HAZARD IDENTIFICATION OF BOILER PLANT THROUGH FUZZY BASED HAZOP STUDY

K. Keerthivasan [1], Dr. M. Ilangkumaran [2]

[1] Professor, Department of Mechanical Engineering, Knowledge Institute of Technology
Kakapalayam, Salem-637504, Tamil Nadu

[2] PG scholar, Knowledge Institute of Technology
Kakapalayam, Salem-637504, Tamil Nadu

Abstract— **This study proposed a fuzzy-based HAZOP for process risk analysis. Fuzzy theory was used to express uncertain states and this theory has been found to be a useful approach to overcome the inherent uncertainty in HAZOP analyses. Fuzzy logic contrasted sharply with classical logic and provided different risk values according to the degree of its membership functions. The appropriate process parameters and guidelines were selected to describe accident frequency and consequences. Fuzzy modelling calculated risks based on the relationship between accident variables. Modelling was based on mean expected value, trapezoidal fuzzy number method. The objective process for fuzzy-based and conventional HAZOPs was to identify and assess hazards in boiler plant. The most important index is the frequency of risk determination. The comparison results showed that the fuzzy-based HAZOP provides better elaborated risks than the conventional HAZOP. The fuzzy risk matrix represents the importance of risks, negligible risks and the need to reduce risks.**

Keywords— **Fuzzy logic, Failure mode effect analysis (FMEA), Hazard operability study (HAZOP).**

I. INTRODUCTION

The risk analysis and assessment process does not include pre-defined clear steps. Risk assessment is an assessment of these probabilities and consequences. Risk assessment can be either qualitative or quantitative, although the emphasis in the system security process is usually on qualitative risk assessment. Risk factors and assessments are difficult to describe mathematically. However, if you can qualitatively describe the systemic risk assessment, you can use fuzzy logic.

Failure Effect Analysis (FMEA) is one of the hazard identification tools mainly used in complex mechanical and electrical systems. FMEA is one of the qualitative techniques used to identify potential failures. It will also improve the quality and safety of the system by eliminating detected faults. The concept of fuzzy logic helps to expand the risk characteristics that can be considered in FMECA, thus providing a much better risk index that can be used for better comparison of failures. The fuzzy system can serve as a useful risk analysis tool to consider organizational and human factors to improve their study and highlight the uncertainty associated with human performance variability.

The advantages of fuzzy logic management include the integration of human expertise, experience and knowledge into a rule base that has qualitative, descriptive and linguistic quantities. Although many studies using different risk assessment methods are available in the literature, it is too difficult to compare them in terms of closed risk assessments for different systems using different models. For this reason, some risk assessment standards have been developed and are summarized in the study.

The fuzzy logic method, qualitative and quantitative risk methodology is combined, and the structure becomes more flexible. The degree of risk can thus be expressed both by numerical values, as in qualitative risk analysis, and by definitions, as in quantitative risk analysis in the fuzzy logic approach. In this way, the level of risk can be determined using many inputs, such as the possibility of the hazard, the frequency of exposure, and the degree of potential damage. Furthermore, it can be easily applied to any complicated system by changing the rule base. The fuzzy logic method may also involve expert human judgment to define these variables and their relationships. So it can be closer to reality and can be site specific compared to some other methods. For this reason, fuzzy logic is becoming more and more popular for risk assessment nowadays. Various applications have been made recently. She developed a safety model related to the maritime environment and maritime safety systems using a fuzzy logic approach. The developed model provides more efficient results compared to previous risk models. This represents a risk assessment based on fuzzy set theory, which suggests that fuzzy logic is used as an effective analysis tool in the case of excessive risk situations in the Analytical Hierarchy Process (AHP). A risk assessment tool based on fuzzy logic was developed for the risk assessment of river hydropower projects. Fuzzy logic methodology enables multi-criteria decision analysis and provides an easy and comprehensible way of analyzing possible risks that appear in projects. He developed a method in which two linguistic fuzzy scales based on trapezoidal fuzzy numbers are used in modifying the early developed Safety Risk Factor Table (SRFT) model using the concept of fuzzy logic. This method was tested in a refinery and compared to previously used methods to explain it.

