0.407	1.000	0.556	0.820	1.000	0.333	0.640	1.000	0.778	1.000	1.000
H5	0.333	0.757	1.000	0.333	0.767	1.000	0.111	0.556	1.000	0.333	0.566	1.000	0.111	0.312	0.556
H6	0.333	0.556	0.778	0.556	0.778	1.000	0.556	0.778	1.000	0.333	0.577	1.000	0.333	0.556	0.778
H7	0.333	0.767	1.000	0.333	0.778	1.000	0.333	0.767	1.000	0.111	0.746	1.000	0.111	0.228	0.778
H8	0.778	1.000	1.000	0.111	0.376	0.778	0.778	1.000	1.000	0.556	0.831	1.000	0.556	0.820	1.000
H9	0.556	0.778	1.000	0.111	0.545	0.778	0.556	0.894	1.000	0.333	0.799	1.000	0.111	0.683	1.000
H10	0.333	0.661	1.000	0.333	0.556	0.778	0.333	0.651	1.000	0.333	0.556	0.778	0.111	0.545	0.778
H11	0.333	0.556	0.778	0.111	0.333	0.556	0.111	0.439	0.778	0.111	0.333	0.556	0.111	0.450	1.000
H12	0.778	1.000	1.000	0.111	0.333	0.556	0.556	0.778	1.000	0.556	0.778	1.000	0.556	0.778	1.000
H13	0.333	0.704	1.000	0.333	0.767	1.000	0.333	0.693	1.000	0.111	0.683	1.000	0.333	0.556	0.778
H14	0.556	0.989	1.000	0.111	0.386	0.778	0.556	0.862	1.000	0.556	0.778	1.000	0.556	0.778	1.000
H15	0.556	0.905	1.000	0.111	0.460	0.778	0.778	1.000	1.000	0.556	0.937	1.000	0.333	0.683	1.000
H16	0.778	1.000	1.000	0.111	0.333	0.556	0.556	0.852	1.000	0.556	0.852	1.000	0.111	0.524	0.778
H17	0.556	0.989	1.000	0.333	0.577	1.000	0.556	0.884	1.000	0.556	0.778	1.000	0.111	0.439	0.778
H18	0.556	0.979	1.000	0.556	0.778	1.000	0.556	0.778	1.000	0.556	0.778	1.000	0.333	0.556	0.778
H19	0.556	0.937	1.000	0.333	0.725	1.000	0.111	0.683	1.000	0.333	0.820	1.000	0.111	0.651	1.000
H20	0.333	0.831	1.000	0.111	0.153	0.556	0.111	0.481	1.000	0.111	0.418	1.000	0.111	0.333	0.556
H21	0.556	0.799	1.000	0.111	0.587	1.000	0.556	0.799	1.000	0.556	0.799	1.000	0.333	0.651	1.000
H22	0.778	1.000	1.000	0.333	0.661	1.000	0.556	0.958	1.000	0.556	0.958	1.000	0.333	0.799	1.000
H23	0.333	0.746	1.000	0.111	0.651	1.000	0.333	0.778	1.000	0.333	0.735	1.000	0.111	0.598	1.000
H24	0.556	0.968	1.000	0.333	0.767	1.000	0.556	0.799	1.000	0.333	0.704	1.000	0.111	0.196	0.778
H25	0.556	0.979	1.000	0.111	0.661	1.000	0.333	0.884	1.000	0.556	0.862	1.000	0.556	0.820	1.000
H26	0.556	0.979	1.000	0.333	0.683	1.000	0.333	0.778	1.000	0.333	0.788	1.000	0.333	0.852	1.000
H27	0.778	1.000	1.000	0.111	0.545	1.000	0.111	0.651	1.000	0.111	0.651	1.000	0.111	0.577	1.000
H28	0.111	0.598	1.000	0.111	0.661	1.000	0.111	0.460	1.000	0.111	0.418	0.778	0.111	0.323	1.000
H29	0.556	0.947	1.000	0.556	0.831	1.000	0.556	0.862	1.000	0.111	0.799	1.000	0.333	0.778	1.000
H30	0.556	0.958	1.000	0.333	0.788	1.000	0.333	0.841	1.000	0.333	0.820	1.000	0.111	0.683	1.000

Table 18: Fuzzy aggregated normalized weighted decision matrix

Code	Severity			Likelihood			Extent			Time Frame			Manageability		
H1	0.225	0.316	0.406	0.019	0.074	0.172	0.006	0.023	0.053	0.010	0.037	0.090	0.093	0.155	0.217
H2	0.316	0.406	0.406	0.019	0.068	0.172	0.006	0.019	0.053	0.010	0.038	0.090	0.031	0.143	0.217
H3	0.225	0.402	0.406	0.019	0.072	0.172	0.006	0.021	0.053	0.010	0.036	0.090	0.093	0.155	0.217
H4	0.135	0.247	0.406	0.019	0.070	0.172	0.030	0.044	0.053	0.030	0.058	0.090	0.217	0.279	0.279
H5	0.135	0.307	0.406	0.057	0.132	0.172	0.006	0.030	0.053	0.030	0.051	0.090	0.031	0.087	0.155
H6	0.135	0.225	0.316	0.096	0.134	0.172	0.030	0.041	0.053	0.030	0.052	0.090	0.093	0.155	0.217
H7	0.135	0.311	0.406	0.057	0.134	0.172	0.018	0.041	0.053	0.010	0.067	0.090	0.031	0.063	0.217
H8	0.316	0.406	0.406	0.019	0.065	0.134	0.041	0.053	0.053	0.050	0.075	0.090	0.155	0.229	0.279
H9	0.225	0.316	0.406	0.019	0.094	0.134	0.030	0.048	0.053	0.030	0.072	0.090	0.031	0.190	0.279
H10	0.135	0.268	0.406	0.057	0.096	0.134	0.018	0.035	0.053	0.030	0.050	0.070	0.031	0.152	0.217
H11	0.135	0.225	0.316	0.019	0.057	0.096	0.006	0.023	0.041	0.010	0.030	0.050	0.031	0.125	0.279
H12	0.316	0.406	0.406	0.019	0.057	0.096	0.030	0.041	0.053	0.050	0.070	0.090	0.155	0.217	0.279
H13	0.135	0.286	0.406	0.057	0.132	0.172	0.018	0.037	0.053	0.010	0.061	0.090	0.093	0.155	0.217
H14	0.225	0.402	0.406	0.019	0.066	0.134	0.030	0.046	0.053	0.050	0.070	0.090	0.155	0.217	0.279
H15	0.225	0.367	0.406	0.019	0.079	0.134	0.041	0.053	0.053	0.050	0.084	0.090	0.093	0.190	0.279
H16	0.316	0.406	0.406	0.019	0.057	0.096	0.030	0.045	0.053	0.050	0.077	0.090	0.031	0.146	0.217
H17	0.225	0.402	0.406	0.057	0.099	0.172	0.030	0.047	0.053	0.050	0.070	0.090	0.031	0.122	0.217
H18	0.225	0.397	0.406	0.096	0.134	0.172	0.030	0.041	0.053	0.050	0.070	0.090	0.093	0.155	0.217
H19	0.225	0.380	0.406	0.057	0.125	0.172	0.006	0.036	0.053	0.030	0.074	0.090	0.031	0.181	0.279
H20	0.135	0.337	0.406	0.019	0.026	0.096	0.006	0.026	0.053	0.010	0.038	0.090	0.031	0.093	0.155
H21	0.225	0.324	0.406	0.019	0.101	0.172	0.030	0.042	0.053	0.050	0.072	0.090	0.093	0.181	0.279
H22	0.316	0.406	0.406	0.057	0.114	0.172	0.030	0.051	0.053	0.050	0.086	0.090	0.093	0.223	0.279
H23	0.135	0.303	0.406	0.019	0.112	0.172	0.018	0.041	0.053	0.030	0.066	0.090	0.031	0.167	0.279
H24	0.225	0.393	0.406	0.057	0.132	0.172	0.030	0.042	0.053	0.030	0.063	0.090	0.031	0.055	0.217
H25	0.225	0.397	0.406	0.019	0.114	0.172	0.018	0.047	0.053	0.050	0.078	0.090	0.155	0.229	0.279
H26	0.225	0.397	0.406	0.057	0.117	0.172	0.018	0.041	0.053	0.030	0.071	0.090	0.093	0.238	0.279
H27	0.316	0.406	0.406	0.019	0.094	0.172	0.006	0.035	0.053	0.010	0.059	0.090	0.031	0.161	0.279
H28	0.045	0.243	0.406	0.019	0.114	0.172	0.006	0.024	0.053	0.010	0.038	0.070	0.031	0.090	0.279
H29	0.225	0.384	0.406	0.096	0.143	0.172	0.030	0.046	0.053	0.010	0.072	0.090	0.093	0.217	0.279
H30	0.225	0.389	0.406	0.057	0.136	0.172	0.018	0.045	0.053	0.030	0.074	0.090	0.031	0.190	0.279

