Iran University of Science and Technology

International Journal of

Railway Research

Determining Safety Integrity Level by Considering Uncertainty Aspects in Fuzzy Environment (Case Study on Train Braking System)

Hasti Jafari[1], Mohammad Ali Sandidzadeh[1]*, Amir Ghavibazoo[1]

[1]School of Railway Engineering, Iran University of Science and Technology, Tehran, Iran

ARTICLE INFO

Article history:
Received: 11.08.2020
Accepted: 18.10.2020
Published: 25.12.2020

Keywords:
Probabilistic modeling
Safety integrity level
Fault tree
Fuzzy theory
Safety instrument systems

A B S T R A C T

The industry sectors occasionally face the difficulty of safety level determination of safety systems. Some standards including ISAS 84.01 and IEC61508 have provided some guidelines but there is no a complete and comprehensive understanding about these standards and their accomplishment. It should be noted that the security analysis is one of the most important factors to measure the risk level, as its measurement in certain environment is difficult, so in this study a new approach is proposed to analyze the risk level of safety instruments in fuzzy environment. The new methodology is applied on a train barking system as a case study and the results indicated that the level of safety integrity level is influenced by the security factors. The determination of safety integrity level needs to implement the safety functions and the uncertainty of probabilistic model parameters, which are affected by the results of security analysis. The level of safety integrity in fuzzy environment is calculated by proposing fuzzy fault tree analysis and the results have been compared with the concluded results obtained from certain methods.

1. Introduction

The understanding and analyzing of intricate systems is an important issue because of the increased number of users. The happened industrial events in recent years have caused changes in experts' approach about the safety. In this regard, many widespread actions have been applied in recent years and many standards have been designed and formulated including the international standard IEC61508 and ISAS 84.01. Prior to these standards, there was not a comprehensive understanding of the way to determine the safety integrity level (SIL) of safety instrument systems (SIS) and the safety level of system could be determined by the reliability calculation of system failures. For example, we can note that Simpson and Gulland (in 2003) applied the Markov method in two separate studies to determine the level of safety integrity for the reparable safety systems and they stated that this methodology makes to achieve the wrong results [1]. In 2004, D .J. Smith and K. G. L. Simpson published their experience in the implementation of IEC61508 standard as a book [2]. Rouvroye and Wiegerinck noted that the periodic functional tests are incomplete and they implemented a new methodology for minimizing the cost of implementing the safety integrity level of the systems [3]. Also in another study in 2006, J. V. Bukowski attempted to determine the level of safety systems with exponential distribution of time repair [4]. In 2007, X. Yang and H. Guo attempted to analysis the level of safety systems by the usage of RBD methodology [5]. Beugin, Renaux and Cauffriez tried to measure the Safety level of systems by Considering the environmental changes of working conditions and Baybutt measured the safety level by optimizing the Risk graph [6] [7]. In another

*Corresponding author, Associate professor
Email: sandidzadeh@iust.ac.ir

[DOI: 10.22068/IJRARE.7.2.51]

study in 2007, Choi and Cho studied how to calculate the exact probability of an event by combining the fault tree analysis and Monte Carlo simulation [8]. In this year, Y. Sato introduced the Markov method as a suitable method to measure and analysis the level of safety in order to introduce the detection techniques for low and high demand systems by comparison the breakdown rate of safety systems [9]. In 2008, Aubry attempted to measure the level of safety by the usage of the fuzzy fault tree analysis and Markowski presented the fuzzy risk matrix while the fuzzy risk graph was introduced by Said [10, 11 and 12]. The safety communication channels in the functional safety analysis was not indicated in the IEC 61511 standard and the channels of data communication in functional safety solutions was introduced in new version of IEC 61511:2015 standard [13]. At the end, we can say that the main problem is to consider the comprehensive integration of safety issues. [14, 15, 16, 17]. In 2018, Sliwinski proposed a new method to measure the SIL by considering the assessment of assurance levels based on quantitative and qualitative information [18]. In this year, a paper was proposed by Zhao et al. to determine Safety Integrity Level based on the Stochastic Petri Nets models and Monte Carlo simulation for high demand systems [19]. In 2016, Piesik et al. proposed a new methodology for the risk analysis of functional safety. They indicated that, the level of safety integrity level which is required is affected by the security factor [20]. Sobral and Soares presented a new methodology to link the safety level of evaluated safety barrier for finding the possibility of hazardous event occurrence [21]. In 2017, a study was done by Mehranfar et al. to consider the risks of cars containing the hazardous materials by proposing a real case study in Sarakhs station of Iran railways [22]. To find the characteristics of switches and crossings of Swedish Railway, a study was done by Ghodrati et al. and a statistics software investigated for data failures by estimating the reliability of switches [23]. The relationship among the costs and measurement for accident preventions of railway considered in 2014 by developing a methodology [24].

