

Reliability Analysis of Fire Alarm Systems Using Fuzzy Fault Tree Analysis

Abhiram CR¹, Akshay PK², Midhun S³, Thoufeek S⁴, Alaka P⁵, Praveen KR⁶

UG Students, Department of Safety and Fire Engineering, Eranad Knowledge City Technical Campus, Manjeri, Malappuram, Kerala, India¹ Orcid Id:0009-0008-0272-9862

UG Students, Department of Safety and Fire Engineering, Eranad Knowledge City Technical Campus, Manjeri, Malappuram, Kerala, India² Orcid Id:0009-0003-9840-6980

UG Students, Department of Safety and Fire Engineering, Eranad Knowledge City Technical Campus, Manjeri, Malappuram, Kerala, India³ Orcid Id: 0009-0007-3942-4387

UG Students, Department of Safety and Fire Engineering, Eranad Knowledge City Technical Campus, Manjeri, Malappuram, Kerala, India⁴ Orcid Id:0009-0006-5269-8190

Assistant Professor, Department of Safety and Fire Engineering, Eranad Knowledge City Technical Campus, Manjeri, Malappuram, Kerala, India⁵ Orcid Id:0009-0004-2850-4099

Assistant Professor, Department of Safety and Fire Engineering, Eranad Knowledge City Technical Campus, Manjeri, Malappuram, Kerala, India⁶ Orcid Id:0009-0004-6775-7056

ABSTRACT: Among the most significant risks to industrial, commercial, educational, and healthcare establishments are fires. The detection and management of fires rely heavily on fire alarm systems. The alarm system must promptly trigger the extinguisher system in the case of a fire. Fire alarm systems thus play a crucial role in lowering the risks of fires and damage in virtually every industry. As a result, it's important to assess how well they work in emergency scenarios. The current work aims to apply fault tree analysis (FTA) to identify the fundamental reasons behind fire alarm system failure, as well as to estimate relative probabilities using fuzzy set theory and expert elicitation.

KEYWORDS: Reliability, Fuzzy, Fire alarm system, Failures, Fault tree

I. INTRODUCTION

One of the most important hazards to threaten commercial, educational, industrial, and healthcare facilities is fire. The detection and management of fires rely heavily on fire alarm systems. The extinguisher system must promptly be activated by the alarm system in the case of a fire. If this isn't done, a fire will grow exponentially, becoming harder to control and expensive to repair. One piece of equipment that is essential for minimizing the risk and harm a fire may create in any industry is a fire alarm system

Fault tree analysis (FTA) is a prominent tool for the reliability evaluation of composite elements. By the evaluation of failure rates of basic events, the probability of a top event can be originated. Finding basic event occurrence pulls up the occurrence of failure of top events, this relates to the dependence of basic events and top events. Therefore, the determination of the probability of basic events is essential for fault tree analysis.

In 1965 Lotfizadeh introduced the fuzzy set theory to stamp the probability evaluation on the conventional theories. Conventional theories are incompetent for a variety of uncertainty. For a mysterious and uncertain condition, fuzzy set theory is acceptable over undefined conditions. This can also convert qualitative expressions to numerical probabilities. Fault tree exists some limitations in the determination of probabilities, to overcome the limitations and diminish the uncertainty of conditions, the fuzzy set theory holds on with the Fault tree analysis method. In the fuzzy fault tree method, the scaling of different aspects is loaded based on standards to get the output probability of failures. The fuzzy set theory can reduce the uncertainty in resource persons and the probability evaluation of basic events.

Organized by
 Ernad Knowledge City Technical Campus, Manjeri, Malappuram Dist, Kerala, India

II. RELATED WORKS

Fire alarm system failures are one of the unsafe conditions in causing an accident. [1] Analyze the root causes and determine the reliability of fire alarm systems in a certain period. [2] Determine the reliability of firefighting systems in the atmospheric storage tank of the petrochemical industry. [3] Perform a risk assessment using fuzzy set theory and expert elicitation along with fuzzy AHP and fuzzy TOPSIS in a process industry. [4] Risk assessment of an ethylene transportation line unit using fuzzy set theory and expert knowledge along with FTA through the Bayesian Network. [5] Risk assessment of fire alarm system in a process industry using Fuzzy set theory.

