Fuzzy Reliability Evaluation of a Fire Detector System

R.K. Bhardwaj
Department of Statistics
Punjabi University, Patiala
Punjab, India

S.C.Malik
Department of Statistics
M.D. University, Rohtak
Haryana, India

ABSTRACT

Reliability has vital significance to engineers and designers in a safety system. Consequently, failures free operation of components or sub-systems is of their key concern. To assess the reliability of such systems quantitatively, failure data of the components or sub-systems is essentially required. In general, such data is either not pre-recorded or present in linguistic form (good, bad etc). For quantitative evaluation of reliability the usual probabilistic considerations seems to be inadequate. Therefore, in this paper, conventional fault tree analysis (FTA) approach integrated with fuzzy theory has been used to evaluate the reliability of a fire detector system using fuzzy failure possibilities of components (or sub-systems).

General Terms

Fuzzy Reliability Evaluation

Keywords

Fire Detector System, Fault tree, Fuzzy failures, Fuzzy numbers, FTA and Reliability.

1. INTRODUCTION

Safety is the primary concern of reliability and safety engineers in production or process industry. To meet safety requirements certain safety equipments are installed in these industries. A fire detection system is one such equipment installed to detect the initiation of critical situation caused due to fire. To meet the safety and reliability requirements of the industry its fire detection system must perform its function adequately. Failure of such system may cause hazardous results. Thus, keeping safety aspects in mind the reliability and the failure possibility evaluation of a fire detection system is necessary.

Fault tree analysis is the commonly used failure analysis technique in all major fields of safety and reliability engineering [2]. In this technique an undesired state (called as top/ most critical event) is specified and the system is analyzed for the possible chain of basic events (system faults) that may cause the top/ most critical event to occur. In conventional method reliability of the system is characterized in perspective of probability procedures. But it becomes unfeasible to assess precise probabilities due to presence of inaccuracy and uncertainty in data and information [4]. Therefore, in practice, to describe the system reliability, more realistically, fuzzy approach is needed. Firstly, Zadeh [8] introduced the concept of fuzzy sets in 1965. Singer [10] discussed a fuzzy set approach to fault tree and reliability analysis. Liang et al [6] presented fuzzy fault tree analysis incorporating the assumption of failure possibilities. In literature [3, 5, 9, 13] various other applications of fuzzy set theory has been proposed in different forms. Keeping practicability in view, in this paper, conventional fault tree analysis technique integrated with fuzzy approach is utilized to evaluate the reliability of a fire detection system [8].

We ask that authors follow some simple guidelines. In essence, we ask you to make your paper look exactly like this document. The easiest way to do this is simply to download the template, and replace the content with your own material.

2. FIRE DETECTION SYSTEM

A fire detection system [8], basically, comprises of- a fire detector, a smoke detector and a manual detector as shown in fig.1. The heat detection system consists of four identical fuse plugs (FPi , i=1,2,3,4), installed in a closed circuit of pneumatic pipe. If the temperature crosses a specified limit, these plugs let the air out of circuit and then the pressure switch (PS) will be on and give signal to the start relay (SR) for alarm and shutdown system. Three highly sensitive optical smoke detectors (SDi, i=I,2,3) are used to detect smoke. To avoid false alarm the smoke detectors are arranged to operate in 2-out-of-3 mode through a voting unit (VU). A provision of manual switch (MS) for the operator to activate start relay for alarm and shutdown is also given in the arrangement.

In all the three situations when the start relay receives an electrical signal (intact with DC source) it is activated and gives a signal to alarm and shutdown process. If we assume the fire starts, then detectors are expected to detect fire and raise warning signal.

