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THE METHOD OF RISK ASSESSMENT IN TRANSPORT SYSTEMS

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Abstract: *One of the methods for an assessment of the system ability to perform its task properly is to establish the risk connected with the transport means functioning. The presented approach involves determination of the risk connected with functioning of one technical object in transport system. The risk associated with functioning of a single technical object has been determined on the basis of a mathematical model of the operation and maintenance process, in the studied transportation system. A mathematical model of the operation and maintenance process has been developed with acceptance of an assumption that the process model is to be represented by a homogeneous semi-Markov model X(t).*

Keywords: Risk assessment, Operation and maintenance process, Transport system.

1. Introduction

In the case of analysis of risk connected to the operation of technical systems, the probability of an unwelcome or dangerous event is determined on the basis of data obtained from functioning research of authentic process of functioning technical objects, e.g. means of transport. The results of an unwelcome or dangerous event may be connected to both the technical object (mean of transport), the worker (i.e. an operator carrying out the assigned transport task) and the environment. The effect of an unwelcome or dangerous event can lead to financial losses, health deterioration or loss of life, most often expressed as the cost, range of influence and duration of inconvenience (Szpytko, 2009).

The following is an examples of definition of the risk contained in acts on standardization:

Risk – the product of frequency or probability of the occurring of a specific dangerous event and economic and social implications of such an event (PN-IEC 60300-3-9),

Risk – the product of probability of the occurring of an unwelcome event and the extent of its results (PN-EN 1050),

Risk – combination of the probability of an event and its consequence (ISO Guide 73:2009 Ed.2.0).

Due to the complexity of the modeled processes and technical systems, there is a need for use of appropriate methods and tools, including stochastic models (Grabski, 2010 and Kulkarni, 1995), matrix calculus (Woropay et al., 2007 and Landowski et al., 2016 and Zastempowski et al., 2015) as well as models and simulation programs (Marbach et al., 2001 and Muślewski et al., 2016) ensuring effective realization of research and analysis of results obtained.

2. Mathematical model of the operation and maintenance process of transport means

The model of the operation and maintenance process was created on the basis of the analysis of the space of operation and maintenance states and events connected with technical objects (transport means) operating in the analyzed authentic transport system. Due to the criterion of risk in the observed system functioning, based on the identification of the multi-state operation and maintenance process of technical

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object, crucial states as well as possible passages between selected states were identified. On such basis a graph of changes of the states of operation and maintenance process was prepared, presented in Fig. 1.

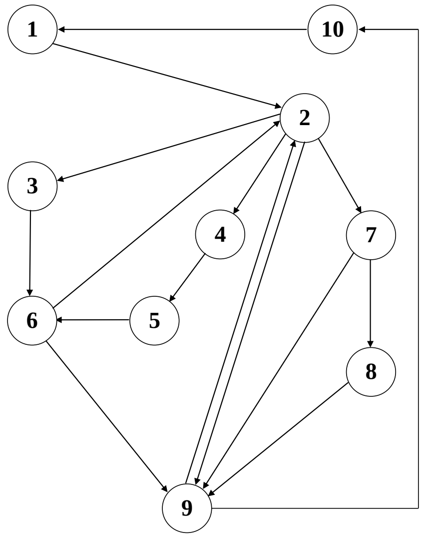

Fig. 1: A directed graph depicting operation and maintenance process of transport means
1 – *stopover at depot parking space,* 2 – *carrying out of transport task,* 3 – *downtime caused by damage (unwelcome event),* 4 – *downtime caused by an accident or collision (unwelcome event),* 5 – *intervention and rescue action after accident or collision (unwelcome event),* 6 – *repair after an unwelcome event,* 7 – *preventive diagnosis,* 8 – *preventive repair,* 9 – *supply,* 10 – *servicing (operation day, periodical, seasonal).*

Applying semi-Markov processes in the mathematical operation and maintenance process, the following assumptions were made:

- the modelled process has a finite number of states $i = 1, 2, \ldots, 10$,
- if the technological object at moment t is in state i, then $X(t) = i$,
- random process $X(t)$ being a mathematical model of the operation and maintenance process is homogenous,
- at moment $t = 0$ the process is in state 1, i.e. $P\{X(0) = 1\} = 1$.

Limit probabilities p_i^* of remaining in states of the analyzed process $X(t)$ were determined based on limit theorem for semi-Markov processes (Grabski, 2014):

If complex Markov chain in a semi-Markov process of finite state set S and kernel of continuous type contains one class of positive recurring states for each state $i \in S$ and the expected positive average values $\overline{\Theta_i}$, $i \in S$ are finite, there exist limit probabilities:

$$p_i^* = \lim_{t \to \infty} p_i(t) = \frac{\pi_i \cdot \overline{\Theta_i}}{\sum_{i \in S} \pi_i \cdot \overline{\Theta_i}} \tag{1}$$

where:

the probabilities π_i comprise stationary distribution of the complex Markov chain fulfilling the system of linear equations:

$$\sum_{i \in S} \pi_i \cdot p_{ij} = \pi_j, \quad j \in S, \quad \sum_{i \in S} \pi_i = 1 \tag{2}$$

p_{ij} signifies conditional probability of passing from state i to state j:

$$p_{ij} = \lim_{t \to \infty} p_{ij}(t) \tag{3}$$

$$p_{ij}(t) = P\{X(t) = j | X(0) = i\} \tag{4}$$

$\overline{\Theta_i}$ signifies average values of unconditional duration of the states of process.

