Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 149 (2019) 185–194

Procedia Computer Science

www.elsevier.com/locate/procedia

ICTE in Transportation and Logistics 2018 (ICTE 2018)

Determination model of the apparatus state for railway automatics with restrictive statistical data

Valentyn Moiseenko[a], Oleksandr Kameniev[a], Volodymyr Butemko[a], Vitalii Gaievskyi[a,]*

[a] *Ukrainian State Univerzity of Railway Transport, Feuerbach sq., Kharkiv, Ukraine*

Abstract

In the report, microprocessor systems of railway automation are represented by a distributed system of computing [1]. Under certain conditions it is expedient to represent them as a non-oriented graph and optimize with the use of the method of the least-clique [2]. The prognostic model and the method of determining the failures of hardware of microprocessor systems of railway automatics have been developed. They allow you to determine the probability of a device failure from a particular group using Student's t-distribution, maximum likelihood estimation and uneven observations. Unlike existing approaches to forecasting, the proposed method takes into account the limited amount of control systems operation statistical data [3-6]

Keywords: Microprocessor systems; Railway automation; Non-oriented graph; Prognostic model

1. Introduction

One of the key problems that arise in the implementation of microprocessor systems of railway automation is the realization of effective technical diagnosis and control in the process of operation. Solving it is an important component of the confirmation and ensuring the required level of reliability and functional safety of the specified systems [1–3].

This problem appears to be the most acute in terms of the timely detection of dangerous failure in separate channels of reserved information-control systems. This is due, above all, to the absence of manifestation of a dangerous failure in the

* Corresponding author. Tel.: +3-8095-25-05-259.
E-mail address: alexstein@meta.ua

10.1016/j.procs.2019.01.122

separate channels of a reserved technical unit from the point of view of direct impact on the controlling elements. Only reliable technical diagnosis can promptly detect and warn of such dangerous failures [3].

One of the priority tasks in technical diagnosis and control is the assessment of permissibility and feasibility of further operation of equipment taking into account results of the prediction of technical condition when detecting a defect in hardware. Such a task is defined in line with a number of international standards (ISO/IEC 17020, ISO 9001–94, IEC 300-1/ISO 9000-4), results of scientific research and methodological recommendations. Significant contribution into the formation of results of the aforementioned prediction is made by statistical methods based on taking the identified defects into account, as well as failures of technical devices in the process of operation [1, 3].

However, using the classical methods of mathematical statistics is significantly complicated for microelectronic devices of the systems of railway automation by a number of factors, the main of which are [5]:

- Relatively limited experience of operating the microprocessor systems of management and control at the railway transport of Ukraine, under conditions of low volume of the implementation, which limits the size of statistical samples and their representativeness
- Limited access to information on the statistics of failures in the process of operating the microprocessor systems of railway automation in foreign countries. This complicates the formation of objective statistical picture, which would have allowed the use of classical methods for its evaluation
- The realized strict requirements on reliability and safety in the operation of such systems, when the cases of failures and defects are an extremely rare phenomenon, which, when applied to a general shortage of statistical data, makes the classical processing of results of observations practically impossible

It should be noted that the analytical prediction of failure rate of hardware devices is essential to ensure high reliability and safety when using railway automatics [4]. Therefore, it is a relevant issue to devise such methods of forecasting, for which limited statistical volume is sufficient

2. The aim of research

The aim of present research is to develop a progressive method of forecasting the technical condition of microelectronic means of railway automation. It should provide for determining the probability of failure of a certain functional node in the information-control system of railway transport under conditions of limited statistical data on its operation.

3. Materials and methods for improving the procedure of predicting the equipment of railway automation

Underlying the research is the principle of identity of microprocessor controllers (MPC). MPCs are thus combined in a single equivalence class by structural-functional attribute. This allows using limited statistical data on reliability of microprocessor devices within the framework of research.

In order to apply the appropriate methods, the whole set L of MPC of a certain level of control system is divided into n equivalence classes $L_i \subset L$, only identical MPC are within the limits of each class.