Given all the above explanations shows the importance of safety analysis by the usage of fault tree analyses. Human injures was caused by rail disasters are significant; there for the design of equipment especially used in trains, is so important. In this study the safety integrity level in IEC61508 standard and uncertainty in different process of SIL measurement has been considered to reduce the cost of system designing. A new methodology is applied on a case study of railway system by proposing the system fuzzy fault tree analysis and considering the level of safety integrity in fuzzy environment. This approach, which was not considered in previous studies, has examined on a train braking system as a case study and the results of SIL determination in fuzzy environment have been compared with the results of its verification in the certain environment.

2. Determination of the System Safety Level

In this section the safety instrument system are described to determine the level of safety for the processes then SIL of low and high demand systems are described

In the IEC (61508) standard SIL divided in to 4 levels, as in each level has interval of probability. In this standard, the safety systems are divided into Low Demand and high demand systems (Table 1). In IEC 61508 the high demand is called when the demand of a safety function is greater than once per a year and when it is less frequent is called the low demand function [16].

Table 1. Fault probability of high and low [17] demand systems in the SIL level

	High demand	Low demand
Safety integrity level	Failures/hour	PFDavg
4	10^{-9}<=to<10^{-8}	10^{-5}<=to<10^{-4}
3	10^{-8}<=to<10^{-7}	10^{-4}<=to<10^{-3}
2	10^{-7}<=to<10^{-6}	10^{-3}<=to<10^{-2}
1	10^{-6}<=to<10^{-5}	10^{-2}<=to<10^{-1}

2.1. Safety Instrument System (SIS)

The availability of safety systems results to mitigate the hazardous events. In order to reduce the risk level, different activities are applied as the layer of protection and the typical way of safety systems are shown in Fig 1. [17]. One of the layers presented in the figure is

[DOI: 10.22068/IJRARE.7.2.51]

called safety Instrumented System (SIS) consisting of sensors, logical solver and final components to achieve safe situation by taking some process. SIL is defined as the safety function of the SIS, which can be found by its PFD [25].

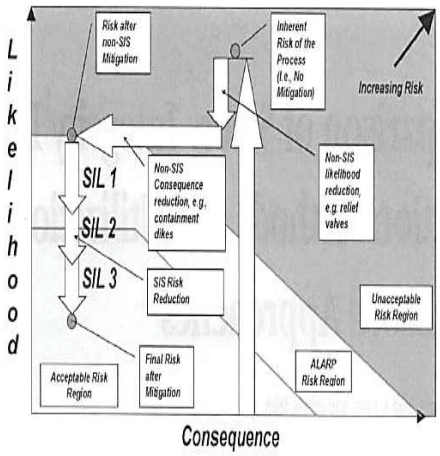

Figure 1. Steps to reduce risk and the role of the immune system of SIS [25]

3. SIL Analysis by the usage of the Fuzzy Fault Tree

In this method, these stages are the main process to reach the system failure rate:

- Analyzing the fault tree of safety system.
- Preparing function belongs to failure rate of each system component.
- Preparing the smallest non-repetitive discontinuity sets for the fault tree obtained.
- The calculation operations of fuzzy numbers to obtain the function of fault rate in the demand time.
- The determination of function belongs to each level of safety integrity.

3.1. Fuzzy Numbers

If a continuous variable x belongs to $\mu_{(x)} \epsilon [0,1]$, satisfying the following assumptions, can be considered as a fuzzy number.

- $\mu_{(x)}$ is a continuous set of variables;
- $\mu_{(x)}$ is a convex fuzzy set;
- $\mu_{(x)}$ is a normal fuzzy set.

To reduce the computational operation the membership functions is defined in α level.