III. METHODOLOGY

By implementing the failure data of the fire alarm in a FTA we found the reliability of the fire alarm then we used fuzzy set theory to overcome the limitations of the FTA. The fuzzy set theory is suitable for converting possible qualitative expressions to numerical probabilities. Fuzzy set theory is widely used for analyzing the reliability of a system.

The classical set theory is expanded in fuzzy set theory to include items with varying degrees of membership. Membership with values in the range [0,1] is allowed by fuzzy set theory. Fuzzy information was widely used in human reasoning (analysis, logic, interpretation).

Fuzzy logic is defined as "symbolic logic with a comparative notion of truth fully developed in the spirit of classical logic." It is a branch of many-valued logic built on inference under the uncertainty paradigm. Fuzzy logic is a subset of multi-valued logic that was developed from fuzzy set theory to deal with reasoning that is more approximate than precise. While fuzzy logic can be used to cope with hazy ideas, it is not a system of vague reasoning. The degree of truth of a statement in fuzzy logic can vary between 0 and 1, unlike in classical predicate logic, where the degree of truth is limited to the two truth values true/false, where the set membership values can (inclusively) range between 0 and 1. The issue is that in the "real" world, some of the information we have about the world comes from sensors: the amount of heat measured in degrees centigrade, the length recorded in meters, the weight (the amount of substance) measured in grams, etc. A linguistic variable's term set must be translated onto this quantitative, rather accurate factual information using the fuzzification method. The proposed failures are represented by a fault tree in Fig. 1, which uses fault tree analysis to determine their underlying causes. Table 1 shows a plot of each base event and each intermediate event along with a description of each.

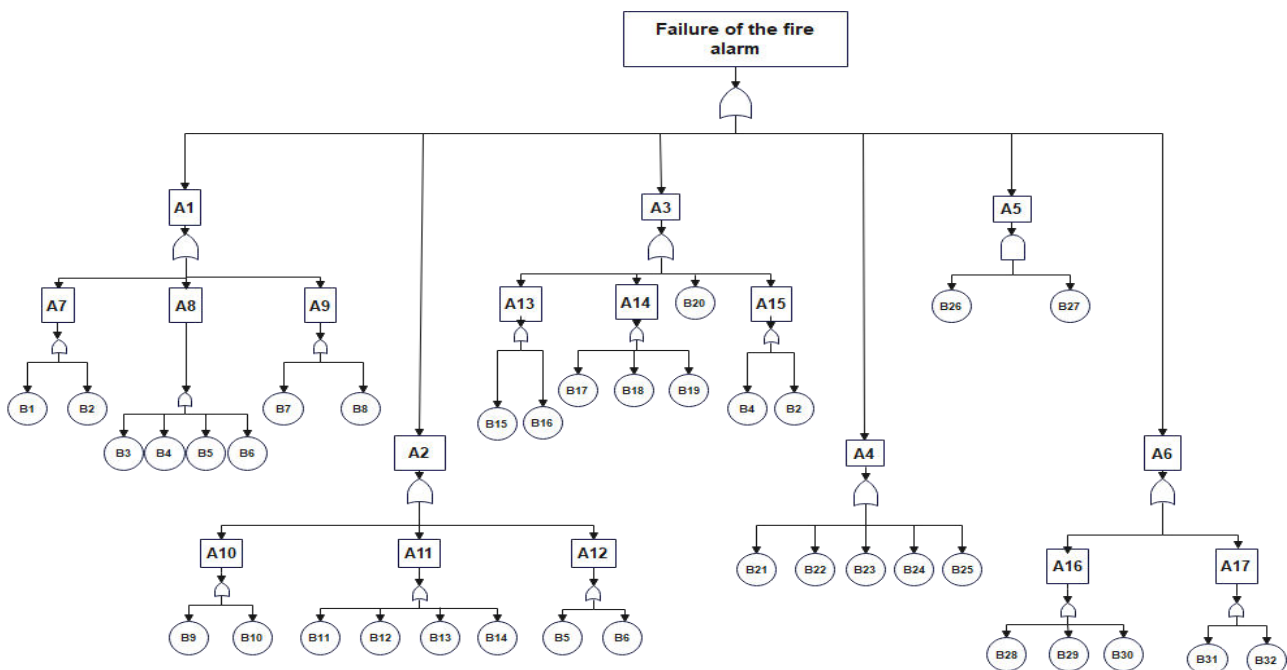


Fig.1 Fault tree of fire alarm system Failures



Organized by

Eranad Knowledge City Technical Campus, Manjeri, Malappuram Dist, Kerala, India

Table 1 Description of intermediate and basic events within the fault tree.

