Rotshtein A. Shtovba S. Risk Assessing by Fuzzy Logic–Algorithmic Fault Tree / Proc. Fifth international scientific school "Modelling and analysis of safety and risk in complex systems". Saint-Petersburg, 2005. – P. 339–343.

RISK ASSESING BY FUZZY LOGIC-ALGORITHMIC FAULT TREE

Alexander Rotshtein[1] and Serhiy Shtovba[2]

[1]Jerusalem College of Technology – Machon Lev,
21 HaVaad HaLeumi St., Givat Mordechai, Jerusalem, 91160, Israel,
e-mail: rot@mail.jct.ac.il

[2]Vinnitsa National Technical University,
Khmelnitskoe Shosse, 95, Vinnitsa, 21021, Ukraine
e-mail: shtovba@ksu.vstu.vinnica.ua

Abstract

The new method for risk assessment of the man-machine system functioning is proposed. The feature of the method is combining the fuzzy fault tree analysis and theory of fuzzy reliability of algorithmic processes. This provides a consideration from a unified framework the structural accidents with algorithms of its detecting and avoiding. Method also allows to use fuzzy "if-then" rules about man-machine and environment factors influencing upon probabilities of various events connected with each hazard situation.

Keywords: Risk Assessment, Fault Tree, Reliability of Algorithms, Man-Machine Systems, Fuzzy Probability, Fuzzy Inference, and Fuzzy Extension Principle.

1. Introduction

While designing workplace and new equipment it is necessary to be sure they are providing the required level of man-operator safety. Fault tree analysis [1] is a very popular tool for risk assessing of complex large-scale systems. A fault tree provides a logical, and hierarchical description of an accident (top event) in terms of sequences and combinations of malfunction of individual components and adverse operating conditions (basic or fundamental events). By resorting to a fault tree the reliability or safety of a complex systems can be computed via probabilities of occurrence of basis events. In case of lack of proper data the probabilities of occurrence of hazardous events one can use the fuzzy fault tree [2], in which fuzzy numbers represent the probabilities of events.

But using conventional and fuzzy fault trees it is very difficult to take into consideration the ability of man-operator for detecting and for avoiding a hazard situation in the man-machine system process functioning. These specifics can be easy described based upon theory of fuzzy reliability of algorithms [3-5]. A new method for risk assessment in man-machine systems is described in this paper. The method is based upon the following components [6]:

- an usage of man-operator activity algorithm for description of the events connected with appearance, detection and avoiding of hazardous situations (*algorithmic part of the fault tree*);
- an usage of logical functions for description of the events connected with appearance of hazardous situations (*logical part of the fault tree*);
- a transfer from logic-algorithmic description to probabilistic one to make it possible to calculate the quantitative level of risk;
- a representation of uncertain source data about probabilities of events leading to hazard situation in a fuzzy number form (*fuzzy part of the fault tree*);
- an usage of fuzzy inference and fuzzy rule base for taking into account various factors influencing upon probabilities of events connected with appearance, detection and avoiding of hazardous situations.

2. Construction of the Logic-Algorithmic Fault Tree

The process of task execution of the workspace can be represented as a consequence of labor operations. An example of logic-algorithm description for one operation is shown in Figure 1.