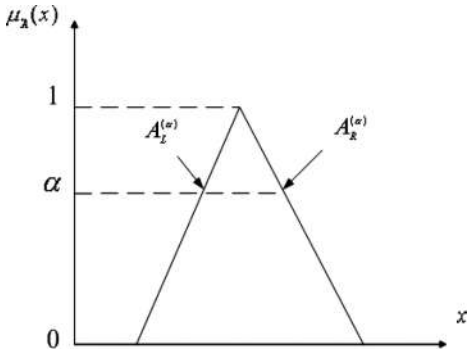

Figure 2. The bounds of a fuzzy number for α level

The membership function of a fuzzy number A is shown by $\mu_A(x)$ and two points are used to demonstrate the interval bounded of this value at α level $(0 \leq \alpha \leq 1)$ by the usage of α cut method. The lower and the upper bounds of this interval are shown by A^{α}_L and A^{α}_R respectively [11].

3.2. Fuzzy Fault Tree Analysis

Each event has a degree of uncertainty and the probability of top event can be calculated by the probabilities of each component failures. A simple calculation of fuzzy fault tree analysis is shown in Fig 3.

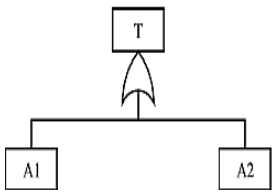

Figure 3. Fuzzy fault tree analysis

It is assumed that each event is independent and the top event failure rate can be calculated by:

$$P_{(y)} = sup\{PA1+PA2\}min\{PA1,PA2\} \quad (1)$$

4. Case Study

In this section, we test our model by using an example of JI Simpson study (2004) [2] on braking system of trains.

[DOI: 10.22068/IJRARE.7.2.51]

