Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-25 (2016) 272–277

Monte Carlo Reliability Analysis of Systems with a Human Operator

M. Jirgl*. M. Havlikova.**
Z. Bradac*. L. Stastny******

** Department of Control and Instrumentation, Faculty of Electrical Engineering and Communication, Brno University of Technology, Technicka 3082/12, 616 00 Brno, Czech Republic (e-mail: miroslav.jirgl@phd.feec.vutbr.cz), **(e-mail: havlika@feec.vutbr.cz),*** (e-mail: bradac@ feec.vutbr.cz), **** (e-mail: xstast01@stud.feec.vutbr.cz)*

Abstract: This paper deals with a description of systems with a human operator - the MMS systems and their reliability. Reliability of these systems is given by technical reliability and reliability of a human operator. Using a modern approach - the Monte Carlo reliability analysis for reliability analysis of systems MMS is main goal of this paper. This method is explained at a fundamental level with emphasis on its application to reliability analysis of MMS systems. The last part of this paper presents an example of MMS reliability analysis using Monte Carlo reliability analysis.

Keywords: Man-machine systems, Reliability, Human reliability, System reliability, Monte Carlo simulation, Mean Time between failures (MTBF).

1. INTRODUCTION

Nowadays, the technical systems are often quite complex and it is difficult to ensure their reliability. However, prediction of their reliability is very important. There are a lot of reliability analyses for technical systems and the issue of reliability analysis of technical system is fairly well mastered. The most widely used quantitative analyses are Analysis of Reliability Block Diagram (RBD), Fault Tree Analysis (FTA) or Markov Reliability Analysis (MA). However, the Monte Carlo statistical reliability analysis has recently become very popular (Ericson, 2005).

Many of today's systems are in cooperation with a human operator. These systems are called Man-Machine Systems (MMS). (Boril, Jalovecky, & Ali, 2012) The global reliability of these systems is influenced and degraded by a human factor. The evaluation of reliability parameters is bounded on human fail quantification. Reliability discipline called Human Reliability Assessment (HRA) deals with an influence of human errors on the reliability of technical systems.

In the following text is presented a new approach to reliability analysis of the MMS systems - using Monte Carlo reliability analysis. The Monte Carlo simulation was developed in the 1940s by scientists at the Los Alamos National Laboratory for modelling of the random diffusion of neutrons. The name refers to the Monte Carlo Casino in Monaco. (Alexander, 2003) Today, the Monte Carlo is used in a wide array of application. One of these applications is just the quantitative reliability analysis.

2. THE SYSTEMS WITH A HUMAN OPERATOR

The interaction between a human and the technical system called MMS is demonstrated in Fig. 1. Reliability of these systems is given by reliability of all consisting elements, i.e. reliability of technical system – Machine and human - Man reliability.

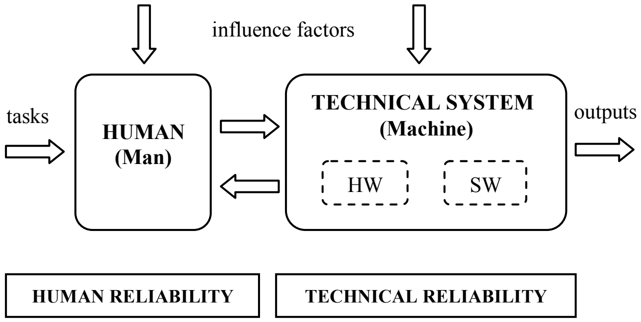

Fig. 1. MMS system and its reliability.

2.1 The technical reliability

Reliability of the technical systems is defined as a capability of a system to perform a required function. This capability (or attribute) constitutes a complex property of the given system and it is expressed via probabilistic variables, where the random variable is time to the first failure - t. These probabilistic variables are called reliability indicators and they are described using exponential distribution of probability most often (Smith, & Simpson, 2004).

The most widely used reliability indicators are probability of failure $Q(t)$, failure probability density $f(t)$, probability of reliability $R(t)$, Mean time between failure *MTBF* and failure rate $\lambda(t)$. The calculation and relations of these indicators are described via followed equations in general (Ericson, 2005).

$$Q(t) = \int_0^t f(\tau)d\tau \qquad [-] \qquad (1)$$

10.1016/j.ifacol.2016.12.046

$$f(t) = \frac{dQ(t)}{dt} \qquad [\mathrm{h}^{-1}] \qquad (2)$$

$$R(t) = 1 - Q(t) \qquad [-] \qquad (3)$$

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{f(t)}{1-Q(t)} \qquad [\mathrm{h}^{-1}] \qquad (4)$$

$$MTBF = \int_{0}^{\infty} R(t)dt = \frac{1}{\lambda} \qquad [\mathrm{h}] \qquad (5)$$

The overall calculation of these indicators is carried out using quantitative reliability analyses, which are suitable tools to express total reliability – the value of the indicators, lifetime and other aspects.