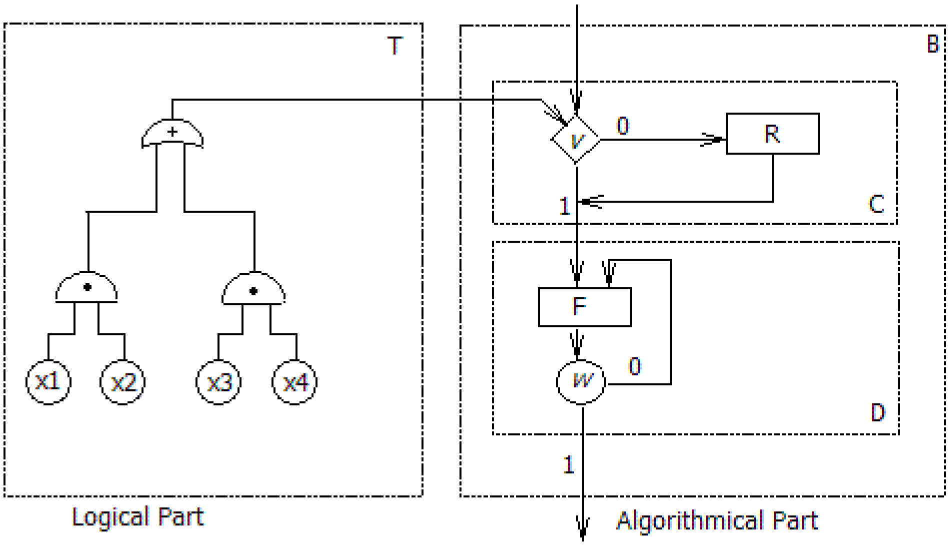


Figure 1. An example of a logic-algorithmic description

The left part of this figure is a conventional fault tree in terms of [1, 2] for tools necessary for the system functioning. This is the following logic function:

$$T=(x_1 \wedge x_2)\vee(x_3 \wedge x_4) \qquad (1)$$

where T denotes top even which characterize the accident conditions with labor tools;

x_i is fundamental event which characterizes the malfunctions of system elements, $i=\overline{1,4}$.

The right part of Figure 1 is an algorithm of man-operator activity during labor operation execution. The algorithm is described by algebraic language [7] as follows:

$$B=\underset{\nu}{(E\vee R)}\underset{\omega}{\{F\}}\,, \qquad (2)$$

where $\nu=\overline{T}=\overline{(x_1 \wedge x_2)\vee(x_3 \wedge x_4)}$ denotes checking the logic condition “Are the labor tools OK?” ($\nu=1$ equals ‘yes’; $\nu=0$ equals ‘no’);

R is repairing the labor tools;

E is fixation of the checking results;

F is execution the labor operation on the workplace;

ω is checking the logic condition “Has labor operation F been executed correctly?” ($\omega=1$ equals ‘yes’; $\omega=0$ equals ‘no’).

Hence, Figure 1 or the sequence of formulas (1) and (2) provides the united logical-algorithmic description of the man-machine systems, which allows to take into consideration:

via logical part

- malfunctions and failures in the labor tools (work clothes, climate-conditions, lighting etc.), which can lead to an accident on the workplace;

via algorithmic part

- detection and avoiding by the man-operator of malfunctions and failures in the labor tools;
- non-correct execution of the labor operations which can lead to the hazard situation;
- detection and avoiding by the man-operator of errors during labor process execution.

3. Evaluation of the Logic-Algorithmic Fault Tree

Rules from Table 1 allows transferring from logic-algorithm description of man-machine systems functioning process to probabilistic description, which allows to estimate the level of risk. The followings notations are used in Table 1:

P_{x_i} is probability of event x_i occurrence;

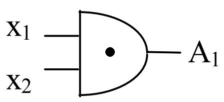
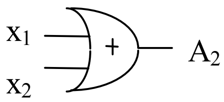
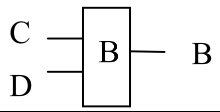
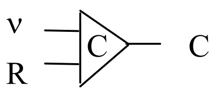
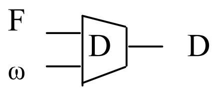
P_C^1, P_D^1, and P_R^1 are probabilities of correct executions of operators C, D, and R, correspondingly;

P_ν is probability of event $\nu=1$;

P_T is probability of event T=1, $P_T+P_\nu=1$;

k_ν^{00} and k_ω^{00} are probabilities of detection of malfunctions and errors during checking procedures ν and ω, correspondingly.

Table 1. Rules for transferring from logical-algorithmic structures to the models for calculation [8, 9]

Logical and algorithmic operations	Symbols on the fault tree	Probabilistic models
Logical AND: $x_1 \wedge x_2 = A_1$		$P_{A_1}=P_{x_1}P_{x_2}$
Logical OR: $x_1 \vee x_2 = A_2$		$P_{A_2}=P_{x_1}+P_{x_2}-P_{x_1}P_{x_2}$
Linear structure: $C \cdot D = B$		$P_B^1=P_C^1 \cdot P_D^1$
Branching structure: $(E \vee R)=C$ ν		$P_C^1=P_\nu+(1-P_\nu)k_\nu^{00}P_R^1$
Iterative structure: $\{F\}=D$ ω		$P_D=1-(1-P_F^1)(1-k_\omega^{00})$

Formulas in the right part of Table 1 are correct for case of absence "false alarm" errors during checking procedures ν and ω [8, 9].