Table 19: Fuzzy positive ideal solution

Severity			**Likelihood**			**Extent**			**Time Frame**			**Manageability**		
0.316	0.406	0.406	0.134	0.172	0.172	0.041	0.053	0.053	0.050	0.086	0.090	0.217	0.279	0.279

Table 20: Fuzzy negative ideal solution

Severity			**Likelihood**			**Extent**			**Time Frame**			**Manageability**		
0.045	0.135	0.225	0.019	0.021	0.096	0.006	0.018	0.030	0.010	0.030	0.050	0.031	0.031	0.093

Table 21: Distances from FPIS

Code	Severity	Likelihood	Extent	Time Frame	Manageability	Di*
H1	0.074	0.086	0.027	0.037	0.107	0.331
H2	0.000	0.088	0.028	0.036	0.137	0.289
H3	0.053	0.087	0.028	0.037	0.107	0.311
H4	0.140	0.087	0.009	0.020	0.000	0.256
H5	0.120	0.049	0.025	0.023	0.169	0.387
H6	0.157	0.031	0.010	0.023	0.107	0.327
H7	0.119	0.048	0.016	0.026	0.167	0.376
H8	0.000	0.092	0.000	0.007	0.046	0.144
H9	0.074	0.082	0.008	0.014	0.118	0.296
H10	0.132	0.066	0.018	0.026	0.134	0.376
H11	0.157	0.103	0.028	0.046	0.138	0.472
H12	0.000	0.103	0.010	0.009	0.050	0.172
H13	0.126	0.049	0.017	0.027	0.107	0.326
H14	0.053	0.092	0.008	0.009	0.050	0.212
H15	0.057	0.087	0.000	0.001	0.087	0.232
H16	0.000	0.103	0.008	0.005	0.136	0.252
H17	0.053	0.060	0.008	0.009	0.144	0.274
H18	0.053	0.031	0.010	0.009	0.107	0.209
H19	0.055	0.051	0.023	0.014	0.120	0.262
H20	0.113	0.115	0.026	0.036	0.167	0.458
H21	0.071	0.076	0.009	0.008	0.090	0.255
H22	0.000	0.055	0.007	0.000	0.078	0.139
H23	0.121	0.073	0.016	0.016	0.124	0.351
H24	0.053	0.049	0.009	0.018	0.171	0.300
H25	0.053	0.073	0.015	0.005	0.046	0.191
H26	0.053	0.053	0.016	0.015	0.075	0.211
H27	0.000	0.079	0.024	0.028	0.126	0.257
H28	0.184	0.073	0.027	0.038	0.152	0.474
H29	0.054	0.027	0.008	0.025	0.079	0.194
H30	0.054	0.048	0.015	0.014	0.118	0.248

Table 22: Distances from FNIS

Code	Severity	Likelihood	Extent	Time Frame	Manageability	Di-
H1	0.180	0.055	0.014	0.023	0.108	0.380
H2	0.245	0.053	0.014	0.023	0.097	0.433
H3	0.213	0.054	0.014	0.023	0.108	0.412
H4	0.132	0.053	0.024	0.030	0.209	0.449
H5	0.152	0.081	0.015	0.028	0.049	0.326
H6	0.090	0.090	0.024	0.029	0.108	0.340
H7	0.154	0.082	0.020	0.031	0.075	0.362
H8	0.245	0.034	0.032	0.042	0.173	0.526
H9	0.180	0.048	0.026	0.035	0.142	0.431
H10	0.139	0.053	0.018	0.020	0.101	0.330
H11	0.090	0.021	0.007	0.000	0.122	0.240
H12	0.245	0.021	0.024	0.040	0.168	0.498
H13	0.144	0.081	0.019	0.029	0.108	0.381
H14	0.213	0.035	0.025	0.040	0.168	0.482
H15	0.199	0.040	0.032	0.045	0.147	0.464
H16	0.245	0.021	0.025	0.042	0.098	0.432
H17	0.213	0.067	0.026	0.040	0.090	0.436
H18	0.212	0.090	0.024	0.040	0.108	0.473
H19	0.205	0.078	0.017	0.036	0.139	0.475
H20	0.164	0.003	0.014	0.023	0.051	0.256
H21	0.183	0.065	0.024	0.041	0.144	0.456
H22	0.245	0.073	0.027	0.046	0.159	0.551
H23	0.151	0.069	0.020	0.033	0.134	0.407
H24	0.210	0.081	0.024	0.032	0.074	0.421
H25	0.212	0.070	0.022	0.043	0.173	0.520
H26	0.212	0.075	0.020	0.035	0.165	0.507
H27	0.245	0.062	0.017	0.028	0.132	0.484
H28	0.120	0.070	0.014	0.012	0.114	0.330
H29	0.206	0.094	0.025	0.033	0.157	0.515
H30	0.208	0.083	0.022	0.036	0.142	0.491

Table 23: Calculation of hazards ranking using FTOPSIS

Code	Di*	Di-	CCi	Rank
H22	0.139	0.551	0.798	1
H8	0.144	0.526	0.785	2
H12	0.172	0.498	0.743	3
H25	0.191	0.520	0.731	4
H29	0.194	0.515	0.727	5
H26	0.211	0.507	0.706	6
H14	0.212	0.482	0.695	7
H18	0.209	0.473	0.693	8
H15	0.232	0.464	0.666	9
H30	0.248	0.491	0.665	10
H27	0.257	0.484	0.654	11
H19	0.262	0.475	0.644	12
H21	0.255	0.456	0.642	13
H4	0.256	0.449	0.636	14
H16	0.252	0.432	0.631	15
H17	0.274	0.436	0.615	16
H2	0.289	0.433	0.599	17
H9	0.296	0.431	0.593	18
H24	0.300	0.421	0.584	19
H3	0.311	0.412	0.570	20
H13	0.326	0.381	0.539	21
H23	0.351	0.407	0.537	22
H1	0.331	0.380	0.535	23
H6	0.327	0.341	0.510	24
H7	0.376	0.362	0.491	25
H10	0.376	0.330	0.468	26
H5	0.387	0.326	0.457	27
H28	0.474	0.330	0.411	28
H20	0.458	0.256	0.359	29
H11	0.472	0.240	0.337	30

The 21 decision matrices were ultimately aggregated into a single combined decision matrix using equation (11).

$$l_{ij} = \mathrm{m}\ \left(l_{ijk}\right), m_{i}j = \frac{1}{k}\left(\sum_{k=1}^{k} m_{ijk}\right), u_{ij} = \mathrm{m}\ \left(u_{ijk}\right) \quad (11)$$

Here, k (k = 1, 2, 3, K) represents the experts. The fuzzy aggregated decision matrix is shown in Table 16. To normalise the decision matrix, two equations, (12) and (13) were used in FTOPSIS.