Symbol	Description	Symbol	Description
A1	Detector failure	B9	Mechanical damage
A2	Failure of alarm system components	B10	Door switch/lock damage
A3	Signal communication subsystem failure	B11	Electronic failure
A4	Failure in auxiliary control subsystem	B12	Initiating circuit
A5	Power supply failure	B13	Alarm notification
A6	False alarm	B14	Indicator light bulb
A7	Dirty detector	B15	Wire broken/loose
A8	Faulty detector	B16	Installation failure/bad connection
A9	Wet detector	B17	Detector disconnected
A10	Mechanical failure in control panel	B18	Address fault
A11	Electrical/electronic failure in control	B19	Detector bad contact
A12	Failure in manual initiating device	B20	Announcement forwarding
A13	Wire/cable failure	B21	Failure in computer/coding
A14	No/bad connection to detector	B22	Control of fire dampers
A15	Removed circuit	B23	Control in extinguishing system
A16	Human error	B24	Control of fire pump
A17	Instruction error	B25	Control of alarming/notification appliances
B1	Contaminated in use	B26	Failure in main voltage or circuit current
B2	External cause	B27	Failure in standby batteries
B3	Damaged in use	B28	Communication error
B4	Unknown cause	B29	Control error
B5	Technical failure	B30	Testing error
B6	Mechanical failure	B31	Insufficient/faulty guidance
B7	Open/leaking sprinkler head	B32	Design error, modification
B8	Space damp		

IV. EXPERIMENTAL RESULTS

The fault tree analysis distinguishes the root causes of the failure of the fire alarm system. The MATLAB software identified the fuzzy relative probabilities of the system with different causes of the failure of the fire alarm. The chance of occurrence and severity were the output functions used to determine the fuzzy logic. Each root cause event is linguistically termed on the specified standard for the membership functions. The rules proposed on the basis of event occurrence with membership function range are evaluated by software and given the proposed output with respect to the input.

Organized by

Eranad Knowledge City Technical Campus, Manjeri, Malappuram Dist, Kerala, India

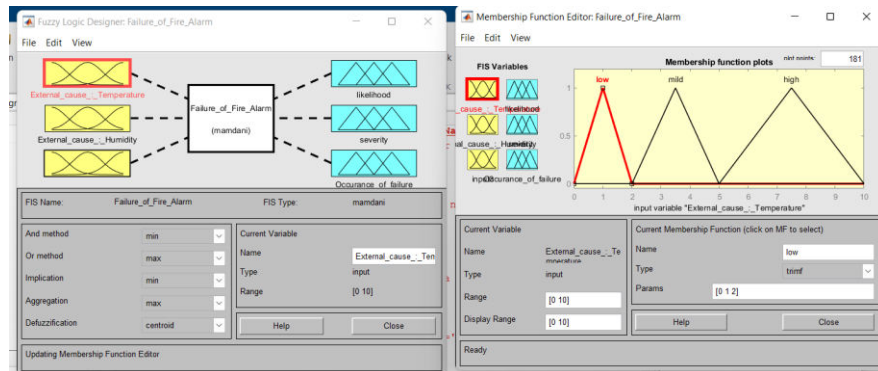


Fig. 2 Membership functions of external cause: Temperature

In Fig. 2 the membership functions of the FIS external cause; Temperature is defined in the MATLAB software as the fuzzy logic designer. The membership functions include the linguistic terms of failures that are plotted. Fig. 3 Membership functions of external cause: Humidity and then followed by the inputs Fig.4, Fig. 5. As the fire variable, mechanical failures respectively.