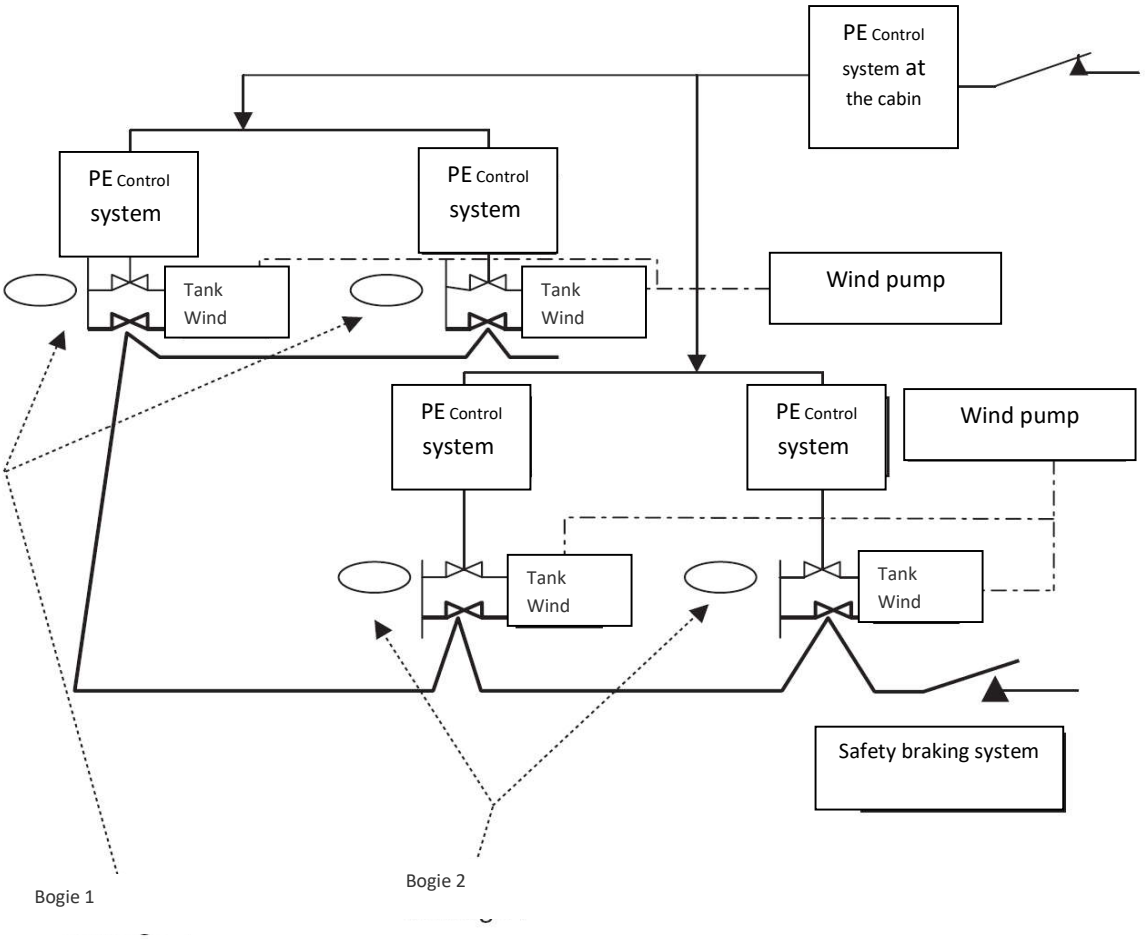

Figure 4. Diagram related to the braking system

In mentioned system, there are two safety systems. We combine the primary and emergency braking systems. The first one is a system with high demand and the other one is a low demand system.

Initial studies showed that this set braking system covers third level of safety integrity. These two braking systems are dependent, so, we could consider the braking system as an integrity set or have two separate systems and SIL can be calculated by multiplying two fault rates. The 'high demand' system activated not only by the train driver but also by receiving the automatic signal to send electronic signals and consequently the brake pressure can be transferred to each bogie by the usage of an air valve.

The air generator can supply the air pressure for each bogie to operate the brakes. The braking will be reduced by %25 if one bogie braking system is broken. When three out of the four bogies are operated, the safety function can be considered in a good condition. Regarding to mentions above, we attempt to model the system fault tree. There are some assumptions that are considered in the paper such as: The time distribution is considered constant for the fault rates of components. It is assumed that the design faults (Bum-in failure), Wear out-failure and Preventive – failure have been removed. Common cause failure of parallel systems determined by the beta factor and the beta value is considered 1%. For SIL quantitative analysis, knowing the fault rate of subset components is essential. The fault rates determined by JL Simpson [2] are shown in Table 2.

[DOI: 10.22068/IJRARE.7.2.51]

Table 2. Failure rates of braking system component [3]

Subsystem name	Failure mode	Failure rate of subsystem (overall) (10^{-6} per hour)	failure rate of Subsystem (failure mode) (10^{-6} per hour)
PE control of cabin	The output serial is low	2	0.6
PE control of bogie	The output analogue is low	2	0.6
Air control valve of primary brake	unable to move	5	1.5
Solenoid valve	Unable to open	0.8	0.16
Initial brake lever	Does not work	1	0.1
Emergency brake lever	Not disrupt the flow of electricity	1	0.1
Bogie air reservoir	Fail	1	1
Brake shoes	Fail	0.5	0.5
Common errors of Wind Tanks			0.05
same reason of brake shoe failures			0.005

4.1. Primary braking analysis by the fuzzy fault tree

The analysis of primary braking system is shown in Fig 5, which gates G22 and G23 are similar to G21 and G24 so are not shown in the figure.

Fault rate obtained from J.L. Simpson fault analysis is calculated $0.550E^{-07}$, so this system is third level of safety integrity. Here by comparison the study in fuzzy environment, the fault tree can be found. We assume that fault rate has the interval between 5% and 10%. This fault rates are shown in Table 3.

Table 3. Fault rate of system components reliability

Component names	Maximum fault rate	average fault rate(m)	Minimum fault rate(LL)
CCFB	5.E-04	5.E-04	5.E-04
EMERG	1.E-02	1.E-02	9.E-03
PE1	6.E-02	6.E-02	5.E-02
LEVER	1.E-02	1.E-02	9.E-03
CCFA	5.E-03	5.E-03	5.E-03
AIR21	1.E-01	1.E-01	9.E-02
BRAK21	5.E-02	5.E-02	5.E-02
SOL21	2.E-02	2.E-02	1.E-02
PE21	6.E-02	6.E-02	5.E-02
VAL21	2.E-01	2.E-01	1.E-01
AIR22	1.E-01	1.E-01	9.E-02
BRAK22	5.E-02	5.E-02	5.E-02
SOL22	2.E-02	2.E-02	1.E-02
PE22	6.E-02	6.E-02	5.E-02
VAL22	2.E-01	2.E-01	1.E-01
AIR23	1.E-01	1.E-01	9.E-02
BRAK23	5.E-02	5.E-02	5.E-02
SOL23	2.E-02	2.E-02	1.E-02
PE23	6.E-02	6.E-02	5.E-02
VAL23	2.E-01	2.E-01	1.E-01
AIR24	1.E-01	1.E-01	9.E-02
BRAK24	5.E-02	5.E-02	5.E-02
SOL24	2.E-02	2.E-02	1.E-02
PE24	6.E-02	6.E-02	5.E-02
VAL24	2.E-01	2.E-01	1.E-01