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^*}, \frac{m_{ij}}{u_j^*}, \frac{u_{ij}}{u_j^*}\right) \text{ and } u_j^* = \max(u_{ij}) \quad \text{[Benefit Criteria]} \tag{12}$$

$$\tilde{r}_{ij} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}}\right) \text{ and } l_j^- = \min(l_{ij}) \quad \text{[Cost Criteria]} \tag{13}$$

At first, this study determined whether the criteria under evaluation were benefit or cost criteria. Benefit criteria are defined as the alternative needs to achieve the highest evaluation score while cost criteria are described as the alternative needs to obtain the lowest evaluation score in those criteria. Since all chosen criteria in the study were severity indicators of hazards, the benefit criteria equation [equation (12)] was used. The higher the score in each criterion, the more significant the hazard. The normalised decision matrix is shown in Table 17.

The normalised matrix derived from equation (12) was then multiplied by the criteria weights derived from the FAHP to obtain a fuzzy aggregated normalised weighted decision matrix. The step is shown in equation (14) below. A tabular representation is provided in Table 18.

$$\tilde{V}_{ij} = \tilde{r}_{ij} \otimes w_j \tag{14}$$

The FPIS and FNIS were then determined using equations (15) and (16).

$$A^+ = (v_1^+, v_2^+, \ldots, V_n^+), \text{ where }, v_j^+ = max\{v_{ij3}\} \tag{15}$$

$$A^- = (v_1^-, v_2^-, \ldots., V_n^-), \text{ where}, v_j^- = \min\{v_{ij1}\} \tag{16}$$

The FPIS and FNIS matrices are shown in Tables 19 and 20. Each alternative's distance from FPIS (A^+) and FNIS (A^-) was calculated using equations (17) to (20).

$$d(\tilde{v}_{ij}, \tilde{v}_j^+) = \sqrt{\frac{1}{3}\sum \left(v_{ij} - v_j^+\right)^2} \quad (17)$$

$$d(\tilde{v}_{ij}, \tilde{v}_j^-) = \sqrt{\frac{1}{3}\sum \left(v_{ij} - v_j^-\right)^2} \quad (18)$$

$$d_i^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^+) \quad (19)$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \quad (20)$$

The distance from FPIS and FNIS of each of the alternatives can be found in Tables 21and 22. Finally, the closeness coefficient (CC_i) for each alternative was calculated to generate a final ranking using equation (21). Alternatives were ranked in descending order based on their own CC_i value to the ideal solution.

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \quad (21)$$

The calculations done to obtain the ranking of hazards in this study is shown in Table 23. The obtained final ranking from FTOPSIS is shown in Table 24 and Figure 3.

Table 24: Final hazard ranking obtained from FTOPSIS

Code	Rank	Code	Rank	Code	Rank	Code	Rank	Code	Rank	Code	Rank
H22	1	H26	6	H27	11	H17	16	H13	21	H10	26
H8	2	H14	7	H19	12	H2	17	H23	22	H5	27
H12	3	H18	8	H21	13	H9	18	H1	23	H28	28
H25	4	H15	9	H4	14	H24	19	H6	24	H20	29
H29	5	H30	10	H16	15	H3	20	H7	25	H11	30

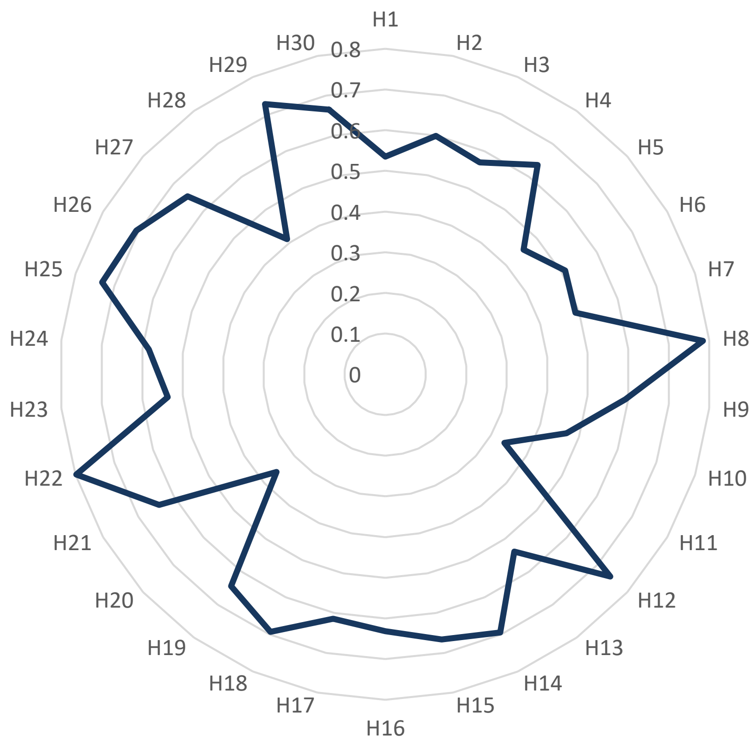

Figure 3: Radar chart of final ranking by FTOPSIS

3.6 Identification of Hazard Mitigation Methods Based on Expert Opinion

After ranking the hazards using FAHP-FTOPSIS, it's important to explore the mitigation steps that can be taken to reduce the impact of the most important hazard and check the interrelationship among them. This will lead to the formation of a more efficient and cost-effective mitigation strategy. For this purpose, from the ranked hazards shown in Table 24, the top 25 hazards were selected for further analysis to identify and explore appropriate hazard mitigation methods. In this part of the study, a total of 17 hazard mitigation methods were identified based on expert opinion and previous literature to address the aforementioned top 25 hazards, as shown in Table 25.

Table 25: Mitigation methods for top-ranked hazards

Code	Hazard Mitigation Method	Relevant Literature/Source
M1	Electrical Safety Regulations	(Zhao et al., 2015)
M2	Standard Operating Procedure (SOP)	(Chow and Walker, 2019)
M3	Lock Out Tag Out (LOTO)	(Illankoon et al., 2019)
M4	Personal Protective Equipment (PPE)	(Li et al., 2019)
M5	Elimination of hazardous material	(Zhao et al., 2015)
M6	Work at height regulations	(Bussier et al., 2020)
M7	Material Safety Data Sheet (MSDS)	(Sudarso and Probolinggo, 2018)
M8	Fire Protection System	(Sangode and Metre, 2020)
M9	Confined Space Entry Regulations	Expert Opinion
M10	Training	(Schmitz et al., 2021)
M11	Proper ventilation	Expert Opinion
M12	Watch keeping	Expert Opinion
M13	Housekeeping	(Schmitz et al., 2021)
M14	Permit to Work (PTW)	(Schmitz et al., 2021)
M15	Reduce stress in the workplace	(Schmitz et al., 2021)
M16	Entry Restriction of unauthorised personnel	Expert Opinion
M17	Maintain Logbook	(Schmitz et al., 2021; Ezrahovich et al., 2017)

3.7 Analysis of Hazard Mitigation Methods Using ISM-MICMAC

Eleven experts participated in a questionnaire-based evaluation for pairwise comparison of the hazard mitigation methods, for which profiles are provided in Table 1 of section 3.1. A sample questionnaire with aggregated evaluation responses is shown in **Appendix C**. A structural self-interaction matrix (SSIM) was then formed for the pairwise comparison, based on the expert evaluation of the 17 hazard mitigation methods.

The SSIM formation was developed following the steps detailed in Section 3 (Attri and Grover, 2018; Gopal and Thakkar, 2016). The SSIM is provided in Table 26.