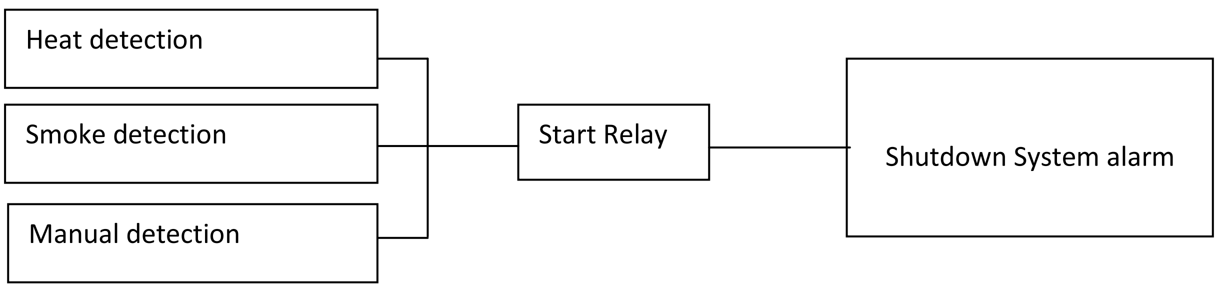


Fig. 1 An overview of fire detector system

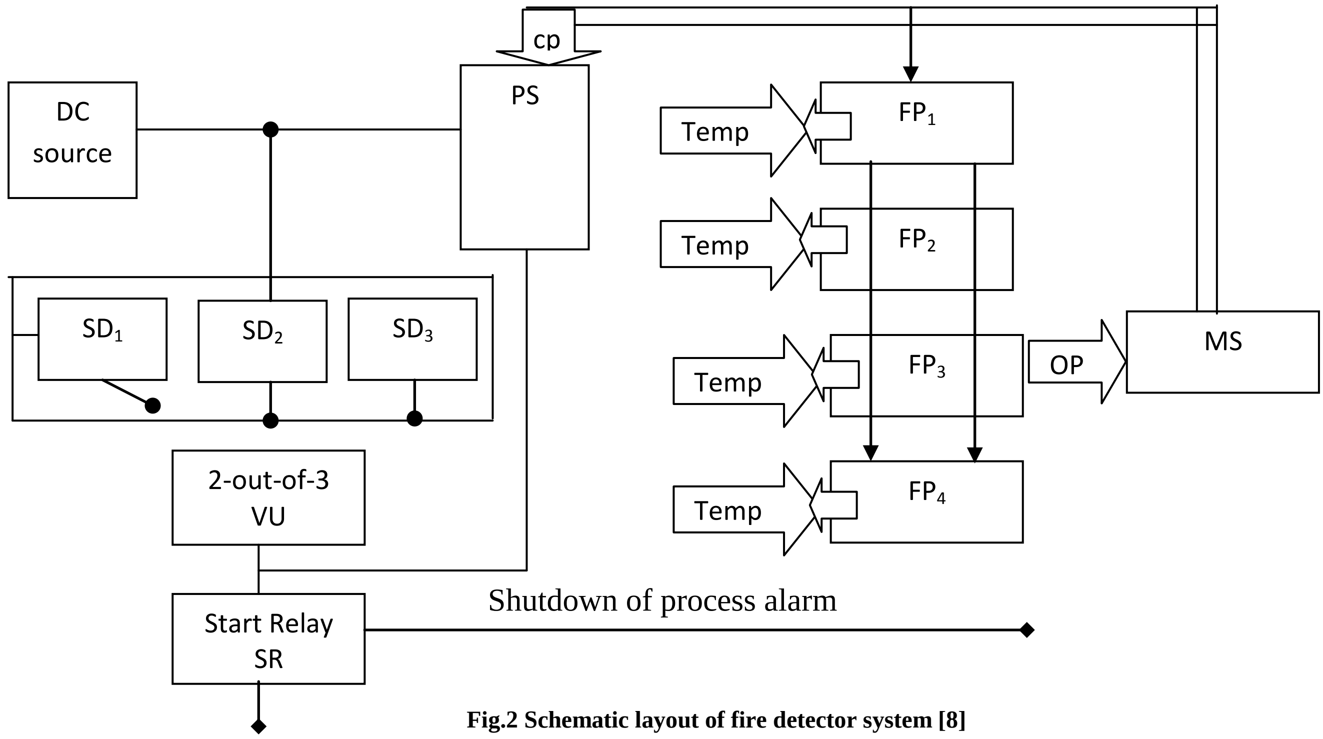


Fig.2 Schematic layout of fire detector system [8]