Problem Identification

Final stages of implementation, HAZOP study is to identify, prior to simulation and analysis, Identify Cause, Identification cause of the deviation is based on a study of P & ID, Interlock Schedule, and the manual book (Pulverize inverting, Fire Fighting System and Operating Procedure Pulverize). Identify Consequence, identification is based on the analysis due to deviation of each node and find a relationship between a deviations that resulted in another deviation. A Process and Instrumentation Diagram (P & ID) shows the process flow and interconnection of the process equipment that is used to control the process. The P & ID includes all mechanical aspects of the facility except for flow, piping, pipe lengths, pipe fittings, supports, construction and foundations. The P&ID provides information to begin planning for plant construction. There are different sets of symbols that are used to represent mechanical equipment, piping, piping components, valves, controls, and instruments and controls.

II. Objective and Methodology

A. *Objective of the Project*

The goal of this fuzzification step is to quantify the failure possibilities into corresponding quantitative data in the form of a membership function of fuzzy numbers taken from the linguistic value and a membership function of qualitative failure possibilities. The distribution of failure possibilities is

implemented in a linguistic value based on the probable occurrences of failure and the respective membership functions of fuzzy sets, which are implemented in the membership function using an inductive reasoning approach. The membership functions representing these qualitative linguistic values are in the form of triangular fuzzy numbers or trapezoidal fuzzy numbers. Experts used linguistic terms to assess the probability of occurrence of failure modes, and a numerical approximation system was used to convert the linguistic terms into their corresponding fuzzy numbers.

B. *Methodology*

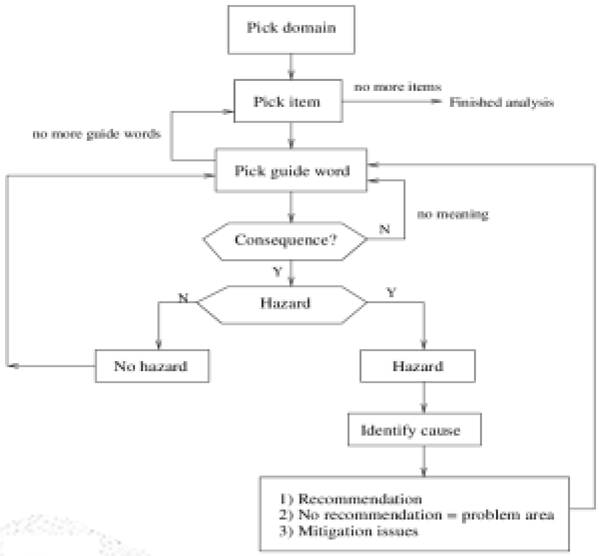
Risk-based design consists of three steps: hazard identification, risk analysis, and decision making. A hazard is defined as a situation that has the potential to cause damage to human safety, property and the environment. It can be a physical situation, activity or material. Risk is a combination of the frequency of an event and its consequence. Practically, the risk is estimated by numerically multiplying the frequency a consequence of the event. The hazard identification step finds inherent hazards by analyzing the system and identifies causes, probability, impacts, and safety measures. The risk analysis step determines the risks with respect to the probability and extent of damages. The final step is to decide whether the

current design should be adopted, what safety measures should be taken for each hazard if the risk is unacceptable, and to what extent the risk is reduced by the safety measures. These measures should either reduce the frequency of accidents or mitigate the extent of their damage. Material includes or passes through this particular node. Process parameters, say a flow, are identified and an intent is created for the node based on consideration. Use the first lead word, say "no" and create a complete deviation of meaning like "no flow". The next step is to determine all the possible causes due to which such a deviation may occur, on the other hand, the HAZOP team must also identify all the consequences if such a deviation occurs, what possible outcome it leads to. Finally, the design should be recorded along with the deviation and reasons in a specific tabular format. Now the same process needs to be repeated for all the guide words and the result should be recorded, after completing one node the team moves to the next node and repeats the same process again.