Table 26: Structural self-interaction matrix

	M17	M16	M15	M14	M13	M12	M11	M10	M9	M8	M7	M6	M5	M4	M3	M2	M1
M1	X	V	O	X	A	A	O	A	V	A	V	O	A	A	X	A	X
M2	V	V	V	V	V	V	O	X	O	V	V	O	V	V	V	X	
M3	X	V	O	X	A	A	O	A	O	A	O	O	O	O	X		
M4	V	V	V	V	V	O	O	A	V	X	V	V	V	X			
M5	V	O	V	V	X	X	O	A	O	A	V	V	X				
M6	O	V	X	A	A	O	X	A	O	O	O	X					
M7	A	V	V	A	A	A	A	A	V	A	X						
M8	O	V	O	V	V	V	V	A	V	X							
M9	A	X	A	A	O	O	A	A	X								
M10	V	O	V	V	V	V	O	X									
M11	A	O	X	O	A	A	X										
M12	V	O	V	V	X	X											
M13	V	O	V	V	X												
M14	X	V	O	X													
M15	A	O	X														
M16	O	X															
M17	X																

The initial reachability matrix (IRM) was then formed (shown in Table 27) using the SSIM, following the rule outlined in Table 3. The IRM later underwent a transitivity test. Transitivity means that if variable A influences variable B, and variable B influences another variable C, then variable A influences variable C. After fulfilling all transitivity requirements among the variables, the final reachability matrix (FRM) was identified, which is shown in Table 28.

Table 27: Initial reachability matrix (IRM)

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17
M1	1	0	1	0	0	0	1	0	1	0	0	0	0	1	0	1	1
M2	1	1	1	1	1	0	1	1	0	1	0	1	1	1	1	1	1
M3	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1
M4	1	0	0	1	1	1	1	1	1	0	0	0	1	1	1	1	1
M5	1	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	1
M6	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1	0
M7	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	1	0
M8	1	0	1	1	1	0	1	1	1	0	1	1	1	1	0	1	0
M9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
M10	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1
M11	0	0	0	0	0	1	1	0	1	0	1	0	0	0	1	0	0
M12	1	0	1	0	1	0	1	0	0	0	1	1	1	1	1	0	1
M13	1	0	1	0	1	1	1	0	0	0	1	1	1	1	1	0	1
M14	1	0	1	0	0	1	1	0	1	0	0	0	0	1	0	1	1
M15	0	0	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0
M16	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
M17	1	0	1	0	0	0	1	0	1	0	1	0	0	1	1	0	1

Table 28: Final reachability matrix (FRM)

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	Sum	
M1	1	0	1	0	0	1*	1	0	1	0	1*	0	0	1	1*	1	1	*10*	**Driving Power**
M2	1	1	1	1	1	1*	1	1	1*	1	1*	1	1	1	1	1	1	*17*	
M3	1	0	1	0	0	1*	1*	0	1*	0	1*	0	0	1	1*	1	1	*10*	
M4	1	0	1*	1	1	1	1	1	1	0	1*	1*	1	1	1	1	1	*15*	
M5	1	0	1*	0	1	1	1	0	1*	0	1*	1	1	1	1	1*	1	*13*	
M6	0	0	0	0	0	1	1*	0	1*	0	1	0	0	0	1	1	0	*6*	
M7	0	0	0	0	0	1*	1	0	1	0	1*	0	0	0	1	1	0	*6*	
M8	1	0	1	1	1	1*	1	1	1	0	1	1	1	1	1*	1	1*	*15*	
M9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	*2*	
M10	1	1	1	1	1	1	1	1	1	1	1*	1	1	1	1	1*	1	*17*	
M11	0	0	0	0	0	1	1	0	1	0	1	0	0	0	1	1*	0	*6*	
M12	1	0	1	0	1	1*	1	0	1*	0	1	1	1	1	1	1*	1	*13*	
M13	1	0	1	0	1	1	1	0	1*	0	1	1	1	1	1	1*	1	*13*	
M14	1	0	1	0	0	1	1	0	1	0	1*	0	0	1	1*	1	1	*10*	
M15	0	0	0	0	0	1	1*	0	1	0	1	0	0	0	1	1*	0	*6*	
M16	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	*2*	
M17	1	0	1	0	0	1*	1	0	1	0	1	0	0	1	1	1*	1	*10*	
Sum	*11*	*2*	*11*	*4*	*7*	*15*	*15*	*4*	*17*	*2*	*15*	*7*	*7*	*11*	*15*	*17*	*11*		
Dependence Power																			

The values marked with * in FRM (Table 28) display transitivity. To better explain the transitivity checking method, variable M1 can be taken as an example here. In the IRM in Table 27, it can be seen that M1 is dependent on M3, M7, M9, M14, M16, and M17 (orange-colored boxes). While checking transitivity, it is found that M14 is dependent on M6, and M1 is dependent on M14. Therefore, M1 is dependent on M6 as well, and the corresponding '0's in the IRM has been replaced by '1*'s in the FRM. Similarly, M17 is dependent on M11 and M15, whereas M1 is dependent on M17. Therefore, M1 is dependent on M11 and M15 as well and hence, again, the corresponding '0's in the IRM has been replaced by '1*'s in the FRM. This procedure has been carried out for all 17 variables to check the transitivity, and thus the FRM, as shown in Table 28, is formed.

Level partitioning iterations were performed after the FRM was established. For this purpose, reachability, antecedent, and the intersection of the variables were analysed. Reachability shows how one variable can reach or influence many other variables. On the other hand, how one variable is reached or influenced by many other variables is shown by the antecedent. The intersection of reachability and antecedent is performed for level partitioning iteration. In this study, six iterations were required because all 17 mitigation methods took their place at some level within the sixth iteration. Six iterations also imply six partitioning levels. All iteration steps are shown in **Appendix D**. Table 29 illustrates the final level partitioning and Figure 4 shows the interpretive structural model for implementing the hazard mitigation method.

Table 29: Level partitioning

Event	Reachability	Antecedents	Intersection	Level
M1	M1, M3, M6, M7, M9, M11, M14, M15, M16, M17	M1, M2, M3, M4, M5, M8, M10, M12, M13, M14, M17	M1, M3, M14, M17	Level 3
M2	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14, M15, M16, M17	M2, M10	M2, M10	Level 6
M3	M1, M3, M6, M7, M9, M11, M14, M15, M16, M17	M1, M2, M3, M4, M5, M8, M10, M12, M13, M14, M17	M1, M3, M14, M17	Level 3
M4	M1, M3, M4, M5, M6, M7, M8, M9, M11, M12, M13, M14, M15, M16, M17	M2, M4, M8, M10	M4, M8	Level 5
M5	M1, M3, M5, M6, M7, M9, M11, M12, M13, M14, M15, M16, M17	M2, M4, M5, M8, M10, M12, M13	M5, M12, M13	Level 4
M6	M6, M7, M9, M11, M15, M16	M1, M2, M3, M4, M5, M6, M7, M8, M10, M11, M12, M13, M14, M15, M17	M6, M7, M11, M15	Level 2
M7	M6, M7, M9, M11, M15, M16	M1, M2, M3, M4, M5, M6, M7, M8, M10, M11, M12, M13, M14, M15, M17	M6, M7, M11, M15	Level 2
M8	M1, M3, M4, M5, M6, M7, M8, M9, M11, M12, M13, M14, M15, M16, M17	M2, M4, M8, M10	M4, M8	Level 5
M9	M9, M16	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14, M15, M16, M17	M9, M16	Level 1
M10	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14, M15, M16, M17	M2, M10	M2, M10	Level 6
M11	M6, M7, M9, M11, M15, M16	M1, M2, M3, M4, M5, M6, M7, M8, M10, M11, M12, M13, M14, M15, M17	M6, M7, M11, M15	Level 2
M12	M1, M3, M5, M6, M7, M9, M11, M12, M13, M14, M15, M16, M17	M2, M4, M5, M8, M10, M12, M13	M5, M12, M13	Level 4
M13	M1, M3, M5, M6, M7, M9, M11, M12, M13, M14, M15, M16, M17	M2, M4, M5, M8, M10, M12, M13	M5, M12, M13	Level 4
M14	M1, M3, M6, M7, M9, M11, M14, M15, M16, M17	M1, M2, M3, M4, M5, M8, M10, M12, M13, M14, M17	M1, M3, M14, M17	Level 3
M15	M6, M7, M9, M11, M15, M16	M1, M2, M3, M4, M5, M6, M7, M8, M10, M11, M12, M13, M14, M15, M17	M6, M7, M11, M15	Level 2
M16	M9, M16	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14, M15, M16, M17	M9, M16	Level 1
M17	M1, M3, M6, M7, M9, M11, M14, M15, M16, M17	M1, M2, M3, M4, M5, M8, M10, M12, M13, M14, M17	M1, M3, M14, M17	Level 3