3. FUZZY APPROACH

3.1 L-R fuzzy numbers

Practically the membership function can be approximated by two functions L(x) and R(x). Let A Є (-∞, +∞) and L and R be referring functions of fuzzy numbers. Then A is termed as L-R fuzzy number and its membership function is defined as

$$\mu_A(x) = \begin{cases} L(\frac{m-x}{\alpha} & \text{for } x \leq m,\ \alpha > 0 \\ R(\frac{m-x}{\beta} & \text{for } x \leq m,\ \beta > 0 \end{cases} \quad (1)$$

Here, m represents the mean and α and β are the left and right spreads.

3.2 Triangular fuzzy numbers

A is said to be triangular fuzzy number if its membership function, $\mu_A(x) \in [0,1]$, is defined as

$$\mu_A(x) = \begin{cases} 0 & ; x < \alpha \\ \frac{x-\alpha}{m-\alpha} & ; \alpha \leq x \leq m \\ \frac{\beta-x}{\beta-m} & ; m \leq x \leq \beta \\ 0 & ; x > \beta \end{cases} \quad (2)$$

Triangular fuzzy number is the special case of L-R fuzzy number and is denoted by A= (α, m, $\boldsymbol{\beta}$)

3.3 Arithmetic operations on Triangular fuzzy numbers

Let A = (α_1, m_1, β_1) and B = (α_2, m_2, β_2) be two triangular fuzzy numbers then

i) Addition: A⊕B= (α_1, m_1, β_1) + (α_2, m_2, β_2) =($\alpha_1+\alpha_2, m_1+m_2, \beta_1+\beta_2$) (3)

ii) Subtraction: A-B= (α_1, m_1, β_1) -(α_2, m_2, β_2) =($\alpha_1-\alpha_2, m_1-m_2, \beta_1-\beta_2$) (4)

Also 1-A= 1-(α_1, m_1, β_1) = $(1-\alpha_1, 1-m_1, 1-\beta_1)$ (5)

Multiplication: A⊗B=($\alpha_1\,\alpha_2, m_1\,m_2, \beta_1\beta_2$) (6)

Also CA= C (α_1, m_1, β_1) = (Cα_1, Cm_1, Cβ_1) (7)

Here C is any real number.

4. Analysis of Fire Detector System

4.1 Proposed Algorithm for Fuzzy FTA

Following algorithm shows the general steps to obtain the reliability of system.

Step 1: Start

Step 2: To identify the top/most critical event of the system i.e. the event whose failure cause the entire system failure.

Step 3: To identify the independent intermediate events whose failure affects the top event.

Step 4: To establish the relations between the events.

Step 5: To construct failure fault tree using AND, OR etc operations.

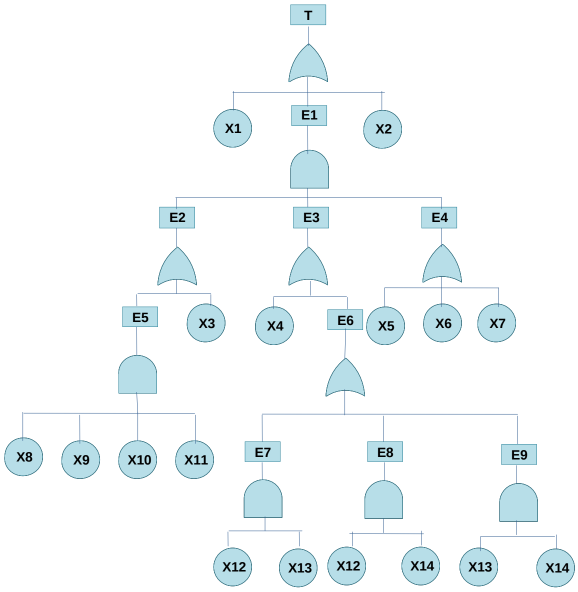
Step 6: To assign possible failure probabilities to the intermediate events according to experts knowledge and experience.