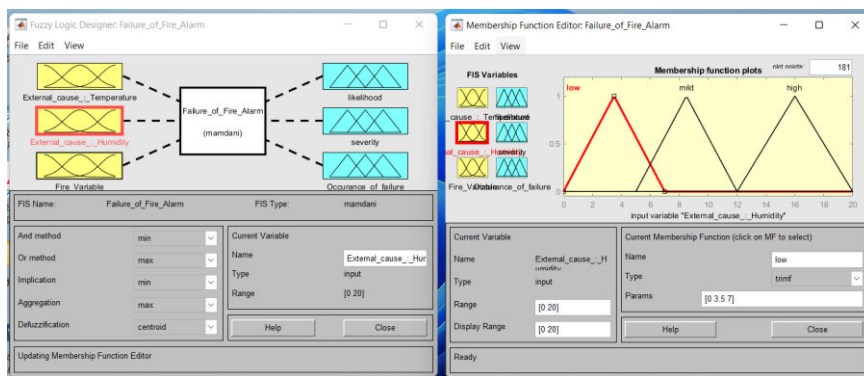


Fig. 3 Membership functions of external cause: Humidity

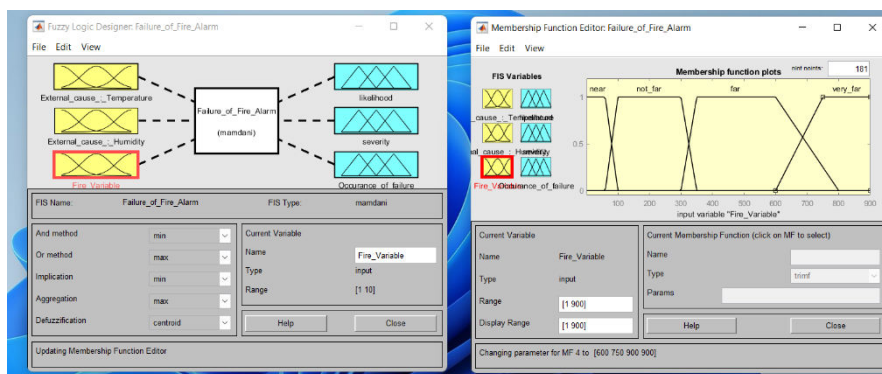


Fig. 4 Membership functions of Fire variable.

Organized by

Eranad Knowledge City Technical Campus, Manjeri, Malappuram Dist, Kerala, India

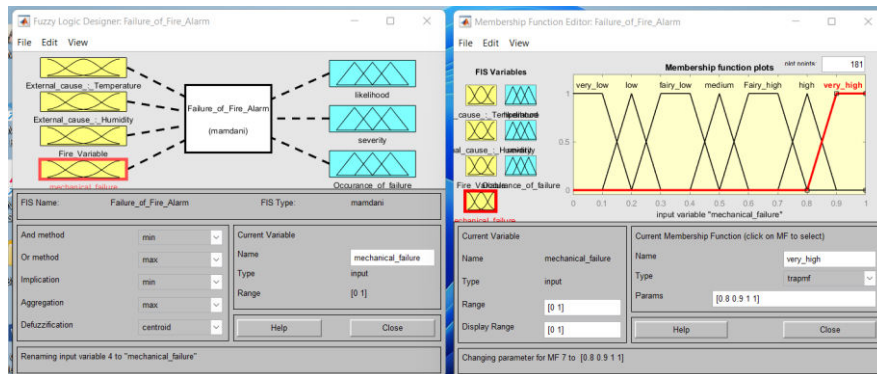


Fig. 5 Membership functions of Mechanical failure

The output membership functions of severity and occurrence of failure are logically designed as per the standards. The severity of the fire alarm failures is determined on the basis of the range of scaling and the input variable selection.