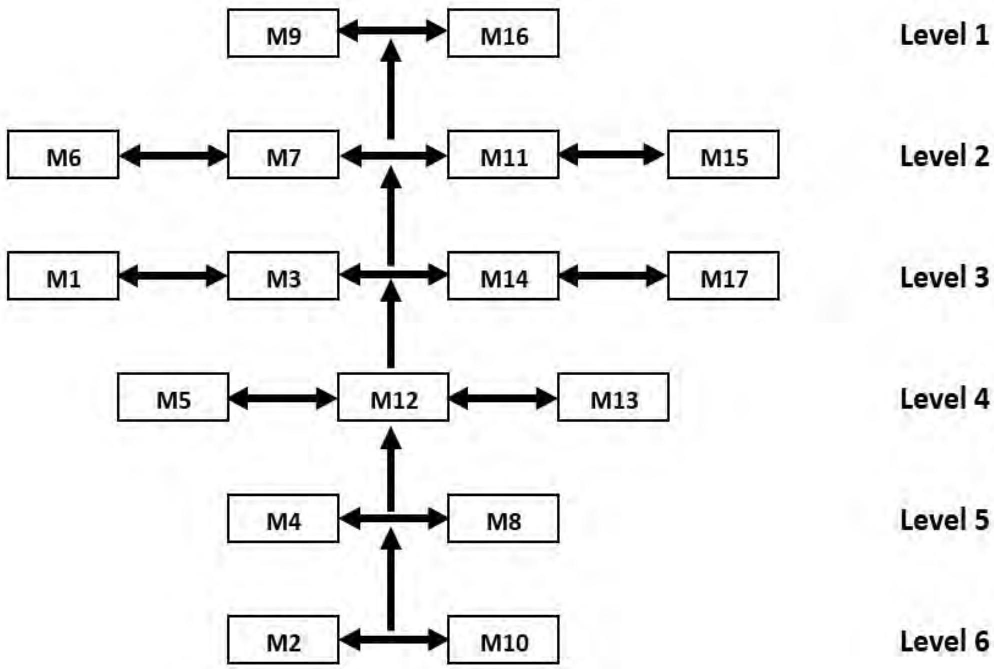

Figure 4: Interpretive structural model

For MICMAC analysis, values of the driving and dependence power were summed from the final reachability matrix and were graphically presented into four groups. The methods with weak driving and dependence power were placed in the 'autonomous' group while mitigation methods with weak driving but strong dependence power were categorised into the 'dependent' group. Mitigation methods with strong driving and strong dependence power were placed in the 'linkage' group, while those with strong driving but weak dependence power was located in the 'independent' group, as shown in Figure 5.

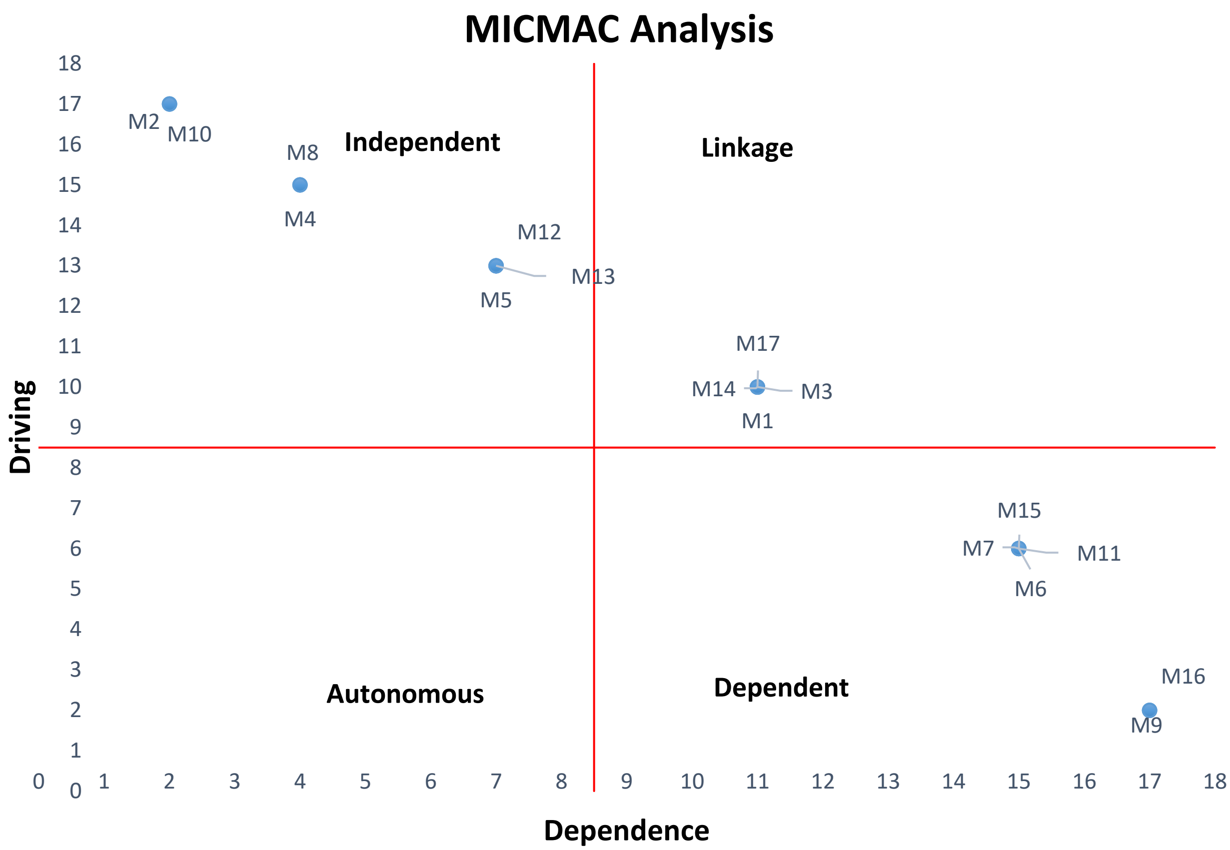

Figure 5: MICMAC analysis of hazard mitigation methods

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results and Discussion of Hazard Prioritization

In this study, a hybrid FAHP-FTOPSIS method was used to systematically prioritise and rank the operational hazards of HFO-based power plants. Thirty potential hazards in HFO-based power plants were identified at the beginning of the study. Due to the unavailability of sufficient research in the relevant area, most of the 30 hazards were identified from literature addressing other relevant industries and from expert opinion (Table 4). Following identification, fuzzy weights of criteria were determined using FAHP with a 9-point fuzzy scale. Weights were subsequently de-fuzzified to crisp numerical values for use in the FTOPSIS method. De-fuzzified criteria weights were utilised in the later steps since a modified 5-point fuzzy scale was used in the FTOPSIS method, and the fuzzy scale of evaluation is different for the FAHP and FTOPSIS methods in this study.