Step 7: To obtain possible failure probability interval for the top/ most critical event by using concept of fuzzy numbers.

Step 8: To obtain the reliability interval of the system as the difference between failure probability of top event and one.

Step 9: To draw membership function graph.

Step 10: Stop.



4.2 Quantitative Analysis

Let P_i denotes the possible failure probability of i^{th} event then from the fault tree of fire detector system we have obtained:

$$P_T = P_{X_1} P_{X_2} P_{E_1} = \prod_{i=1}^{2} P_{X_i} . \prod_{i=2}^{4} P_{E_i}, \text{ where} \qquad (8)$$

$$P_{E_2} = (1 - P_{X_3})[1 - \prod_{i=8}^{11} P_{X_i}] \qquad (9)$$

$$P_{E_3} = (1 - P_{X_4})[1 - \{1 - \prod_{i=7}^{9}(1 - P_{E_i})\}] \qquad (10)$$

$$P_{E_4} = [1 - \prod_{i=5}^{7}(1 - P_{X_i})] \qquad (11)$$

Reliability of the fire detector system is given by

$$R_{FDS} = 1 - P_{FDS} \qquad (12)$$

Here P_{FDS} denotes the possible failure probability of the fire detector system, which in turn is given exactly by the possible failure probability of the top/ most critical event.

Using (3-9) we obtained following numerical results

Possible failure probability interval of the top (most critical) event $P_T = (0.000557, 0.002517, 0.007986)$ and hence reliability interval of system

$$R_{FDS} = (1 - P_{FDS}) = (1 - P_T) = (0.992014, 0.997483, 0.999443)$$

4.3 Comparison with Conventional FTA

Using conventional fault tree analysis the parallel-series arrangement of fault tree of fire detector system is given in fig. The top event can be represented as

$$T = \{X_1 \cup X_2 \cup E_1\}$$
$$= (X_1 \cup X_2) \cup (E_2 \cap E_3 \cap E_4) \qquad (13)$$

The failure probability of the top/ most critical event in given by

$$P_T = \{1 - (1 - P_{E_1}) \prod_{i=1}^{2}(1 - P_{X_i})\} \qquad (14)$$

Substituting the values of failure probabilities of intermediate events, using the same set of data, we obtained the failure probability as well as the reliability of the fire detector system as below

$$P_T = 0.011043 \text{ and } R_T = R_{FDS} = 0.988957$$

Evidently the numerical value obtained by fuzzy FTA approach is more practical as compared to the same obtained by traditional FTA.

4.4 MATLAB Syntax for Membership Graph

```
x=0:0.0001:0.009;
y=trimf(x,[α  m  β]);
plot(x,y)
xlabel('trimf, P=[ α  m  β]')
```

5. CONCLUSION

In this study the conventional fault tree analysis approach integrated with fuzzy theory has been utilized to evaluate the reliability of a fire detector system. The numerical results obtained for the stated data set indicate that the reliability of the FDS lies in the interval {0.992014, 0.999443} and the most possible value is (0.997483). When same data set is used for calculating the reliability of FDS using conventional FTA, it is observed that the value thus obtained even does not fall in the above calculated interval. Introduction of fuzzy approach makes the results more practical. Therefore, this study will have practical importance for computing reliability index and establishing satisfactory plan for installing fire detector systems to meet safety requirements in various industries or systems.

6. REFERENCES

[1] Birolini, A. 2007. Reliability engineering-theory and practice, 5th ed., Springer-Verlag.

[2] Bozzano, M. and Villafiorita, A. 2011. Design and safety assessment of critical systems, CRC Press, Taylor and Francis Group, New York.