In accordance with the principle of equivalence, results of testing, tests or other studies, executed relative to a separate element of equivalence class l_j, are L_i, are applicable to the whole set L_i. Based on the theory of relations, results of studies, performed relative to the system of representatives of all equivalence classes are applicable for the entire set L. Dissemination of research results over the system of representatives on all relevant equivalence classes directly follows from the transitivity of the given relationship. However, a deviation in the parameters of a particular MPC leads to the group L_i ceasing to be an equivalence class. Such a deviation may be a consequence of damage, production defect or other failure of a technical device. Instead, the class of equivalence in this case is the set $L_i / \left(L_i^{def} = \left\{l_{def}\right\}\right)$. Then results of research into MPC l_{def} cannot apply to the entire set of identical elements.

Thus, from the point of view of the theory of relations, forecasting the technical condition of MPC can be reduced to determining the probabilistic indicators of manifestation of set L_i^{def} [6], which is the basis of the study, which is considered in the present article.

If it was not for the well-organized industrial initial or other inspection control of MPC, there is always a set of unaccounted factors whose influence leads to occasional mistakes, the result of which is the set $L_i^{err} = \{l_{err}\}$ of MPC with unidentified deviations from technical parameters, operation of which leads to hardware failures. Thus, the prediction of technical state of MPC is determined by the probability of membership of element $l \in LL_i$, arbitrarily chosen from the whole totality of MPC, to the class of equivalence $L_i^e = L_i / L_i^{err}$: $P(E : 1 \in L_i^e)$.

The specified random errors are interpreted by the corresponding number of products. Their inspection control (in production, at a maintenance-technological station, etc) did not detect any flaws (defects, etc.). Quantitative estimation of random errors is determined by their ratio to the total number of products in a relevant group. If one has statistical data on the specified quantity from several sites of the implementation of MPC, then the probability $P(E)$ can be calculated based on statistical methods. Random errors are naturally considered as a result of impact from a large number of various reasons. Each one of them contributes with a very small error. None of them is dominant. If one detects dominant errors, then such errors should be attributed to the systematic ones and should be accounted for by appropriate adjustment.

According to Lyapunov theorem, there is a reason to believe that random errors are distributed according to the normal law. Then normally distributed are also magnitudes $\omega = \omega_{jh} = (\mathrm{N}_{err} / \mathrm{N}_{com}) \times 100\%$ that represent such errors. N_{err} here is the number of defective goods of a particular type detected during inspection. Parameter N_{com} specifies a total number of such products. This justifies the application of methods associated with this type of distribution, relative to the defect percentage magnitudes ω, obtained in the course of observations at previous sites of MPC operation (defects, failures). Event E can be regarded as a simultaneous occurrence of two events. The first is when the defect percentage ω of specific MPC from the entire totality N_{com} does not exceed some $\omega_{\max} (\omega \leq \omega_{\max})$. The second comes down to selecting MPC from the totality $\mathrm{N}_{com} - \mathrm{N}_{err}(\omega_{\max})$ of well-functioning devices. The second event is dependent on the first one and occurs in the case of its emergence. Then, in accordance with the rule of finding the probability of occurrence of dependent events:

$$P(E) = P(\omega \leq \omega_{\max}) \times P_{\omega \leq \omega_{\max}}(\mathrm{ll} \in LL_{ij}^{e}). \tag{1}$$

Given that, from all Ncom possible outcomes of choosing MPC, a workable controller is matched with $\mathrm{N}_{com} - \mathrm{N}_{err}$ results, then, according to the classical determining of probability, conditional probability $P_{\omega \leq \omega_{\max}}(\mathrm{ll} \in LL_{ij}^{e})$ is determined as:

$$P_{\omega \leq \omega_{\max}}(\mathrm{ll} \in LL_{ij}^{e}) = \frac{N_{com} - N_{err}^{\max}}{N_{com}} = 1 - \frac{N_{err}^{\max}}{N_{com}} = 1 - \frac{\omega_{\max}}{100\ \%}, \tag{2}$$

where $N_{err}^{\max}$ is the absolute number of defective MPC that corresponds to magnitude ωmax. Thus, formula (1) takes the following form:

$$\begin{aligned} P(E) &= P(\omega \leq \omega_{\max}) \times \left(1 - \frac{\omega_{\max}}{100\ \%}\right) = \\ &= \frac{P(\omega \leq \omega_{\max}) \times (100\ \% - \omega_{\max})}{100\ \%}. \end{aligned} \tag{3}$$