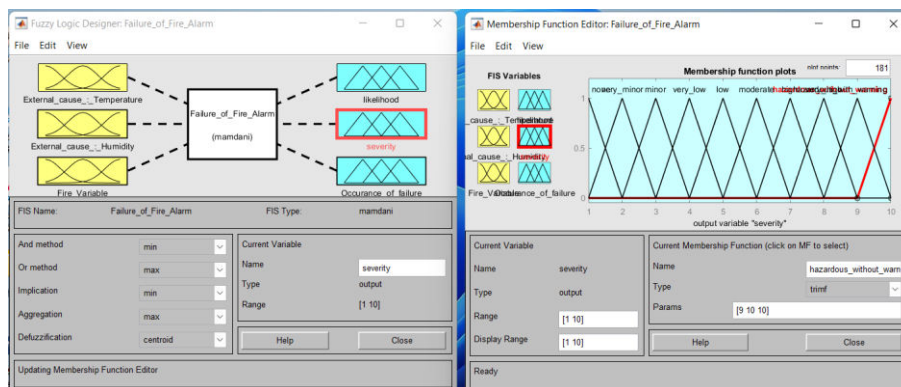


Fig. 6 Membership functions of Severity

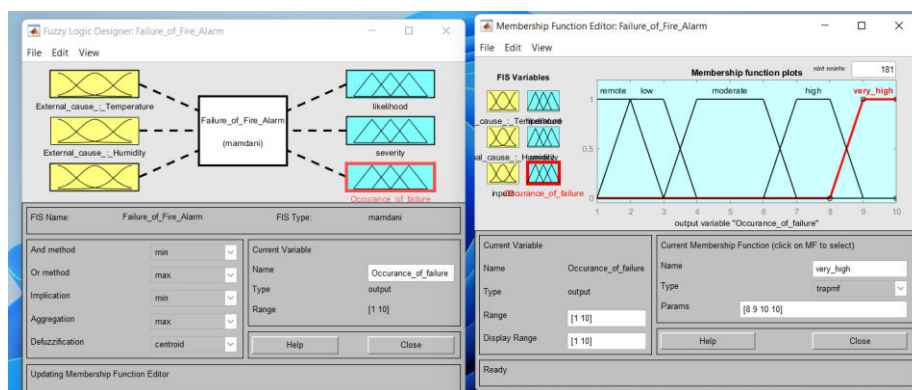


Fig. 7 Membership functions of Occurrence of failure

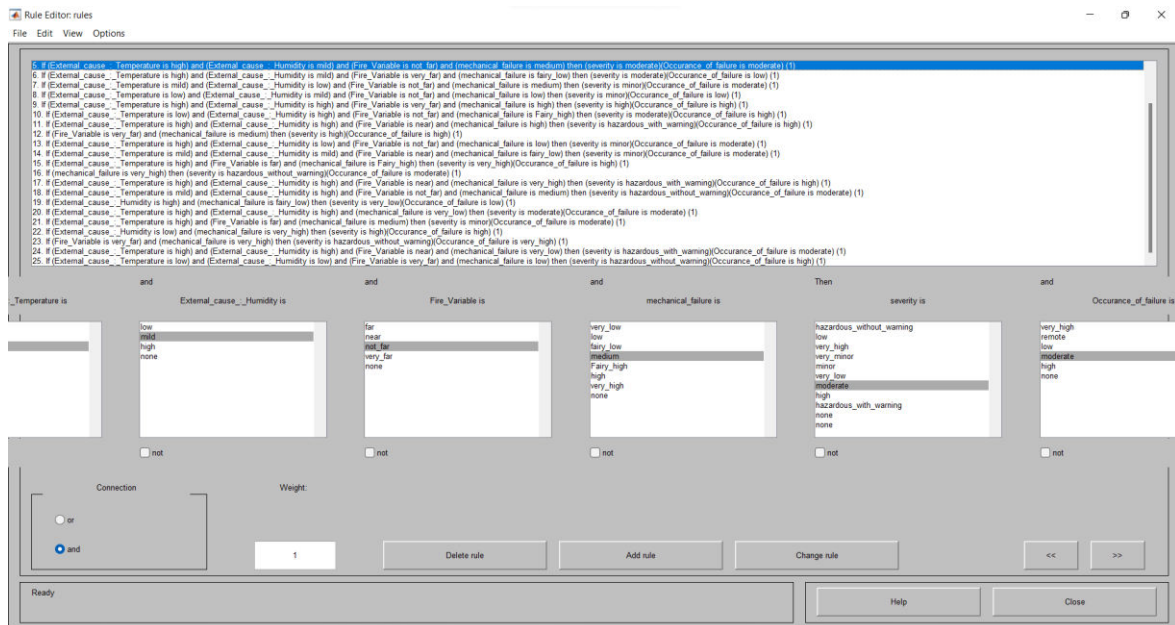


Fig. 8 Fuzzy if-then rules

The rules in Fig. 8 design the whole fuzzy scaling in MATLAB software. The rules are based on the individual preference of rules inputs. The inputs can be related to the way failures can occur in fire alarm systems.