[3] Chen, S.M. 1994. Fuzzy system reliability analysis using fuzzy number arithmetic operations, Fuzzy Sets and Systems, vol. 64, p.p. 31-38.

[4] Chen, S.M. 1996. New method for fuzzy system reliability analysis, Cybernetics and systems: An International Journal, vol. 27(4), pp. 385-401.

[5] Kanfmann, A. and Gupta, M.M. 1988. Fuzzy mathematical models in engineering and management science, Amsterdam North-Holland.

[6] Liang, G.S. and Wang, M.J.J. 1993. Fuzzy fault tree analysis using failure possibilities, Microelectronics and Reliability, vol. 33, pp. 583-597.

[7] Nikolaos, L. 2007. Fault trees, ISTE.

[8] Rausard, M. and Hoyland, A. 2004. System reliability theory: models, statistical methods and applications, 2nd ed., Wiley-Interscience Publisher.

[9] Ross, T.J. 1997. Fuzzy logic with engineering applications, International ed., Mc Graw Hill Inc., New York.

[10] Singer, D. 1990. A fuzzy set approach to fault tree and reliability analysis, Fuzzy Sets and Systems, vol. 34, p.p. 145-155.

[11] Zadeh, L.A. 1965. Fuzzy sets, Information and Control, vol. 8, pp. 338-353.

[12] Zadeh, L.A. 1978. Fuzzy sets as a basis for a theory of possibility, Fuzzy Sets and Systems, vol. 1, pp. 3-28.

[13] Zimmermann, H.J. 1996. Fuzzy sets theory and its applications, 2nd ed., Allied Publishers Ltd

