Contemporary Engineering Sciences, Vol. 7, 2014, no. 6, 287 - 292
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2014.416

The Basic Approach in Designing of the Functional Safety Index for Transport Infrastructure

Dmitry Brusyanin

Ural State University of Railway Transport
Office 335, Kolmogorova str. 66, Ekaterinburg, Russia, 620034

Sergey Vikharev

Ural Federal University
Office 607, Turgeneva str. 4, Ekaterinburg, Russia, 620075

Abstract

In this paper we discuss the basic approach to the functional safety assessment. The construction is done for any of the transport system, wherein one can clearly distinguish the functional elements of the infrastructure. Assumes a system allowing tests to assess the status of each item. Used to build the index automata theory. Explanation of the model are made by the example of the railway infrastructure. Nevertheless, similar approaches can be applied to other transport systems not only road, but also, for example, the gas tube transportation system.

Keywords: interaction stabilization, risk management, organizational network, Pareto efficiency.

1 Introduction

Functioning of technical subsystem elements is aimed to identify deviations from norms and dangerous failure of core elements (in case geometrical parameters diagnosis system of railway track, rail defectoscopy and etc.) and to recover their operability (the system of current track and locomotives maintenance). Much of Contemporary Functional Safety Standards contains rules but does not provide an index for transport infrastructure exactly (see for ex. [1-4]) that can be easy to use and common for each part of functional system.

Improving the efficiency of technical subsystem elements functioning is a task of reliability theory. Thus, increasing reliability of the new generation defectoscopes is implemented by means of usage more channels and new sounding schemes [5, 6].

Providing the reliability of railway automatics and telemechanics systems is achieved by introduction structural and temporal reservation and redundancy, informational and functional reservation and redundancy, parametrical redundancy, by building algorithms unsusceptible to fault, failures and software errors algorithm and by masking malfunctions by means of majority reservation and hardware implementation the anti-interference coding [7].

2 The functional safety index

Let's introduce a functional safety index $K_m^{(f)}$, which shows the probability that the core "wheel-rail" will not be in inoperable state because of the technical subsystem element dangerous failures (errors). Here a number of function implemented by subsystem element is denoted by superscript f, a number of investigated economy is m. For example, the following elements can be identified on the current content of path: m = 1 is rails; m = 2 is sleepers and etc. Will then be used approaches previously applied in the works [8—16].

Let's introduce an index of functional safety control system of the core defective elements f=1. Thus, $K_m^{(1)}$ is the probability that the core "wheel-rail" will not be in inoperable state because of the missing defective elements by control system.

An index of technical personnel functional safety $K_m^{(2)}$ (when changing defective element) is the probability that the core "wheel-rail" will not be in inoperable state when a defective element will be changing because of dangerous mistakes or actions of technicians.

Thus, the proposed indexes allow evaluating functioning of elements of the organizational chain technical subsystem when core elements are being controlled and works to eliminate them are being carried out.

Modeling a functional safety index of the control system core elements $K_m^{(1)}$ is implemented by means of Markov random processes with finite set of states of the core S and the transition probability matrix $\Lambda = (p_{ij})$ [10].

The intensity of core λ_m defective elements release is a number or defective elements on plot per the fixed period of time, for instance, temporal interval between two adjacent verifications.

The flow of defective elements, identified in monitoring process $P_m\lambda_m$, leads the core to recovery state, where P_m is a probability of detection defective element m by monitoring device. The flow of defective elements, missing in monitoring process $Q_m\lambda_m$, leads the core to inoperable state, where Q_m is a probability of missing defective element m by monitoring device, $Q_m = 1 - P_m$. The flow of recoveries leads the core to initial state. It, like a previous flow, is characterized by intensity. Intensity is a value reciprocal to time between two verifications.

In further researches it is assumed that the flows of failures λ_m and recoveries of the core elements μ_m are the simplest.