Fuzzy Theory

Fuzzy set theory is a mathematical theory for expressing uncertain states. This theory is based on inadequate and inaccurate information when one makes a rational judgment using ambiguous logic. Zadeh introduced the fuzzy set to explain numerical sets of ambiguous logics. Fuzzy theory is a rule-based methodology for expressing uncertainty. It considers approximations or subjective numbers and quantifies the ambiguity and vagueness of linguistic descriptions. Fuzzy logic provides a useful means of overcoming uncertainties. Because fuzzy logic allows the excluded middle principle to

FIG. 1 HAZOP FLOW CHART.



represent any intermediate state, it is capable of considering uncertainties. This contrasts sharply with classical (sharp) logic. It replaces the "zero or one" state of the sharp logic with different states with degrees of membership. A fuzzy set is defined by membership functions that indicate to what extent an element belongs to the fuzzy set. That is, a crisp set has a unique membership such as zero or one, while a fuzzy set has different types of membership functions and the membership degree of an element in a closed interval. illustrates the concept of crisp set and fuzzy set on risk value.

The fuzzy set Q with respect to the universal set U is characterized by the following equation.

$$Q = \{ (u, \mu_Q); u \in U, \mu_Q \in [0,1] \}$$

In this section, a systematic approach to the extension to fuzzy environments is proposed. This method is very suitable for solving the problem of group decision-making in a fuzzy environment. In this paper, the importance weights of various criteria and the ranking of qualitative criteria are treated as linguistic variables. These linguistic variables can be expressed by positive triangular fuzzy numbers. The importance weight of each criterion can be obtained either by direct assignment or indirectly by pairwise comparison. Here, it is proposed that decision makers use linguistic variables to evaluate the importance of criteria and evaluate alternatives with respect to different criteria.

Among the different shapes of fuzzy numbers, triangular fuzzy number (TFN) is the most popular.

Definition (triangular fuzzy number) It is a fuzzy number represented by three points as follows:

A = (a1, a2, a3)

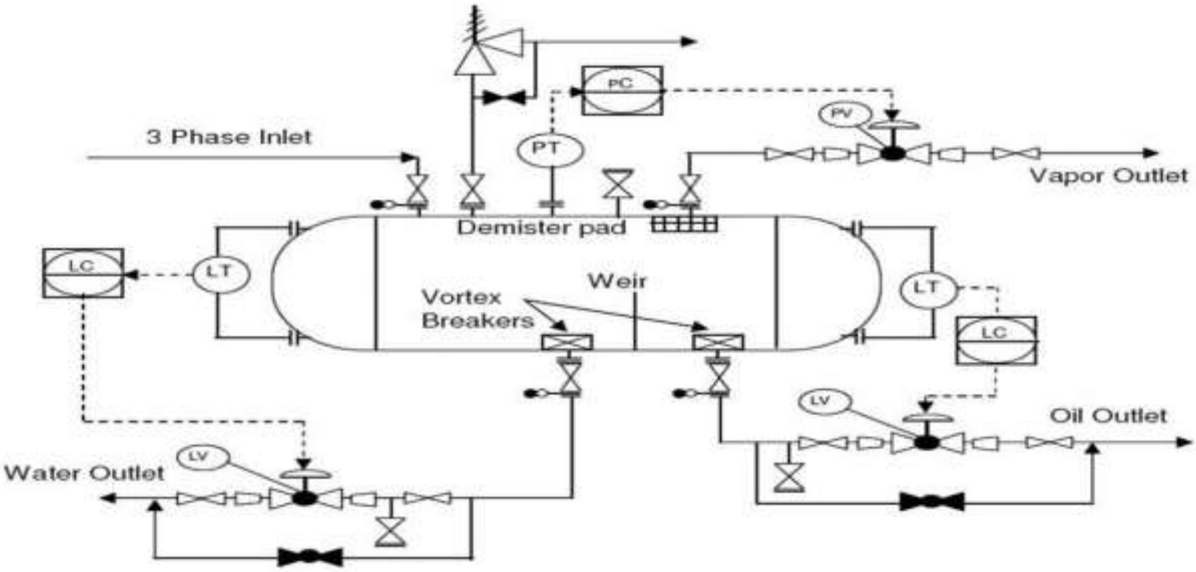


FIG 2 P&I DIAGRAM

$$\mu_{(A)}(x) = \begin{cases} 0, & x < a_1 \\ \dfrac{x - a_1}{a_2 - a_1}, & a_1 \le x \le a_2 \\ \dfrac{a_3 - x}{a_3 - a_2}, & a_2 \le x \le a_3 \\ 0, & x > a_3 \end{cases}$$