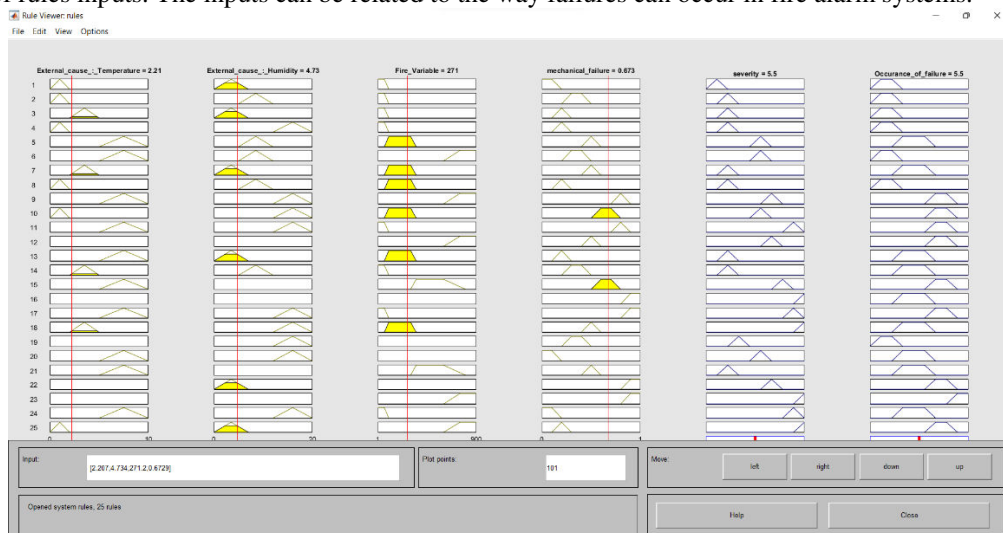


Fig. 9 Analysed behavior of FIS

V. CONCLUSIONS

According to this paper, we found that the failure of the fire alarm is mainly due to mechanical failure and the fire variable distance. In this approaches the failure can be minimized by the regular maintenance of the fire alarm system. The Fuzzy relative probability of the failures is determined by the level of faults that occurred in the fire alarm system. Regular maintenance, periodic inspection, and proper housekeeping are the major control measures to prevent the failure of the fire alarm system.

Organized by

Ernad Knowledge City Technical Campus, Manjeri, Malappuram Dist, Kerala, India

REFERENCES

- [1] Jafari, M. J., Pouyakian, M., & Hanifi, S. M. (2020). Reliability evaluation of fire alarm systems using dynamic Bayesian networks and fuzzy fault tree analysis. *Journal of Loss Prevention in the Process Industries*, 67, 104229.
- [2] Laal, F., Pouyakian, M., Jafari, M. J., Nourai, F., Hosseini, A. A., & Khanteymooori, A. (2020). Technical, human, and organizational factors affecting failures of firefighting systems (FSs) of atmospheric storage tanks: providing a risk assessment approach using Fuzzy Bayesian Network (FBN) and content validity indicators. *Journal of Loss Prevention in the Process Industries*, 65, 104157.
- [3] Yazdi, M. (2017). Hybrid probabilistic risk assessment using fuzzy FTA and fuzzy AHP in a process industry. *Journal of Failure Analysis and Prevention*, 17(4), 756-764.
- [4] Yazdi, M., & Kabir, S. (2017). A fuzzy Bayesian network approach for risk analysis in process industries. *Process safety and environmental protection*, 111, 507-519.
- [5] Na, Q., Zhonghai, L., Naiwei, C., & Jianwei, L. (2013, December). Failure risk assessment of fire alarm system. In *Proceedings 2013 International Conference on Mechatronic Sciences, Electric Engineering and Computer (MEC)* (pp. 250-253). IEEE.
- [6] Sarwar, B., Bajwa, I. S., Ramzan, S., Ramzan, B., & Kausar, M. (2018). Design and application of fuzzy logic based fire monitoring and warning systems for smart buildings. *Symmetry*, 10(11), 615.
- [7] Shahriar, A., Sadiq, R., & Tesfamariam, S. (2012). Risk analysis for oil & gas pipelines: A sustainability assessment approach using fuzzy based bow-tie analysis. *Journal of loss prevention in the process Industries*, 25(3), 505-523.
- [8] Na, Q., Zhonghai, L., Naiwei, C., & Jianwei, L. (2013, December). Failure risk assessment of fire alarm system. In *Proceedings 2013 International Conference on Mechatronic Sciences, Electric Engineering and Computer (MEC)* (pp. 250-253). IEEE.
- [9] Bhardwaj, R. K., & Malik, S. C. (2012). Fuzzy reliability evaluation of a fire detector system. *International Journal of Computer Applications*, 43(3), 41-46.
- [10] Yu, Q., Zheng, D., Fu, Y., & Dong, A. (2009, May). Intelligent fire alarm system based on fuzzy neural network. In *2009 International Workshop on Intelligent Systems and Applications* (pp. 1-4). IEEE.