As an elementary example let's consider core transaction to inoperable state when it is checked. Fig. 1 illustrates possible states of the core. The vertex "0" shows the initial state of the core at the fig. 1. The vertex "1" corresponds to state when there is a core defective element. The vertex "2" shows recovery state occurred after detection a failure of a core element with probability P_m (intensity of transition from the zero state to the first one: $P_m\lambda_m$).

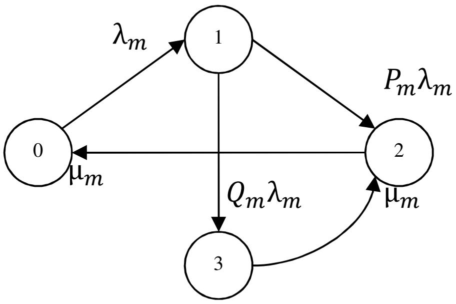

Fig. 1 Graph model of the core states in the control process

The vertex "3" shows dangerous state when there is a missing defective element on the plot. Intensity of core transition from zero state to the second one is $Q_m\lambda_m$). Core transition to the "0" state is provided by the recovery flow with intensity μ_m. $p_i(t)$ is a probability that at the moment t a system will be in i-state.

A matrix of transitions intensities Λ (graph is presented at the fig. 1) is:

$$\Lambda = \begin{pmatrix} -\lambda_m & 0 & \mu_m & 0 \\ \lambda_m & -(P_m\lambda_m + Q_m\lambda_m) & 0 & 0 \\ 0 & P_m\lambda_m & -\mu_m & \mu_m \\ 0 & Q_m\lambda_m & 0 & -\mu_m \end{pmatrix}$$

A system of A. N. Kolmogorov differential equations [19] (it is determined by graph of states) is:

$$\frac{dp_0(t)}{dt} = -\lambda_m p_0(t) + \mu_m \cdot p_2(t);$$

$$\frac{dp_1(t)}{dt} = -(P_m\lambda_m + Q_m\lambda_m) \cdot p_1(t) + \lambda_m \cdot p_0(t);$$
$$\frac{dp_2(t)}{dt} = -\mu_m \cdot p_2(t) + P_m\lambda_m \cdot p_1(t) + \mu_m \cdot p_3(t);$$
$$\frac{dp_3(t)}{dt} = -\mu_m \cdot p_3(t) + Q_m\lambda_m \cdot p_1(t);$$
$$\sum_{i=0}^{3} p_i(t) = 1.$$

When $t \to \infty$ $p_i(t) = p_i$ and $\frac{dp_i(t)}{dt} = 0$, where $i = 0{,}1{,}2{,}3$.

A system of algebraic equations for steady-state operations (when $t \to \infty$) is:

$$-\lambda_m p_0 + \mu_m \cdot p_2 = 0;$$
$$-(P_m\lambda_m + Q_m\lambda_m) \cdot p_1 + \lambda_m \cdot p_0 = 0;$$
$$-\mu_m \cdot p_2 + P_m\lambda_m \cdot p_1 + \mu_m \cdot p_3 = 0;$$
$$-\mu_m \cdot p_3 + Q_m\lambda_m \cdot p_1 = 0;$$
$$\sum_{i=0}^{3} p_i = 1.$$

A functional safety index is defined like a probability of being core in one of the following states: $K_m^{(1)} = p_0 + p_1 + p_2$ or $K_m^{(1)} = 1 - p_3$.

In the result of solving the algebraic equations system, the stationary probability that the core will not be in inoperable state because of monitoring devices failures is: $K_m^{(1)} = 1 - \frac{Q_m}{1+2\cdot\frac{\mu_m}{\lambda_m}+Q_m}$.

Intensity of the core defective elements output λ_m is defined through the middle duration of non-failure operations (a middle interval in days between the possible defects appearance): $\lambda_m = 1/t_0$, where t_0 is a middle duration of non-failure operations of core elements, days. Middle duration of the core non-failure operations is defined using an index of average annual number of defects N: $t_0 = 365/N$. Intensity (frequency) of the core elements control is: $\mu_m = 1/t_1$, where t_1 is a middle time of detecting a defect by monitoring devices (time between adjacent verifications), days.