FIG.3 FUZZY MEMBERSHIP FUNCTION.

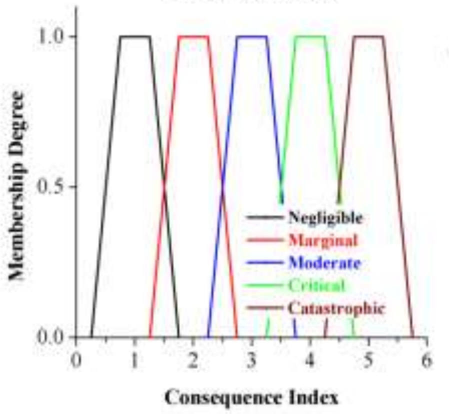


FIG.3 MEMBERSHIP FUNCTION CONSEQUENCE.

FMEA

"Failure modes" means the ways or modes in which something can fail. Failures are any errors or defects, especially those that affect the customer, and can be potential or actual. "Effect analysis" refers to the study of the consequences of these failures.

Defects are prioritized based on how severe their consequences are, how often they occur, and how easily they can be detected. The purpose of an FMEA is to take action to eliminate or reduce failures, starting with those with the highest priority.
Analysis of failure modes and effects also documents current knowledge and actions on failure risks for use in constant improvement. FMEA is used in the design of prevent breakdowns. Later is used to control, before and during ongoing process operation. Ideally, FMEA begins in the earliest conceptual stages of design and continues throughout the life of the product or service.

The main purpose of conducting an FMEA is to prevent the possibility that a new design, process or system will not meet, in whole or in part, the proposed requirements under certain conditions, such as a defined purpose and established limits. Through FMEA, client requirements are evaluated and products and processes are developed in a way that minimizes the risks of potential failure states with an emphasis on ensuring the safety and health of personnel and the security of systems. Another purpose of FMEA is to develop, evaluate, and improve design development and testing methodologies to achieve the elimination of defects and thereby obtain world-class competitive products. The main advantages of using the FMEA method are reducing costs with a critical impact on warranty returns, shortening the time needed from the project phase to market launch and improving the quality and reliability of products, increasing the safety of their operation. The ultimate goal for achieving these benefits is to increase customer satisfaction, which will ensure the growth of the organization's competitiveness and the improvement of its image in the market.