[DOI: 10.22068/IJRARE.7.2.51]

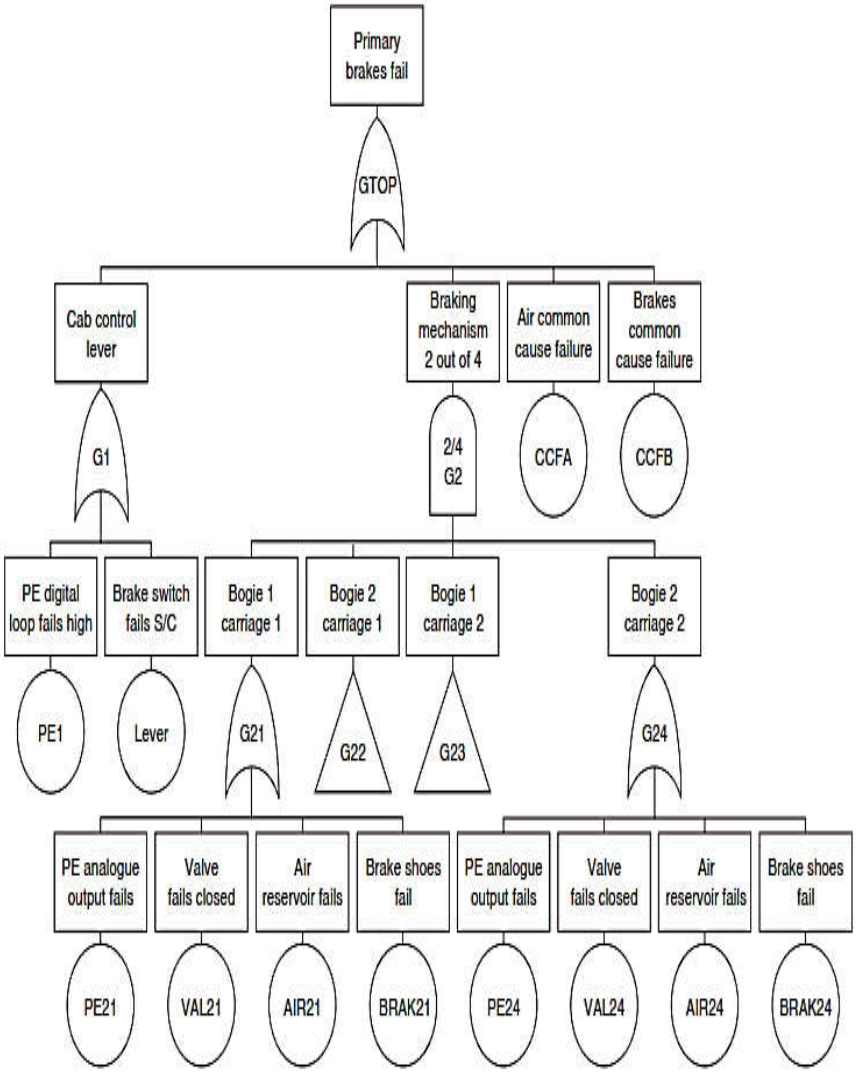

Figure5. Fault tree analysis for primary train braking system[4]

4.2. Determination the Alpha cut for each basic event

To calculate the alpha cut we used this formula

$$u_A(x)=u_A(x;LL,m,UL)=\begin{cases}(x-LL)/(m\_LL): LL\le x<m\\ (UL-x)/(UL-m): m\le x\le UL\\ 0: x>UL,\ x<LL\end{cases} \quad (2)$$

The Alpha cut for each basic event is shown in Table 4**.**

In this section, the basic events and alpha cuts have been shown in the Table 5.