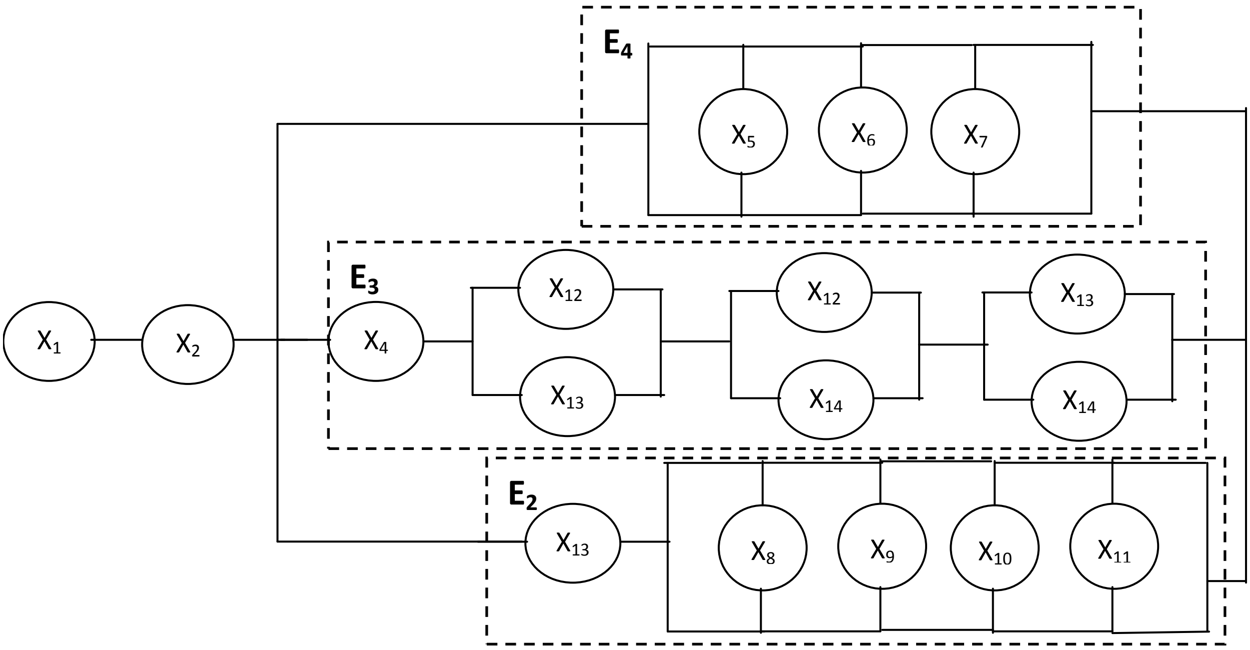


Fig. 3 Series- parallel arrangement of Intermediate events of FT

Graph: Membership Function of Failure Possibilities

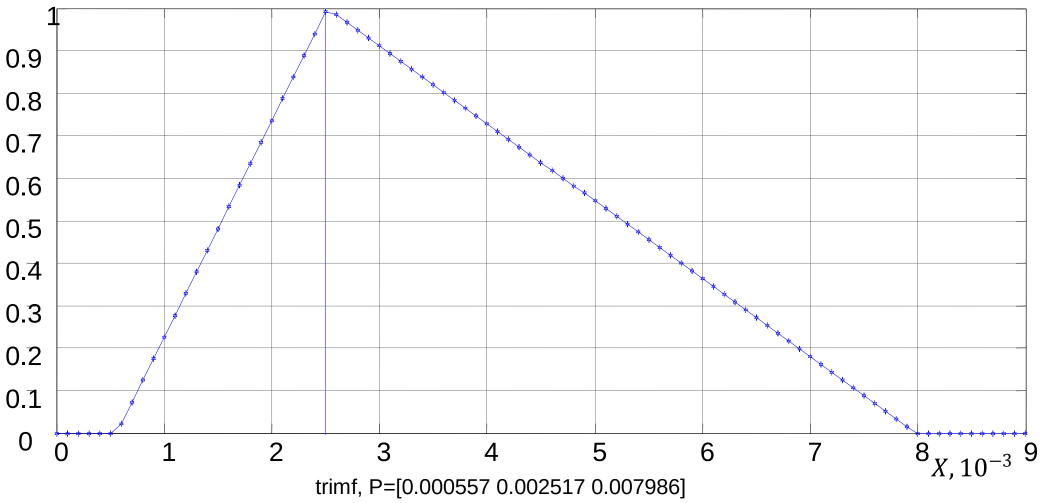


Table I
Basic events and their possible failure probabilities.

Event ID (Fault Tree)	Event ID (Schematic Diag.)	Event Description	m_i	a_i	b_i
X_1	DC	No current from DC source	0.3	0.2	0.4
X_2	SR	Start relay fail in open position	0.2	0.1	0.3
X_3	PS	Pressure switch fail in closed position	0.3	0.3	0.4
X_4	VU	Voting unit fail to raise signal	0.21	0.16	0.23
X_5	MS	Manual switch fail to open	0.25	0.2	0.3
X_6	PS	Pressure switch fail in open position	0.27	0.25	0.28
X_7	OP	Operator fail to take action	0.12	0.10	0.14
X_8	FP_1	Fuse plug1 doesn't respond	0.18	0.11	0.26
X_9	FP_2	Fuse plug2 doesn't respond	0.18	0.11	0.26
X_{10}	FP_3	Fuse plug3 doesn't respond	0.18	0.11	0.26
X_{11}	FP_4	Fuse plug4 doesn't respond	0.18	0.11	0.26
X_{12}	SD_1	Smoke detector1 doesn't respond	0.16	0.13	0.2
X_{13}	SD_2	Smoke detector2 doesn't respond	0.16	0.13	0.2
X_{14}	SD_3	Smoke detector3 doesn't respond	0.16	0.13	0.2

Table II
ID and description of top and intermediate events

Event ID (Fault tree)	Event Description
T	No signal from start relay
E_1	No signal from detection system
E_2	No signal from heat detection system
E_3	No signal from smoke detection system
E_4	No signal from manual activation system
E_5	Fuse plugs are not activated
E_6	At least 2-out-of-3 smoke detectors do not respond
E_7	Combination first fails
E_8	Combination second fails
E_9	Combination third fails