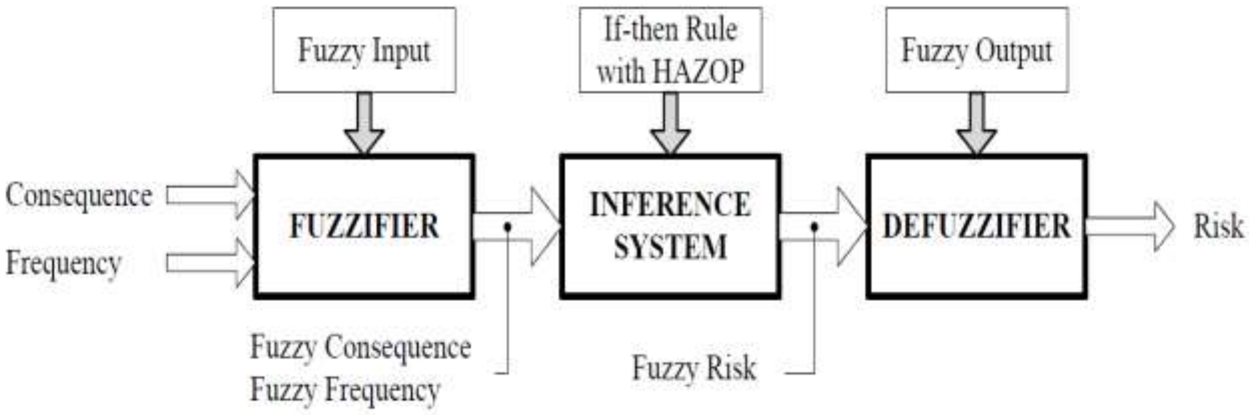


FIG 4 FUZZIFICATION

$$E_L = \int_{-\infty}^{+\infty} F^*(u)du = b - \int_{-\infty}^{b} \mu_Q(u)du = b - \frac{\alpha}{2}$$

$$E_U = \int_{-\infty}^{+\infty} F_*(u)du = c + \int_{c}^{+\infty} \mu_Q(u)du = c + \frac{\beta}{2}$$

Fuzzification means transforming a sharp value into a fuzzy value. Unlike the fuzzification of numerical variables, it is difficult to determine the fuzzy interval using linguistic variables. Many techniques such as rank ordering, neural networks, genetic algorithms, and inductive reasoning are used to determine membership functions. Because they are based on people's subjective opinions, membership degrees and fuzzy intervals depend on the intuition of experts. On the other hand, Dubois et al. proposed an interval bounded using the mean expected value and the possibility distribution. It is a numerical technique to reduce uncertainty arising from subjective intuitions.

$$\begin{aligned} \alpha &= 2b - 2E_L \\ &= 2(b - E_L) \\ &= 2\left(\frac{E_L + E[Q]}{2} - E_L\right) \\ &= E[Q] - E_L \end{aligned}$$

$$\beta = E_U - E[Q]$$

$$a = b - \alpha$$

$$d = c + \beta$$

III. Data Collection

Fuzzy-based HAZOP

HAZOP is an analytical method for identifying an individual and dynamic risks for process operations. An experienced leader in an independent position designs guidelines with respect to process parameters. In practice, HAZOP relates to flow, temperature, pressure, level, reaction, mixing, isolation, discharge, inspection, maintenance, start-up and shutdown. Guide words are selected according to process parameters and operating conditions: no, less, low, more, high, reverse, fluctuation and soon. HAZOP participants discuss process systems in detail using cover words. All these participants are experts who have different experience and knowledge for the systems. Identified hazards, consequences, risks and recommendations should be recorded in a standard form.

RISK PRIORITY NUMBER	**RANKING**
0 >10	7
11 >20	6
21 >30	5
31 >40	4
41 >50	3
51 >60	2
61 >100	1

TABLE I RISK PRIORITY NUMBER

HAZOP linguistically represents the views of the participants on the system. The frequency and consequences of the accident are summarized. These combine to express an accident. It is effective to systematically distinguish between causes and effects with respect to technical faults or human errors. However, the completeness of the linguistic descriptions depends on the facilitation of the HAZOP leader and the knowledge of the participants. Sometimes it is difficult to accurately describe the conditions of a system.

Estimated Occurrence Probability		**value**
Improbable	Once every 100 years	1
Remote	Once every 10 years	2
Occasional	Once a years	3
Probable	Until five times a year	4
Frequent	More than five times a year	5

TABLE 2 ESTIMATED OCCURRENCE PROBABILITY TABLE

SEVERITY	**Value**	**Meaning**	
		Personal injuries	**Material damages**
Incident	1	No injuries	Minimum material damages or damages not requiring repair
Minor	2	Injuries only requiring first aid.	Repairable without requiring to stop process.
Serious	3	Injuries that require medical treatment, or temporary work disability (TWD)	Stopping the process is required to perform the repair actions.
Major	4	Serious injuries that may be permanent or with DAW	Partial destruction of the system (complex and expensive repair).
Fatal or catastrophic	5	Death or hospitalization of three or more employees	Total destruction of the system (difficult to be renewed).