The FAHP was used to determine the weights of the evaluation criteria based on expert feedback. The priority sequence of the criteria based on the calculated weight was- severity (0.40587), manageability (0.27882), likelihood (0.17204), time frame (0.09008), and extent (0.05316), as shown in Table 12. Severity, a function of the magnitude of the associated risk, was identified as the most important criterion by most experts, while manageability, a function of the capability to improve, manage, and maintain risky processes, was ranked as the second most important criterion. On the other hand, extent, a function of the scale or range of the area affected by the hazard, was ranked as the least important criterion.

The FTOPSIS uses the criteria weights determined by FAHP as inputs to generate the final ranking of potential hazards. The final ranking was created based on the descending order of the closeness and coefficient values of alternatives obtained from the FTOPSIS method, as demonstrated in Table 24. The radar diagram in Figure 3 also demonstrates the final ranking. In this study, the hazard 'explosion of high-pressure steam drum of EGB (H22)' is first in the ranking. This hazard occurs mostly in the boiler and the stack area of the plant and can be particularly dangerous for both the operators and the plant. As EGBs are not installed far from the engine hall in HFO-based power plants, an explosion of the steam drum near the engine and alternator can cause other disastrous hazards. 'Crankcase explosion and fire hazard due to oil mist pressure rise (H8)' is in second place in the hazard ranking and occurs in the engine hall area. In a running engine, oil mist from lube oil can develop in the engine crankcase due to various technical reasons and is a normal phenomenon in any HFO-run heavy engine. However, failure to continuously release the pressure from the oil mist in the engine crankcase can be highly dangerous for operators working in the engine hall. The shockwave that can result from a potential serious explosion can cause considerable devastation, including the death of adjacent workers. Sudden release of oil mist in the environment due to crankcase explosion may also cause oxygen deficit and increase the proportion of other gases in the surrounding area, resulting in potential death by asphyxiation. 'Explosion of the compressed air reservoir (H12)' takes third position in the ranking. Compressed air reservoirs or pressure vessels are located in both the engine hall and the compressor room areas. A series of compressors to compress and reserve air are located in air reservoirs. A sudden rise of air pressure above the maximum allowable pressure level in reservoirs and pipelines can result in explosion, causing serious injury to nearby operators triggering other hazards in surrounding areas. The fourth critical hazard according to the ranking is 'explosion in the chemical store (H25)'. Chemical stores of HFO-based power plants reserve many types of necessary but combustible chemicals for the quality testing of fuel oil, lube oil, boiler feed water, and engine coolants. Operational errors and negligence can cause serious damage from the explosion of chemicals stored in the storage area. Other major hazards ranked in this study include 'fire hazard from hot works (H29)', 'fire hazard from flammable chemical (H26)', 'explosion of circuit breaker during operation at switchgear (H14)', 'electric arc while isolating and switching at sub-station area (H18)', and 'fire from heat build-up in high voltage electrical equipment (H15)'. Interestingly, hazards related to explosion and fire were deemed most important by experts, a logical conclusion for the sophisticated industry HFO-based power plant industry, in which highly combustible fuels are frequently burned.

4.2 Results and Discussion of Hazard Mitigation

From the ISM study of the hazard mitigation methods of HFO-based power plants shown in Figure 4, 'confined space entry regulations (M9)' and 'entry restriction of unauthorised personnel (M16)' were found at level 1, which identifies methods with the weakest driving but strongest dependence power. Level 2 contains 'work at height regulations (M6)', 'material safety data sheet (M7)', 'proper ventilation (M11)', and 'reduce stress in the workplace (M15)'. Hazard mitigation methods in level 2 have greater driving power and less dependence power than those in level 1. 'Electrical safety regulations (M1)', 'lock out tag out (M3)', 'permit to work (M14)', and 'maintain logbook (M17)' were placed at level 3 of the ISM study. These methods showed more driving power than levels 1 and 2 but less dependence power. Similarly, level 4 contained 'elimination of hazardous material (M5)', 'watch-keeping (M12)', and 'housekeeping (M13)', while level 5 contained 'use of personal protective equipment (M4)' and 'fire protection system (M8)'. 'Implementation of standard operating procedure (SOP) (M2)' and 'training (M10)' were placed at level 6. Methods at level 6 have the strongest driving but weakest dependence power among all methods.

In the MICMAC analysis, hazard mitigation methods at levels 1 and 2 of the ISM analysis were found in the ‘dependent’ group. In the ‘linkage’ group, mitigation methods at level 3 of the ISM analysis took their place. Mitigation methods at levels 4, 5, and 6 of the ISM analysis were placed in the ‘independent’ group, while no methods in this study were categorised in the ‘autonomous’ group.

‘Standard operating procedures (M2)’ and ‘training (M10)’ can be critical in hazard mitigation strategies due to their strong driving power over other methods. Standard operating procedures drive operators and workers to strictly follow the rules of each process and thus can keep hazards to a minimum level. Training can provide a better understanding of the risks associated with each hazard and can allow implementation of best practices for operation and maintenance. Implementation of SOPs and training both drive and depend on one another and hence were found at the same ISM level in the study. Again, since the ‘use of PPE (M4)’ and ‘ fire protection system (M8)’ are driven by SOPs and training, these methods also have significant driving power over the rest of the hazard mitigation methods. Implementing SOPs and proper training influence plant personnel to use PPE and the fire protection system, where necessary. Thereby, implementing the independent methods uncovered by MICMAC analysis can drive all other methods, which in turn lead to the implementation of the overall mitigation strategy.

CHAPTER 5

MANAGERIAL AND POLICY IMPLICATIONS

5.1 Managerial Implications

This study underlines that severity, manageability, and likelihood are the most critical criteria when prioritising industrial hazards. Managers should focus to a greater extent on these criteria when prioritising and analysing industrial hazards. For HFO-based power plants, 'explosion of the high-pressure steam drum of EGB', 'crankcase explosion and fire hazard due to oil mist pressure rise', 'explosion of the compressed air reservoir', and 'explosion in the chemical store' are hazards with the highest priority in this study. Managers should regularly monitor these areas of the plant with high priority and employ other preventive action plans to avoid most unwanted hazardous incidents. Managers should also be prepared for the after-effects of these hazards and identify appropriate recovery measures to minimise the loss of life and property.

This study further indicates that SOP implementation and training are the strongest mitigation methods for HFO-based power plant hazards. Hence, managers should prepare and implement SOPs for all operational and maintenance activities performed in the plant, and train workers and personnel to drive other mitigation methods to considerably reduce the most hazardous incidents. The sequential implementation of hazard mitigation methods will help managers take strategic decisions more efficiently and safely while complying with the organisational budget and time frame. Furthermore, the research framework developed in this study can be applied in other relevant sectors with minimal or no modifications.

5.2 Policy Implications

Government and industrial policymakers can find interesting insights from the hazard prioritization and mitigation method utilized in this study. A diversified energy policy can be an effective solution for a developing country like Bangladesh (Islam et al., 2022), where there is still a large amount of energy deficit in the national grid. Policymakers can introduce hazard analysis and mitigation finding methods utilized in this study in other bio-fuel-based (coal, gas, diesel, etc.) thermal power plants to compare their respective operational risks. This way, it will help policymakers devise a long-term energy policy involving selecting proper bio-fuel-based technology, considering both the relevant costs and operational hazards.