The estimation of the quantitative level of risk consists of sequential employing formulas from Table 1. The consecution of the formulas is defined by concrete logic-algorithmic fault tree. The consecution of calculations for systems from Figure 1 is shown on Figure 2.

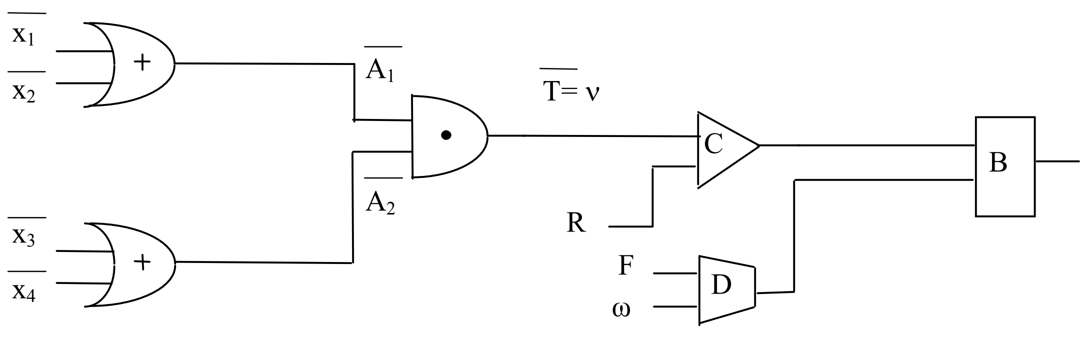


Figure 2. An example of logic-algorithmic fault tree

4. Fuzzy Logic-Algorithmic Fault Tree

To present each probability P from Table 1 in the fuzzy number form $\tilde{P}$ we use following 3 forms: l-, l(X)-, and α - forms.

The l-form of uncertain probability $\tilde{P}$ is the following triple:

$$\tilde{P} = <\underline{P}, \overline{P}, l>,$$

where l is the linguistic assessment (low, average, high etc.) of the parameter P in the range $[\underline{P}, \overline{P}]$, $\underline{P} \geq 0$, $\overline{P} \leq 1$. Term l is selected from the term-set $L = \{l_1, l_2, ..., l_m\}$ such that $l_j = \int_{[\underline{P}, \overline{P}]} \mu_{l_j}(P)/P$, where $\mu_{l_j}(q)$ is the membership function of fuzzy probability $\tilde{P}$ to term $l_j \in L$, $j = \overline{1,m}$.

The l(X)-form of uncertain probability P is the triple

$$\tilde{P} = <\underline{P}, \overline{P}, l(x)>$$

where l(X) is the expert knowledge base in the form of systems of fuzzy logical propositions:

$$\text{if } \left(x_1 = a_1^{j1}\right) \text{ and } \left(x_2 = a_2^{j1}\right) \text{ and } \ldots \text{ and } \left(x_n = a_n^{j1}\right) \text{ or}$$

$$\ldots$$

$$\text{if } \left(x_1 = a_1^{jk_j}\right) \text{ and } \left(x_2 = a_2^{jk_j}\right) \text{ and. } \ldots \text{ and } \left(x_n = a_n^{jk_j}\right), \text{ then } l = l_j,$$

where $a_i^{jp} = \int_{[\underline{x_i}, \overline{x_i}]} \mu^{jp}(x_i)/x_i, i = \overline{1,n}, p = \overline{1,k_j}$, where k_j is the number of fuzzy rules for $l = l_j$, and

$\mu^{ip}(x_i)$ is the membership function of the variable $x_i \in [\underline{x_i}, \overline{x_i}]$ to the fuzzy term a_i^{jp} estimating the factor x_i in rule with number jp, $i = \overline{1,n}, j = \overline{1,m}, p = \overline{1,k_j}$.

L(X)- form ties linguistic level l of fuzzy probability $\tilde{P}$ with vector of influential factors $X = (x_1, x_2, ..., x_n)$. The l(x)-form is transformed into l-form by fuzzy inference [10].