TABLE 3 SEVERITY TABLE

IDENTIFICATION NUMBER(ID)	**NODE 1: WATER FLOW**							**Estimated Occurrence Probability**	**SEVERITY**	**PROBABILITY OF NON DETECTION (D)**	**RISK PRIORITY NUMBER**	**RANKING**
	PROJECT PARAMETER	**GUIDE WORD**	**DEVIATION**	**CAUSES**	**DETECTION**	**CONSEQUENCES**	**ACTION REQUIRED**					
1	Flow	More	More flow	Failure in the pressure switch of the water supply automatic system.	Annual calibration and periodical inspection	Explosion of the boiler with consequent injuries	proper monitoring of pressure switch of the water supply automatic system	2	5	2	20	**6**
2	Flow	More	More flow	Failure in the boiler indicator's level	Corrective maintenance & periodic inspection	Explosion of the boiler	Regular checkup of the indicator	2	4	2	16	**6**
3	Flow	More	More flow	Steam leakage in the water level	periodic inspection	Severe damage in the boiler	Proper function test and periodic inspection	4	5	3	60	**2**
4	Flow	More	More flow	Electric failure in the pump since there is failure in the pressure switch and level	Annual calibration and periodical inspection	Leads to severe injuries and damage due to explosion of boiler	implement of preventive and predictive plan	3	4	2	24	**5**
5	Flow	Less	Less flow	Incrustation in the water pipe	Control of water out flow in the system and monitoring	Temperature increase	implementation of alarm system of low water level	4	3	3	36	**4**

TABLE 4 HAZOP TABLE

IDENTIFICATION NUMBER(ID)	NODE 1: WATER FLOW							Estimated Occurrence Probability	SEVERITY	PROBABILITY OF NON DETECTION (D)	RISK PRIORITY NUMBER	RANKING
	PROJECT PARAMETER	GUIDE WORD	DEVIATION	CAUSES	DETECTION	CONSEQUENCES	ACTION REQUIRED					
6	Flow	Less	Less flow	Pump failure (Mechanical, Electrical)	periodic inspection in the pump	Deformation of internal piping	Proper inspection of pump	3	5	2	30	**5**
7	Flow	Less	Less flow	Semi open valve	periodic inspection in the valve	Pressure and temperature increase	implementation of alarm system of low water level	2	4	3	24	**5**
8	Flow	Less	Less flow	Failure in the pressure switch	Sound signal or low level of the water and visual inspection	emmission of black smoke, and fire in the boiler	Proper monitoring of pressure switch	3	4	**3**	36	**4**

TABLE 5 HAZOP TABLE

NODE 2: STEAM PRESSURE												
IDENTIFICATION NUMBER(ID)	PROJECT PARAMETER	GUIDE WORD	DEVIATION	CAUSES	DETECTION	CONSEQUENCES	ACTION REQUIRED	Estimated Occurrence Probability	SEVERITY	PROBABILITY OF NON DETECTION (D)	RISK PRIORITY NUMBER	RANKING
9	Flow	More	More Pressure	Excess of fuel in the boiler	Boiler and Pressure vessel manometer.	Safety & Health Explosion Risk	Eloborate and Implement a maintenance plan	3	5	3	45	**3**
10	Flow	More	More Pressure	Pressure register closes during the boilers operation.	Visual Inspection	Safety & Health Explosion Risk	Qualified boiler's operator	2	5	3	30	**5**
11	Flow	Less	Less Pressure	Obstruction or leakage in the oil pipe	Boiler an Pressure vessel manometer.	Safety & Health Fire risk	Eloborate and Implement a operating andmaintenance plan	3	4	3	36	**3**
12	Flow	Less	Less Pressure	Operating failure of the operator during the boiler's pressure control	Visual Inspection	Safety & Health Commitment to the productive process	Proper awareness related to the operating procedures of the boiler.	3	3	5	45	**3**