Conclusion

The proposed methodology for quantifying functional safety control system allows to take into account the state of the core, various de-stabilizing factors (quality control devices and personnel to implement it), organizational and technological measures. Methodology for quantifying the functional safety of technical personnel $K_m^{(2)}$ is an actual topic for further research. In the next part of work will be carried out verification of the proposed index $K_m^{(1)}$.

Acknowledgements

Supported under the Agreement 02.A03.21.0006 of 27.08.2013 between the Ministry of Education and Science of the Russian Federation and Ural Federal University.

Supported under the incentive program international publications of Ural State University of Railway Transport.

References

[1] EN 50128, Railway Industry Specific

[2] IEC EN 61508 Parts 1 to 3 is a core Functional Safety standard, applied widely to all types of safety critical E/E/PS and to systems with a safety function incorporating E/E/PS.

[3] UK Defence Standard 00-56 Issue 2

[4] ISO 25119 - Tractors and Machinery for Agriculture and Forestry - Safety-Related Parts of Control Systems

[5] Гурвич А.К., Давыдов А.В. Схемы прозвучивания и эффективности средств сплошного УЗК рельсов. В мире неразрушающего контроля. – 2003. – № 3. – С. – 71. – 73.

[6] Li, H.a , An, Z.a , Zhang, X.a , Liu, Y.b , Wang, L.b. Simulation test on highway transportation vibration for cartridge (2013) QR2MSE 2013 - Proceedings of 2013 International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering, art. no. 6625747, pp. 1056-1059.

[7] Розенберг Е.Н., Шубинский И.Б. Методы и модели функциональной безопасности технических систем: Монография. – М.: ВНИИАС, 2004. – 188 с.

[8] S. Vikharev. Comparative vendor score // Applied Mathematical Sciences, Vol. 7, 2013, no. 100, 4949-4952. http://dx.doi.org/10.12988/ams.2013.36414

[9] S. Vikharev. Mathematical modeling of development and reconciling cooperation programs between natural monopoly and regional authorities. // Applied Mathematical Sciences, Vol. 7, 2013, no. 110, 5457-5462. http://dx.doi.org/10.12988/ams.2013.38454

[10] S. Vikharev. Verification of mathematical model of development cooperation programs between natural monopoly and regional authorities. // Applied Mathematical Sciences, Vol. 7, 2013, no. 110, 5463-5468. http://dx.doi.org/10.12988/ams.2013.38463

[11] S. Vikharev. Mathematical model of the local stability of the enterprise to its vendors //Applied Mathematical Sciences, Vol. 7, 2013, no. 112, 5553-5558 http://dx.doi.org/10.12988/ams.2013.38465

[12] I. Nizovtseva. The generalized stability indicator of fragment of the network. I. Modeling of the corporate network fragments. Applied Mathematical Sciences, Vol. 7, 2013, no. 113, 5621-5625. http://dx.doi.org/10.12988/ams.2013.38471

[13] I. Nizovtseva. The generalized stability indicator of fragment of the network. II Critical performance event. Applied Mathematical Sciences, Vol. 7, 2013, no. 113, 5627-5632. http://dx.doi.org/10.12988/ams.2013.38472

[14] A. Sheka. The generalized stability indicator of fragment of the network. III Calculating method and experiments. Applied Mathematical Sciences, Vol. 7, 2013, no. 113, 5633-5637. http://dx.doi.org/10.12988/ams.2013.38473

[15] A. Sheka. The generalized stability indicator of fragment of the network. IV Corporate impact degree. Applied Mathematical Sciences, Vol. 7, 2013, no. 113, 5639-5643. http://dx.doi.org/10.12988/ams.2013.38474

[16] I. Nizovtseva. Index of the economic interaction effectiveness between the natural monopoly and regions. I. Math model. Applied Mathematical Sciences, Vol. 7, 2013, no. 124, 6181-6185. http://dx.doi.org/10.12988/ams.2013.39522

[17] E. B. Dynkin. Theory of Markov Processes. Dover Publications, 2006.

Received: January 5, 2014