We calculate the probability of top event (TE), and the alpha cut is shown here:

$$P(TE)^{-}{}_{\alpha}=5\times10^{-8}+6\times10^{-9}\alpha+7\times10^{-16}\alpha^2$$

$$P(TE)^{+}{}_{\alpha}=5\times10^{-8}+6\times10^{-9}\alpha+7\times10^{-16}\alpha^2 \quad (3)$$

$$\alpha\in[0,1]$$

Since the coefficients of the third and the fourth grades are suppressed because these are small. The alpha cut for the top event is shown here:

[DOI: 10.22068/IJRARE.7.2.51]

$$P(TE)_{\alpha}^{-} = 5\times10^{-8} + 6\times10^{-9}\alpha + 7\times10^{-16}\alpha^{2}$$
$$P(TE)_{\alpha}^{+} = 6\times10^{-8} - 3\times10^{-9}\alpha + 2\times10^{-16}\alpha^{2} \quad (4)$$
$$\alpha \in [0,1]$$

Table 4. The Alpha cut for each basic event

Component name of the safety system	A_{α}^{+}	A_{α}^{-}
CCFA	$5\times10^{-8}-(3\times10^{-9})\alpha$	$5\times10^{-8}+(3\times10^{-9})\alpha$
CCFB	$5\times10^{-9}-(3\times10^{-10})\alpha$	$5\times10^{-9}+(3\times10^{-10})\alpha$
EMERG	$1\times10^{-7}-(5\times10^{-9})\alpha$	$9\times10^{-8}+(1\times10^{-10})\alpha$
PE1	$6\times10^{-7}-(3\times10^{-8})\alpha$	$5\times10^{-8}+(5\times10^{-9})\alpha$
LEVER	$1\times10^{-7}-(5\times10^{-9})\alpha$	$5\times10^{-7}+(6\times10^{-8})\alpha$
AIR21	$1\times10^{-6}-(5\times10^{-8})\alpha$	$9\times10^{-8}+(1\times10^{-8})\alpha$
BRAK21	$5\times10^{-7}-(3\times10^{-8})\alpha$	$9\times10^{-7}+(1\times10^{-7})\alpha$
SOL21	$2\times10^{-7}-(8\times10^{-9})\alpha$	$5\times10^{-7}+(5\times10^{-8})\alpha$
PE21	$6\times10^{-7}-(3\times10^{-8})\alpha$	$5\times10^{-7}+(6\times10^{-8})\alpha$
VAL21	$2\times10^{-6}-(7\times10^{-8})\alpha$	$1\times10^{-6}+(2\times10^{-7})\alpha$
AIR22	$1\times10^{-6}-(5\times10^{-8})\alpha$	$9\times10^{-8}+(1\times10^{-8})\alpha$
BRAK22	$5\times10^{-7}-(3\times10^{-8})\alpha$	$9\times10^{-7}+(1\times10^{-7})\alpha$
SOL22	$2\times10^{-7}-(8\times10^{-9})\alpha$	$5\times10^{-7}+(5\times10^{-8})\alpha$
PE22	$6\times10^{-7}-(3\times10^{-8})\alpha$	$5\times10^{-7}+(6\times10^{-8})\alpha$
VAL22	$2\times10^{-6}-(7\times10^{-8})\alpha$	$1\times10^{-6}+(2\times10^{-7})\alpha$
AIR23	$1\times10^{-6}-(5\times10^{-8})\alpha$	$9\times10^{-8}+(1\times10^{-8})\alpha$
BRAK23	$5\times10^{-7}-(3\times10^{-8})\alpha$	$9\times10^{-7}+(1\times10^{-7})\alpha$
SOL23	$2\times10^{-7}-(8\times10^{-9})\alpha$	$5\times10^{-7}+(5\times10^{-8})\alpha$
PE23	$6\times10^{-7}-(3\times10^{-8})\alpha$	$5\times10^{-7}+(6\times10^{-8})\alpha$
VAL23	$2\times10^{-6}-(7\times10^{-8})\alpha$	$1\times10^{-6}+(2\times10^{-7})\alpha$
AIR24	$1\times10^{-6}-(5\times10^{-8})\alpha$	$9\times10^{-8}+(1\times10^{-8})\alpha$
BRAK24	$5\times10^{-7}-(3\times10^{-8})\alpha$	$9\times10^{-7}+(1\times10^{-7})\alpha$
SOL24	$2\times10^{-7}-(8\times10^{-9})\alpha$	$5\times10^{-7}+(5\times10^{-8})\alpha$
PE24	$6\times10^{-7}-(3\times10^{-8})\alpha$	$5\times10^{-7}+(6\times10^{-8})\alpha$
VAL24	$2\times10^{-6}-(7\times10^{-8})\alpha$	$1\times10^{-6}+(2\times10^{-7})\alpha$