TABLE 6 HAZOP TABLE

S.No	Guidewords	Causes	Consequences	Conventional			Fuzzy		
				O	S	R	F	S	R
1	More Flow	Failure in the pressure switch of the water supplyh automatic system.	Explosion of the boiuler with consequent injuries.	2	5	10	-0.99	5	12
2	More Flow	Failure in the boiler indicatior's level.	Explosion of the boiler.	2	4	8	-0.99	4	10
3	More Flow	Steam leakage in the water level.	Severe damage in the boiler.	4	5	20	0.05	5	14
4	More Flow	Electric failure in the pump since there is failure in the pressure switch and level.	Leads to severe injuries and damage due to explosion of boiler.	3	4	12	-0.69	4	12
5	Less Flow	Incrustation in the water pipe	Temperature increase	4	3	12	0.05	3	10
6	Less Flow	Pump failure (Mechanical, Electrical)	Deformation of internal piping	3	5	15	-0.90	5	10
7	Less Flow	Semi oipen valve	Pressure and temperature increase.	2	4	8	-1.35	4	12
8	Less Flow	Failure in the pressure switch	Emmission of black smoke, and fire in the boiler.	3	4	12	-1.16	4	8
9	More Pressure	Eccess of fuel in the boiler	Safety & Health Explosion Risk.	3	5	15	-1.35	5	10
10	More Pressure	Pressure register closes during the boiler operation.	Safety & Health Explosion Risk.	2	5	10	-0.99	5	9
11	Less Pressure	Obstruction or Leakage in the oil Pipe	Safety & Health Fire Risk.	3	4	12	-0.99	4	12
12	Less Pressure	Operating failure of the operator during the boilers pressure control	Safety & Health Commitment to the productive process	3	3	9	-1.16	3	9

TABLE 7 FUZZY TABLE

IV. RESULT & DISCUSSION

Fuzzy-based HAZOP represents risks using a fuzzy risk matrix that ranks risks in order of importance, filters out insignificant risks, or evaluates measures to reduce the risks of each hazard. This is consistently applied to personnel, property and the environment. compare conventional and fuzzy-based risk matrices in terms of how the risks match the risk acceptability criteria. Considering the five categories of frequency and consequences, both matrices show risk ratings from 1 to 25 and risk acceptability criteria. A conventional risk matrix has three areas: negligible (1 to 6), ALARP (8 to 16) and unacceptable (20 to 25). The fuzzy risk matrix has seven regions for different ranges rather than a single value. The conventional risk matrix indicates the risk as 1, while the fuzzy risk matrix indicates the risk as a range from 9 to 16, where the frequency and consequences are occasional and critical. It follows from this result that the risks should be evaluated according to specific categories with respect to the member degrees of risks.

The frequency index has a greater influence on the determination of risk than the consequence index. Although the consequence indices are the same for both hazops, different frequency indices affect the risks due to their degree of membership according to Mamdani arithmetic operations; that is, the fuzzy input with the lowest membership degree is reflected in the computation of its output. Although the IF-THEN rules consist of a large number of inputs and outputs, the minimum degree of membership determines the final fuzzy output. In most cases, fuzzy-based HAZOP provides lower risks than conventional HAZOP for identical hazards. The risks are reflected in the design of the process, which should not have an excessive security capability. If risks are overestimated, then risk analyzes such as SIL assignment or fire and explosion analyzes may result in conservative protective measures. Since these analyzes also consider redundancy or design modifications to further reduce risks, the risks lead to increased system costs and complexity at the process design stage using Mamdani's arithmetic operations.

Although the IF-THEN rules consist of a large number of inputs and outputs, the minimum degree of membership determines the final fuzzy output. In most cases, fuzzy-based HAZOP provides lower risks than conventional HAZOP for identical hazards. The risks are reflected in the design of the process, which should not have an excessive security capability. If risks are overestimated, then risk analyzes such as SIL assignment or fire and explosion analyzes may result in conservative protective measures. Because these analyzes also consider redundancy or design modifications to further reduce risks, the risks lead to increased system costs and complexity in the process design.