Policymakers can also utilize the insights from this study to create pressure on the plants' management to follow proper regulations and guidelines to ensure plant safety and smooth operation. Regulatory authorities can also be formed to inspect and ensure that the power plants are sticking to the preapproved SOPs and other safety guidelines to ensure a safe working environment. Operational hazards are a threat to the individual workers and a major threat to the continuity of the plant's operations. Disruption in plant operations (i.e., electricity generation) due to an operational hazard can gravely disrupt the electricity supply to the National Grid, which can consequently hamper the country's emerging economy.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

A hybrid approach using FAHP and FTOPSIS was utilised in this study for hazard prioritisation in HFO-based power plants in Bangladesh. Data were collected from experts working in HFO-based power plants through questionnaires to identify the weights of evaluation criteria. Eleven of the most experienced experts later identified hazard mitigation methods for the top-ranked hazards. Experts employed linguistic variables as inputs through a questionnaire specifically designed for this study based on previous literature. Obtained linguistic variables were then converted into TFN for further mathematical operation in the FAHP and, subsequently, in the FTOPSIS method. After ranking the hazards, the interactions and interrelations among hazard mitigations were explored using the ISM-MICMAC approach based on the driving and dependence power of each method.

Experts and decision-makers who participated in the study provided opinions based on their experience working in and managing HFO-based power plants. Before employment in onshore HFO-based power plants, some experts had also worked in marine vessels that also used some form of HFO-based engine. The offshore experience in marine vessels of some of these experts may therefore be reflected in their evaluations of onshore power plants. As HFO-based power plants are mainly engine-based, and the engine hall – prone to the most critical and devastating hazards – is the largest operating area in such plants, most of the top-ranked hazards originate from this area. All other areas in the plant are considered auxiliary areas that support engine operations. These considerations may have significant implications when identifying, listing, and ranking operational hazards and exploring hazard mitigation methods.

As a developing nation, Bangladesh must depend upon HFO-based power plants to meet the electricity demand of its fast-growing industries and to supply electricity to every corner of the country to support citizens' quality of life. Without a drastic change in the country's energy policy, existing plants will remain in service until the next decade at a minimum. The analysis of the hazards and hazard mitigation methods from this study can help managers formulate critical operational strategies and support critical decisions given power plant operations must be continuously synchronised with demands on the national grid. Managers responsible for similar types of plants can also gain insights from this research and can implement further modifications, if necessary, to address any change in circumstances.

6.2 Recommendations

As the primary goal of the study was to develop a basic framework for ranking the hazards in power plants, a geometric mean method of FAHP was used to simplify the calculation of criteria weights. In future research, a study can be performed based on criteria weights obtained by using other methods of FAHP, including the extent analysis method or FAHP with entropy value. Other combinations of hybrid MCDM such as FVIKOR-FTOPSIS or FANP-FTOPSIS can be considered for future research, and results can be compared for better understanding. Besides ISM-MICMAC, further MCDM approaches can also be contemplated to analyse and explore mitigation methods to justify the structural model. For instance, now-a-days, TISM is being used as a more efficient tool, in place of ISM, to explore interrelationships among factors (Panackal et al., 2022; Priyadarshini et al., 2022). Where tools like ISM can answer questions like 'what?' and 'how?' regarding the factors and their hierarchical relationships, TISM can further address 'why?' (Sushil, 2018). Thereby, future researchers can explore similar researches using TISM-MICMAC, instead of ISM-MICMAC, to bring more explanatory power in the context of theory building.

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Appendix A

Questionnaire to Collect Experts Opinion for Determining Criteria Weights with FAHP (Sample Response from an Expert)

	Equal	Between Equal and Moderat	Moderate	Between Moderate and Strong	Strong	Between Strong and V.	Very Strong	Between V. strong and E.	Extreme Strong
How much important do you think Severity over Likelihood?		Y							
How much important do you think Severity over Extent?							Y		
How much important do you think Severity over Time Frame?					Y				
How much important do you think Severity over Manageability ?			Y						
…………..	…	….	….	……	….	…..	….	….	…..
How much important do you think Manageability over Extent?				Y					
How much important do you think Manageability over Time Frame?			Y						

Appendix B

Questionnaire to Collect Expert Opinion for Prioritizing Hazard with FTOPSIS

(Sample Response from Expert 1)

Code	Hazard description	Severity	Likelihood	Extent	Time Frame	Manageability
H1	Contact with high-speed rotating machines during operation	*high*	*low*	*low*	*Low*	*average*
H2	Fall from height during operation and maintenance at higher places	*very high*	*low*	*low*	*Low*	*average*
H3	Falling of heavy equipment during overhead crane operation	*high*	*low*	*low*	*Low*	*average*
H4	Fire for the presence of hot combustible material	*average*	*low*	*high*	*average*	*very high*
H5	Long term contact with spilled HFO, lubricating oil, and hazardous chemicals	*high*	*high*	*average*	*average*	*low*
...	... ...					
H29	Fire hazard from hot work	*high*	*very high*	*very high*	*very high*	*average*
H30	Contact with buried electric cables while excavating	*very high*	*high*	*very high*	*very high*	*low*

Appendix C

A Sample of the Questionnaire and Aggregated Evaluation Response for ISM-MICMAC

Questions			Write (Y) if yes
Electrical Safety Regulation (M1) influences	M2	Standard Operating Procedure (SOP)	
	M3	Lock Out Tag Out (LOTO)	Y
	M4	Personal Protective Equipment (PPE)	
	M5	Elimination of hazardous material	
	M6	Work at height regulations	
	M7	Material Safety Data Sheet (MSDS)	Y
	M8	Fire Protection System	
	M9	Confined Space Entry Regulations	Y
	M10	Training	
	M11	Proper ventilation	
	M12	Watchkeeping	
	M13	Housekeeping	
	M14	Permit to Work (PTW)	Y
	M15	Reduce stress in the workplace	
	M16	Entry Restriction of unauthorized personnel	Y
	M17	Maintain Logbook	Y

Appendix D

Iterations for level partitioning

Event	Reachability																
M1	M1	0	M3	0	0	M6	M7	0	M9	0	M11	0	0	M14	M15	M16	M17
M2	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17
M3	M1	0	M3	0	0	M6	M7	0	M9	0	M11	0	0	M14	M15	M16	M17
M4	M1	0	M3	M4	M5	M6	M7	M8	M9	0	M11	M12	M13	M14	M15	M16	M17
M5	M1	0	M3	0	M5	M6	M7	0	M9	0	M11	M12	M13	M14	M15	M16	M17
M6	0	0	0	0	0	M6	M7	0	M9	0	M11	0	0	0	M15	M16	0
M7	0	0	0	0	0	M6	M7	0	M9	0	M11	0	0	0	M15	M16	0
M8	M1	0	M3	M4	M5	M6	M7	M8	M9	0	M11	M12	M13	M14	M15	M16	M17
M9	0	0	0	0	0	0	0	0	M9	0	0	0	0	0	0	M16	0
M10	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17
M11	0	0	0	0	0	M6	M7	0	M9	0	M11	0	0	0	M15	M16	0
M12	M1	0	M3	0	M5	M6	M7	0	M9	0	M11	M12	M13	M14	M15	M16	M17
M13	M1	0	M3	0	M5	M6	M7	0	M9	0	M11	M12	M13	M14	M15	M16	M17
M14	M1	0	M3	0	0	M6	M7	0	M9	0	M11	0	0	M14	M15	M16	M17
M15	0	0	0	0	0	M6	M7	0	M9	0	M11	0	0	0	M15	M16	0
M16	0	0	0	0	0	0	0	0	M9	0	0	0	0	0	0	M16	0
M17	M1	0	M3	0	0	M6	M7	0	M9	0	M11	0	0	M14	M15	M16	M17

Event	Antecedents																
M1	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M2	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0
M3	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M4	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0
M5	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M6	M1	M2	M3	M4	M5	M6	M7	M8	0	M10	M11	M12	M13	M14	M15	0	M17
M7	M1	M2	M3	M4	M5	M6	M7	M8	0	M10	M11	M12	M13	M14	M15	0	M17
M8	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0
M9	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17
M10	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0
M11	M1	M2	M3	M4	M5	M6	M7	M8	0	M10	M11	M12	M13	M14	M15	0	M17
M12	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M13	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M14	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M15	M1	M2	M3	M4	M5	M6	M7	M8	0	M10	M11	M12	M13	M14	M15	0	M17
M16	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17
M17	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17