Analysis of Reliability Block Diagram – RBD, Fault Tree Analysis – FTA, Event Tree Analysis – ETA or Markov Reliability Analysis – MA are the most widely used quantitative analyses (Ericson, 2005), (Havlíková & Jirgl, 2013).

Each of these analyses is based on creating a reliability model and applying certain rules to calculate the indicators. The structure of most technical systems is relatively complex. Therefore, the reliability indicators calculation can be difficult. This problem solving is use of commercial software, e.g. BlockSIM, ITEM RBD, etc. However, costs are the main disadvantage of this solution.

Other way to prediction of reliability is use of statistical computer simulation tool, i.e. The Monte Carlo Reliability Analysis.

2.2 Human reliability assessment

Human Reliability Assessment – HRA is part of a reliability discipline, which studies a human performance in operating actions. Human reliability is usually defined as a probability that he/she will correctly perform some system-required activity during a given time period (if time is a limiting factor) without performing any extraneous activity that can degrade the system (Havlíková & Jirgl, 2013).

Human reliability indicators are similar to reliability indicators of technical systems. The log-normal probability distribution $LN(\mu, \sigma)$ is suitable for expression of human reliability. This distribution can be described by equation of failure probability density (6).

$$f(t) = \frac{1}{t\sigma\sqrt{2\pi}} \cdot \exp\left(-\frac{(\ln t - \mu)^2}{2\sigma^2}\right) \qquad [\mathrm{h}^{-1}] \qquad (6)$$

Here μ is mean (expected value) and σ is standard deviation of normal distribution of random variable $\ln(t)$.

However, the quantification of human reliability is usually expressed via $HEP(t)$ – Human Error Probability and $HSP(t)$ – Human Success Probability indicators. These indicators correspond to the probability of failure $Q(t)$ and probability of reliability $R(t)$ for technical systems. The $HEP(t)$ indicator is given by (7), the $HSP(t)$ by (8) (Havlíková & Jirgl, 2013).

$$HEP(t) = \int_{t=0}^{t_m} f(t)dt \qquad [-] \qquad (7)$$

$$HSP(t) = 1 - \int_{t=0}^{t_m} f(t)dt = 1 - HEP(t) \qquad [-] \qquad (8)$$

Description of reliability by the log-normal probability distribution $LN(\mu, \sigma)$ is quite difficult. Therefore, the approximation by Weibull distribution can be used. This distribution is three-parameter in general. However, the two-parameter Weibull distribution is used in practice. This distribution is defined by failure probability density (9).

$$f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \cdot \exp\left(-\left(\frac{t}{\eta}\right)^{\beta}\right) \qquad [\mathrm{h}^{-1}] \qquad (9)$$

Here β is shape parameter and η is scale parameter. The value of β - shape parameter in the range (2 - 3) is suitable for approximation of log-normal distribution (Havlíková & Jirgl, 2013).

The $HEP(t)$ and $HSP(t)$ indicators are given by (10) and (11), in case of Weibull distribution using.

$$HEP(t) = \int_{t=0}^{t_m} f(t)dt = 1 - \exp\left(-\left(\frac{t}{\eta}\right)^{\beta}\right) \qquad [-] \qquad (10)$$

$$HSP(t) = \exp\left(-\left(\frac{t}{\eta}\right)^{\beta}\right) \qquad [-] \qquad (11)$$

Quantitative HRA methods are focused on translating the identified event or error into Human Error Probability – *HEP*. These techniques refer to databases of human tasks and associated error rates to expression of average error probability for a particular task. They are focused on identifying an event or error and the common result of task analysis or incident investigation. There are many quantitative HRA methods, e.g. THERP, ATHEANA, SLIM, etc. However, most of these methods are based on the complex model of human behavior and creating of failure/event tree for individual interactions in MMS. Then, these analyses can be quite difficult.

2.3 Reliability of MMS

As mentioned, reliability of MMS systems is given by reliability of technical system – Machine and human - Man reliability.

Human reliability is usually described by log-normal distributed indicators and technical systems by exponential