V. CONCLUSION

Fuzzy-based HAZOP evaluates risks related to process deviations under uncertain information. This approach is an alternative to overcoming uncertainties in the HAZOP design review step for a risk-based design. It helps designers make scientific decisions using fuzzy set theory. Fuzzy modeling is used to represent risks regarding the frequency and consequences of process deviations. Fuzzy logic quantifies the ambiguity and vagueness of linguistic descriptions and calculates risks according to degree of membership. The mean expected value is introduced to fuzzify the linguistic variables. This is intended to provide numbers of linguistic variables with less uncertainty due to subjectivity. Fuzzy modeling generates 25 IF-THEN rules and final fuzzy outputs to obtain risks. A comparative study is required for different fuzzy numbers and membership functions. Interval bounds on linguistic variables and other fuzzification techniques can lead to slightly different tendencies. If the analyst introduces different types of fuzzy numbers, the risk will change. In a fuzzy-based HAZOP, any index may have a greater impact than others depending on the fuzzy numbers.

REFERENCE

[1] Junkeon Ahn Daejun Chang, Fuzzy-based HAZOP Study for Process Industry. HAZMAT 17785.

[2] Ying-Ming Wang., et al., Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean. Expert Systems with Applications 36 (2009) 1195–1207

[3] Chen-Tung Chen, Extensions of the TOPSIS for group decision-making under fuzzy environment. Fuzzy Sets and Systems 114 (2000) 1-9.

[4] Joel John George., et al., Application of fuzzy failure mode effect and criticality analysis on unloading facility of LNG terminal. JLPP 3906.

[5] Seyed Mohammadreza Miri Lavasani., et al., Application of MADM in a fuzzy environment for selecting the best barrier for offshore wells. Expert Systems with Applications 39 (2012) 2466–2478.

[6] PSS Srinivasan et al., "Risk Analysis (HAZOP Study) for a Hazardous Chemical Storage Plant", 2017 May 11(7): pages 724-726

[7] Appil Ora, et al., "Hazard Identification of Chemical Mixing Plant through Hazop Study", (Volume2, Issue3).

[8] Venkat Venkatasubramanian, Jinsong Zhao, Shankar Viswanathan Srinivasan "Intelligent systems for HAZOP analysis of complex process plants".

[9] Faisal I. Khan and S. A. Abbasi "OptHAZOP-an effective and optimum approach for HAZOP study".

[10] Trevor A Kletz proposed the research paper on" Hazop-past and future".

[11] M.Perez-marin et al (2013) "HAZOP – Local approach in the Mexican oil & gas industry".

[12] Jordi Dunjó et al. (2009) "Hazard and operability (HAZOP) analysis- A literature review".

[13] L. Kotek and M. Tabas "HAZOP study with qualitative risk analysis for prioritization of corrective and preventive actions".

[14] Johannes I. Single, Jürgen Schmidt, Jens Denecke "State of research on the automation of HAZOP studies".

[15] C. Fencott, B.D Hebbron "The application of HAZOP studies to integrated requirements models for control systems"

[16] Paul Baybutt "A critique of the Hazard and Operability (HAZOP) study".

[17] Junkeon Ahn Daejun Chang "Fuzzy-based HAZOP Study for Process Industry".

[18] Feng Wang, Jinji Gao, Huaqing Wang "A new intelligent assistant system for HAZOP analysis of complex process plant".

[19] M. Pérez-Marín a , M.A. Rodríguez-Toral b, "HAZOP - Local approach in the Mexican oil & gas industry".

[20] Antonio C.F. Guimaraes , Celso Marcelo Franklin Lapa "Hazard and operability study using approximate reasoning in light-water reactors passive systems".

[21] Matej Dankoa , Jérôme Frutigerb , Ľudovít Jelemenskýa , Gürkan Sinb "Monte Carlo Based Framework to Support HAZOP Study".

[22] HU Jin-qiu, ZHANG Lai-bin, LIANG Wei, WANG Zhao-hui "Quantitative HAZOP Analysis for Gas Turbine Compressor based on Fuzzy Information Fusion".

[23] Jinqiu Hu, Laibin Zhang, Zhansheng Cai, Yu Wang, "An intelligent fault diagnosis system for process plant using a functional HAZOP and DBN integrated methodology".