Event	Intersection																	Level
M1	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17	
M2	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	
M3	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17	
M4	0	0	0	M4	0	0	0	M8	0	0	0	0	0	0	0	0	0	
M5	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0	
M6	0	0	0	0	0	M6	M7	0	0	0	M11	0	0	0	M15	0	0	
M7	0	0	0	0	0	M6	M7	0	0	0	M11	0	0	0	M15	0	0	
M8	0	0	0	M4	0	0	0	M8	0	0	0	0	0	0	0	0	0	
M9	0	0	0	0	0	0	0	0	M9	0	0	0	0	0	0	M16	0	Level 1
M10	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	
M11	0	0	0	0	0	M6	M7	0	0	0	M11	0	0	0	M15	0	0	
M12	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0	
M13	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0	
M14	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17	
M15	0	0	0	0	0	M6	M7	0	0	0	M11	0	0	0	M15	0	0	
M16	0	0	0	0	0	0	0	0	M9	0	0	0	0	0	0	M16	0	Level 1
M17	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17	

Event	Reachability																
M1	M1	0	M3	0	0	M6	M7	0	0	0	M11	0	0	M14	M15	0	M17
M2	M1	M2	M3	M4	M5	M6	M7	M8	0	M10	M11	M12	M13	M14	M15	0	M17
M3	M1	0	M3	0	0	M6	M7	0	0	0	M11	0	0	M14	M15	0	M17
M4	M1	0	M3	M4	M5	M6	M7	M8	0	0	M11	M12	M13	M14	M15	0	M17
M5	M1	0	M3	0	M5	M6	M7	0	0	0	M11	M12	M13	M14	M15	0	M17
M6	0	0	0	0	0	M6	M7	0	0	0	M11	0	0	0	M15	0	0
M7	0	0	0	0	0	M6	M7	0	0	0	M11	0	0	0	M15	0	0
M8	M1	0	M3	M4	M5	M6	M7	M8	0	0	M11	M12	M13	M14	M15	0	M17
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M10	M1	M2	M3	M4	M5	M6	M7	M8	0	M10	M11	M12	M13	M14	M15	0	M17
M11	0	0	0	0	0	M6	M7	0	0	0	M11	0	0	0	M15	0	0
M12	M1	0	M3	0	M5	M6	M7	0	0	0	M11	M12	M13	M14	M15	0	M17
M13	M1	0	M3	0	M5	M6	M7	0	0	0	M11	M12	M13	M14	M15	0	M17
M14	M1	0	M3	0	0	M6	M7	0	0	0	M11	0	0	M14	M15	0	M17
M15	0	0	0	0	0	M6	M7	0	0	0	M11	0	0	0	M15	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M17	M1	0	M3	0	0	M6	M7	0	0	0	M11	0	0	M14	M15	0	M17

Event	Antecedents																
M1	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M2	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0
M3	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M4	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0
M5	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M6	M1	M2	M3	M4	M5	M6	M7	M8	0	M10	M11	M12	M13	M14	M15	0	M17
M7	M1	M2	M3	M4	M5	M6	M7	M8	0	M10	M11	M12	M13	M14	M15	0	M17
M8	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0
0	M1	M2	M3	M4	M5	M6	M7	M8	0	M10	M11	M12	M13	M14	M15	0	M17
M10	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0
M11	M1	M2	M3	M4	M5	M6	M7	M8	0	M10	M11	M12	M13	M14	M15	0	M17
M12	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M13	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M14	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M15	M1	M2	M3	M4	M5	M6	M7	M8	0	M10	M11	M12	M13	M14	M15	0	M17
0	M1	M2	M3	M4	M5	M6	M7	M8	0	M10	M11	M12	M13	M14	M15	0	M17
M17	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17

Event	Intersection																	Level
M1	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17	
M2	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	
M3	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17	
M4	0	0	0	M4	0	0	0	M8	0	0	0	0	0	0	0	0	0	
M5	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0	
M6	0	0	0	0	0	M6	M7	0	0	0	M11	0	0	0	M15	0	0	Level 2
M7	0	0	0	0	0	M6	M7	0	0	0	M11	0	0	0	M15	0	0	Level 2
M8	0	0	0	M4	0	0	0	M8	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M10	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	
M11	0	0	0	0	0	M6	M7	0	0	0	M11	0	0	0	M15	0	0	Level 2
M12	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0	
M13	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0	
M14	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17	
M15	0	0	0	0	0	M6	M7	0	0	0	M11	0	0	0	M15	0	0	Level 2
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M17	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17	

Event	Reachability																
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M2	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M4	0	0	0	M4	M5	0	0	M8	0	0	0	M12	M13	0	0	0	0
M5	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M8	0	0	0	M4	M5	0	0	M8	0	0	0	M12	M13	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M10	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M12	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0
M13	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Event	Antecedents																
0	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M2	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0
0	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M4	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0
M5	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
0	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
0	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M8	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0
0	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M10	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0
0	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M12	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M13	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
0	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
0	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
0	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
0	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0

Event	Intersection																	Level
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M2	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M4	0	0	0	M4	0	0	0	M8	0	0	0	0	0	0	0	0	0	
M5	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0	Level 4
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M8	0	0	0	M4	0	0	0	M8	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M10	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M12	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0	Level 4
M13	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0	Level 4
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Event	Reachability																
M1	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17
M2	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M3	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17
M4	M1	0	M3	M4	M5	0	0	M8	0	0	0	M12	M13	M14	0	0	M17
M5	M1	0	M3	0	M5	0	0	0	0	0	0	M12	M13	M14	0	0	M17
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M8	M1	0	M3	M4	M5	0	0	M8	0	0	0	M12	M13	M14	0	0	M17
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M10	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M12	M1	0	M3	0	M5	0	0	0	0	0	0	M12	M13	M14	0	0	M17
M13	M1	0	M3	0	M5	0	0	0	0	0	0	M12	M13	M14	0	0	M17
M14	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M17	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17

Event	Antecedents																
M1	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M2	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0
M3	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M4	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0
M5	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
0	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
0	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M8	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0
0	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M10	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0
0	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M12	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M13	0	M2	0	M4	M5	0	0	M8	0	M10	0	M12	M13	0	0	0	0
M14	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
0	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
0	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17
M17	M1	M2	M3	M4	M5	0	0	M8	0	M10	0	M12	M13	M14	0	0	M17

Event	Intersection																	Level
M1	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17	Level 3
M2	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	
M3	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17	Level 3
M4	0	0	0	M4	0	0	0	M8	0	0	0	0	0	0	0	0	0	
M5	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M8	0	0	0	M4	0	0	0	M8	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M10	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M12	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0	
M13	0	0	0	0	M5	0	0	0	0	0	0	M12	M13	0	0	0	0	
M14	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17	Level 3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M17	M1	0	M3	0	0	0	0	0	0	0	0	0	0	M14	0	0	M17	Level 3

Event	Reachability																	Antecedents																	Intersection																	Level
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M2	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M4	0	0	0	M4	0	0	0	M8	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	M4	0	0	0	M8	0	0	0	0	0	0	0	0	0	Level 5
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M8	0	0	0	M4	0	0	0	M8	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	M4	0	0	0	M8	0	0	0	0	0	0	0	0	0	Level 5
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M10	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	M4	0	0	0	M8	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Event	Reachability																	Antecedents																	Intersection																	Level
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M2	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	Level 6
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
M10	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	Level 6
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M2	0	0	0	0	0	0	0	M10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	