In order to delineate the values of limit probabilities p_i^* of remaining in states of semi-Markov model of the operation and maintenance process of transport means, based on the directed graph presented in Fig. 1 the following were created: matrix P of the probabilities of changes of states and matrix Θ of conditional duration of the states of process $X(t)$. Then, with the use of MATHEMATICA software, stationary distribution was delineated for complex Markov chain in the process as well as the limit distribution of semi-Markov process.

3. The unit risk of functioning disruption of the transport system

In this paper the unit risk of disruption of correctly functioning means of transport is defined as a sum of products of limit probabilities of remaining in unwelcome states of semi-Markov model of the operation and maintenance process and values of losses resulting from remaining in those states. The unwelcome states of the modeled operation and maintenance process of transport means are such which cause disruption of correctly functioning means of transport as well as states with generated losses due to such disruption. The correlation defining the unit risk of functioning disruption of transport means while carrying out the operation and maintenance process is described with the formula:

$$r_U = \sum_{i \in W} p_i^* \cdot c_i \tag{5}$$

where:

c_i - unit cost incurred in connection with remaining in the *i*-th unwelcome state of the model of process $X(t)$,

$W \subset S$ - subset of the states of the model of process $X(t)$ being unwelcome states.

In order to define the unit risk of functioning disruption of the analyzed means of transport on the basis of semi-Markov model of the operation and maintenance process, one should distinguish the subset of unwelcome states $W \subset S$, in which additional costs are incurred due to damage, destruction, collision or an accident of the discussed technical objects (costs of intervention and rescue missions, costs of emergency pull offs, costs of repairs, costs of diagnostics, costs of stopover, costs of replacing the technical object with a substitution object, etc.). In the presented model the following unwelcome states of technical object have been distinguished: state 3 – downtime caused by damage (unwelcome event), state 4 – downtime caused by an accident or collision (unwelcome event), state 5 – intervention and rescue action after accident or collision (unwelcome event), state 6 – repair after an unwelcome event.

Then the unit risk of unwelcome event connected with disruption of correctly functioning means of transport:

$$r_U = p_3^* \cdot c_3 + p_4^* \cdot c_4 + p_5^* \cdot c_5 + p_6^* \cdot c_6 \tag{6}$$

$$r_U = \frac{\left\{\left[(p_{2,3}+p_{2,4})\cdot p_{6,9} + p_{2,7}\cdot(p_{7,8}+p_{7,9}) + p_{2,9}\right]\cdot p_{9,10} + p_{2,3}\right\}\cdot \overline{\Theta_3}\cdot c_3 + p_{2,4}\cdot\left(\overline{\Theta_4}\cdot c_4 + p_{4,5}\cdot\overline{\Theta_5}\cdot c_5\right) + (p_{2,3}+p_{2,4})\cdot\overline{\Theta_6}\cdot c_6}{\left[(p_{2,3}+p_{2,4})\cdot p_{6,9} + p_{2,7}\cdot(p_{7,8}+p_{7,9}) + p_{2,9}\right]\cdot\left[p_{9,10}\cdot\left(\overline{\Theta_1}+\overline{\Theta_3}+\overline{\Theta_{10}}\right)+\overline{\Theta_9}\right] + \overline{\Theta_2} + p_{2,3}\cdot\left(\overline{\Theta_3}+\overline{\Theta_6}\right) + p_{2,4}\cdot\left(\overline{\Theta_4}+p_{4,5}\cdot\overline{\Theta_5}+\overline{\Theta_6}\right) + p_{2,7}\cdot\left(\overline{\Theta_7}+p_{7,8}\cdot\overline{\Theta_8}\right)}$$

For the analyzed model of the operation and maintenance process of transport means, basing on the functioning data, values were estimated for the elements of matrix P of passage probabilities as well as unconditional times and unit profit generated in the states of process $X(t)$ were determined (Tab. 1).

Tab. 1: Average unconditional duration times for states of process in [h] as well as unit costs in [PLN/h] generated in states of process X(t).

Process state	$\overline{\Theta_i}$	c_i	Process state	$\overline{\Theta_i}$	c_i
1	5.659	6.77	6	2.333	98.21
2	8.852	-32.74	7	0.414	54.98
3	0.514	69.08	8	2.140	86.89
4	0.873	162.80	9	0.152	23.09
5	1.712	304.63	10	0.582	164.72

$$P = \begin{vmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.2320 & 0.0030 & 0 & 0 & 0.4988 & 0 & 0.2661 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0.4702 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5298 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0799 & 0.9201 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0.2242 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.7758 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{vmatrix} \quad (7)$$

As a result of the calculations unit risk of functioning disruption of transport means was developed:

$$r_U = 6.06 \text{ [PLN/h]}.$$

4. Conclusions

The method presented in the article is the partial result of research to develop a comprehensive method of the control process for using the means of transport where decisive semi-Markov processes are used for control. The assessment of the risk connected with technical objects is an issue of complex character and involves determining numerical value of risk and criteria values (e.g. values of unit profit), to be used for deciding whether so determined risk is possible or impossible to be accepted. In further research a method for determination of criteria risk assessment values will be developed. Assessment of risk connected with technical objects operation and maintenance can be the point of reference to formulate design requirements concerning of the operated objects (transport means) as well as assumptions concerning design or modernization of the technical means necessary for assurance of the vehicle availability in a given transport system.

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