The α -form of uncertain probability P is the union of the pairs:

$$\tilde{P} = \bigcup_{\alpha \in [0,1]} \left(\underline{P}_\alpha, \overline{P}_\alpha\right), \tag{3}$$

where $\underline{P}_\alpha (\overline{P}_\alpha)$ is the smallest (greatest) allowed value of P at the α -level of the membership function, i.e.: $\mu(\underline{P}_\alpha) = \mu(\overline{P}_\alpha) = \alpha$, $\mu(\underline{P}) = \mu(\overline{P}) = 0$.

Transition from l-form to α -form is carried out via the membership function of fuzzy number.

The following extension principle [10] is using for generalization of probabilistic models (Table 1) for case of fuzzy probabilities.

If the function $y = f(P_1, P_2, ..., P_n)$ of n independent variables is given and its arguments P_i are fuzzy numbers $\tilde{P}_i$ in α -form (3) ($i = \overline{1,n}$*),* then the value of the function $\tilde{y} = f(\tilde{P}_1, \tilde{P}_2, ..., \tilde{P}_n)$ is the fuzzy number $\tilde{y}$ represented in α-form:

$$\tilde{y} = \bigcup_{\alpha \in [0,1]} \left(\underline{y}_\alpha, \overline{y}_\alpha\right)$$

where for every α-level:

$$\underline{y}_\alpha = \inf_{P_{i_\alpha} \in [\underline{P}_{i_\alpha}, \overline{P}_{i_\alpha}], i = \overline{1,n}} \left(f(P_{1_\alpha}, P_{2_\alpha}, ..., P_{n_\alpha})\right); \quad \overline{y}_\alpha = \sup_{P_{i_\alpha} \in [\underline{P}_{i_\alpha}, \overline{P}_{i_\alpha}], i = \overline{1,n}} \left(f(P_{1_\alpha}, P_{2_\alpha}, ..., P_{n_\alpha})\right).$$

The extension principle easily produces fuzzy analogues of reliability models. An example of application the fuzzy reliability models for assessment probabilistic characteristics of a ticket-booking information system is described in [4, 5].

5. Conclusion

The new method for risk assessment of the man-machine system functioning is proposed. The feature of the method is combining the fuzzy fault tree analysis and theory of fuzzy reliability of algorithmic processes. This provides a consideration from a unified framework the structural accidents with algorithms of its detecting and avoiding. Method also allows to use fuzzy "if-then" rules about man-machine and environment factors influencing upon probabilities of various events connected with each hazard situation.

References

1. Barlow R.E. and Chatterjee P. Information to Fault Tree Analysis. Rep. OCR 73-70. Operations Research Center, University of California, Berkley, 1973.
2. Tanaka H, Fan L.T. et al. Fault Tree analysis by Fuzzy Probability // IEEE Trans. Reliability, R-32 (5), 1983.- P. 453-457.
3. Rotshtein, A. Fuzzy Reliability Analysis of Man-Machine Systems. In "Reliability and Safety Analysis under Fuzziness, Studies in Fuzziness", Berlin: Physika-Verlag, Springer-Verlag, 1995.- P. 245-270.
4. Ротштейн А.П., Штовба С.Д. Нечеткая надежность алгоритмических процессов.- Винница: Континент-ПРИМ, 1997г.-142с.
5. Rotshtein, A. and Shtovba, S. Prediction the Reliability of Algorithmic Processes with Fuzzy Input Data. *Cybernetics and Systems Analysis.* Vol. 34., No.4, 1998.- P.545-552.
6. Rotshtein A., Shtovba S. Fuzzy Logic-Algorithmic Fault Tree Analysis // Proc. of the *Fourth European Congress on Intelligent Techniques and Soft Computing (EUFIT-96)*. Germany, Aachen, 1996, P.1565-1569.
7. Глушков В.М., Цейтлин Г.Е., Ющенко Е.Л. Алгебра. Языки. Программирование. - К.: Наук. думка, 1978.- 320с.
8. Ротштейн А.П., Кузнецов П.Д. Проектирование бездефектных человеко-машинных технологий К.: Техника, 1992. – 180 с.
9. Rotshtein A. Design of Labour Systems: Formalized Theory. In "Ergonomics of Manual Work (Eds. Willian S. Marras et. al.): Taylor and Francis, 1993. P.457-460.
10. Zimmermann H. Fuzzy Set Theory and its Applications. Third Edition.- Kluwer Academic Publishers, 1996.-435p.