Table 5. The Alpha cut for basic event of train braking system

Basic event	Probably formula
CCFA	$P_{CCFA}(t)$
CCFB	$P_{CCFB}(t)$
AIR21 ,AIR22	$P_{AIR1}(t) + P_{AIR2}(t)$
EMERG PE1	$P_{EMERG}(t) + P_{PE1}(t)$
EMERG LEVER	$P_{EMERG}(t) + P_{LEVER}(t)$

By considering the upper and the lower bounds of alpha, the mean value of system fault rate can be calculated:

$$u_{p(TE)}(x) = (x : 4.951\times10^{-8}, 5.50134\times10^{-8}, 5.776\times10^{-8}) \quad (5)$$

The system fault function is obtained by the first formula.

$$u_{P(TE)}(x) = x: 4.951\times10^{-8},\ 5.5013\times10^{-8},\ 5.776\times10^{-8} \quad (6)$$

The system fault function is obtained by the first formula.

$$u_{p(TE)}(x) = \begin{cases} \dfrac{-6\times10^{-9} + \sqrt{36\times10^{-18} - 28\times10^{-16}}(5\times10^{-8} - y)}{14\times10^{-16}} \\ 4.951\times10^{-8} \le x \le 5.50134\times10^{-8} \\ \dfrac{-3\times10^{-9} - \sqrt{9\times10^{-18} - 8\times10^{-16}}(5\times10^{-8} - y)}{4\times10^{-16}} \\ 5.50134\times10^{-8} \le x \le 5.5776\times10^{-8} \\ 0, otherwise \end{cases} \quad (7)$$

The fault rate diagram of top event by considering different values of alpha is shown in Figure 6.

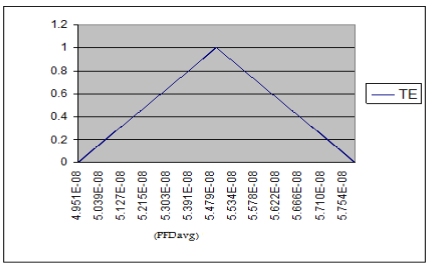

Figure 6. The fault rate function of top event

[DOI: 10.22068/IJRARE.7.2.51]

By comparison the lower and the upper bounds of fault rate of system top event with the different levels of safety integrity table, we can understand that the system has the third level of safety integrity of high demand systems.

6. Conclusions

In this paper, we try to show the importance of safety analysis and to express the safety integrity level in the fuzzy environment. Finally, its application is shown in the train braking system to determine the SIL of this system. The procedure in this case study is proposed as a methodology for the SIL quantitative measurement by considering the uncertainty in the model parameters.

References

[1] K.G.L. Simpson, Reliability Assessments of Repairable Systems – Is Markov Modeling Correct? Technical Report Silvertech Safety Consultancy Ltd prepared for IEC 61508 committee (2003).

[2] D.J. Smith and K.G L. Simpson, Functional Safety-A Straightforward Guide to applying IEC 61508 and Related Standards, Elsevier, second Edition (2004).

[3] JL. Rouvroye, JA. Wiegerinck, Minimizing costs while meeting safety requirements: Modeling deterministic imperfect staggered tests using standard Markov models for SIL calculations, ISA Transactions, Vol. 45, No. 4, (2006), pp. 611–621.

[4] J. V. Bukowski, Using Markov Models to Compute Probability of Failed Dangerous When Repair Times Are Not Exponentially Distributed, Reliability Engineering and System Safety, Vol. 71, (2006), pp. 201_208.

[5] H. Guo, X. Yang, A simple reliability block diagram method for safety integrity verification, Reliability Engineering and System Safety, Vol. 92, (2007), pp. 1267–1273.

[6] J. Beugin, D. Renaux, L Cauffriez, A SIL quantification approach based on an operating situation model for safety evaluation in complex guided transportation systems, Reliability Engineering and System Safety, Vol. 92, No. 12, (2007), pp. 1686–1700.

[7] P. Baybutt, an Improved Risk Graph Approach for Determination of Safety Integrity Levels (SILs), Process Safety Progress, Vol. 26, No.1, (2007), pp. 66–76.

[8] J.S Choi, N. Z. Cho, A practical method for accurate quantification of large fault trees, Reliability Engineering and System Safety, Vol. 92, (2007), pp. 971–982.

[9] Y. Sato, Throwing a Bridge between Risk Assessment and Functional Safety, SICE Annual Conference, Kagawa University, Japan 17-20, 2007.

[10] M, Sallak, C. Simon, J. F. Aubry, A Fuzzy Probabilistic Approach for Determining Safety Integrity Level, IEEE Transactions On Fuzzy Systems, Vol. 16, No. 1, (2008).

[11] A. S. Markowski, M. S. Mannanb, Fuzzy risk matrix, Journal of Hazardous Materials, Vol. 159, (2008), pp. 152–157.

[12] Nait-Said, R. Zidanib, F. Ouzraouia, Modified risk graph method using fuzzy rule-based approach, Journal of Hazardous Materials, Vol. 157, (2008), pp. 97–107.

[13] IEC 61511. Functional safety: safety instrumented systems for the process industry sector, Parts 1–3. International Electrotechnical Commission (2015).

[14] T.C, KT. Kosmowski, E. Piesik, M. Sliwinski, Security aspects in functional safety analysis, Journal of Polish Safety and Reliability Association Summer Safety and Reliab Seminars, Vol. 5, No. 1, (2014).

[15] TO. Grøtan, MG. Jaatun, MB. Line, Secure safety: secure remote access to critical safety systems in offshore installations, Trondheim: SINTEF Technology and Society (2008).

[16] IEC61508 Standard, Functional safety of electrical programmable electronic safety-related systems. International Electro technical Commission, 1999.

[17] K. Bhimavarapu, P. Stavrianidis, Safety Integrity Level Analysis for Processes: Issues and Methodologies, Process Safety Progress, Vol. 19, No.1, (2000), pp. 19-24.

[18] M. Sliwinski, Safety integrity level verification for safety-related functions with security aspects, Process Safety and Environmental Protection, Vol. 118, (2018), pp. 79-92.

[DOI: 10.22068/IJRARE.7.2.51]

[19] X. Zhao, O. Malasse, G. Buchheit, Verification of safety integrity level of high demand system based on Stochastic Petri Nets and Monte Carlo Simulation, Reliability Engineering & System Safety, Volume 184, (2019), pp. 258-265.
[20] E. Piesik, M. Sliwinski, T. Barnert, Determining and verifying the safety integrity level of the safety instrumented systems with the uncertainty and security aspects, Reliability Engineering & System Safety, Volume 152, (2016), pp. 259-272.
[21] J. Sobral, C.G. Soares. Assessment of the adequacy of safety barriers to hazards, Safety Science, Vol. 114, (2019), pp. 40-48.
[22] Mehranfar H, Sadeghi M, Tadayon A, Kamali A, Bagheri M. Risk Analysis of Stationary Rail Cars Containing Hazardous Materials; A Case Study, International Journal of Railway Research, Vol. 4, (2017), pp.37-46.
[23] Ghodrati B, Ahmadi A, Galar D. Reliability Analysis of Switches and Crossings – A Case Study in Swedish Railway, International Journal of Railway Research, Vol. 4, (2017), pp. 1-11.
[24] Ioannidou A, Pyrgidis C. The Safety Level of Railway Infrastructure and Its Correlation with the Cost of Preventive and Mitigation Measures. International Journal of Railway Research, Vol. 4, (2014), pp.19-30.
[25] E.M. Marszal, B.A. Fuller, J. Shah, Comparison of Safety Integrity Level Selection Methods and Utilization of Risk Based Approaches, Process Safety Progress, Vo1.18, No.4, (1999), pp. 189-194.

[DOI: 10.22068/IJRARE.7.2.51]