Thus, as follows from expression (3), the probability P(E) is a function of parameter ωmax, determining which is actually what the problem of forecasting comes down to. Given the fact that the percentage of defects cannot be negative, it is possible to perform the following equivalent transformations over interval $\omega \leq \omega_{\max}$:

$$(\omega \le \omega_{\max}) \equiv \left(0 \le \omega \le \omega_{\max}\right) \equiv \left(\omega_o - \Delta\omega = 0 \le \omega \le \omega_o + \Delta\omega = \omega_{\max}\right) \equiv \left(-\Delta\omega \le \omega - \omega_o \le +\Delta\omega\right). \qquad (4)$$

The values of magnitudes ω_o and $\Delta\omega$ are determined from the following system of equations:

$$\begin{cases} \omega_o - \Delta\omega = 0; \\ \omega_o + \Delta\omega = \omega_{\max}; \end{cases} \rightarrow \begin{cases} \omega_o = \Delta\omega; \\ 2\Delta\omega = \omega_{\max}; \end{cases} \rightarrow \omega_o = \Delta\omega = \frac{\omega_{\max}}{2}. \qquad (5)$$

According to formula (4), there has to be equality: $P(\omega \le \omega_{\max}) = P\left(-\Delta\omega \le \omega - \omega_0 \le \Delta\omega\right)$, that justifies determining the confidence probabilities and confidence intervals to compute the given probability and value $\omega_{\max}$. Taking into account result (5), the value of $P(\omega \le \omega_{\max})$ is determined through the integrals of probability and Laplace:

$$P(\omega \le \omega_{\max}) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\frac{\omega_{\max}}{2}}^{+\frac{\omega_{\max}}{2}} e^{-\frac{\left(\omega - \frac{\omega_{\max}}{2}\right)^2}{2\sigma^2}} d\left(\omega - \frac{\omega_{\max}}{2}\right) = \qquad (6)$$

$$= \sqrt{\frac{2}{\pi}} \int_0^{\chi} e^{-\frac{\chi^2}{2}} d\chi = 2\Phi(\chi),$$

where:

- σ is the root-mean-square deviation (RMSD) of random magnitude ω
- $\Phi(\chi)$ is the Laplace function (integral)
- χ is the parameter that interprets a probability integral into the Laplace integral:

$$\chi = \frac{\omega - \frac{\omega_{\max}}{2}}{\sigma} = \frac{2\omega - \omega_{\max}}{2\sigma}$$

At the known value of RMSD σ, one can determine probability $P(\omega \le \omega_{\max})$ at the assigned valid ωmax or vice versa – the value of ωmax at the assigned permissible (confidence) probability $P(\omega \le \omega_{\max})$ by the reference data that determine the value of function $\Phi(\chi)$ in any point χ. However, in most cases, the magnitude σ is not known, and its calculation is impossible because of missing data on the specific values of distribution function of random magnitudes ω. In order to solve this problem, according to the classical theory of errors, one can employ the method of maximum likelihood and the Bessel formula, according to which the magnitude σ is replaced with the mean value of selective standard smean, which is its approximated value:

$$\sigma \rightarrow s_{mean} = \sqrt{\frac{1}{\rho(\rho-1)} \sum_{h=1}^{\rho} \left(\omega_{jh} - \omega_{mean}\right)^2}, \quad \omega_{mean} = \frac{1}{\rho} \sum_{h=1}^{\rho} \omega_{jh}, \qquad (7)$$

where ωmean is the mean value of parameter ω_{jh} – the point estimation of this parameter; ρ is the number of observations of magnitude ω_{jh} (experimental objects of transport infrastructure where statistical data are collected).

Results (1)–(7) with a certain modification for use under conditions of limited statistical data, which is the process of research, laid the foundation for the developed method for the prediction of technical condition. Direct application of formulas (6) and (7) is limited by a number of factors. Decisive among these is the shortage of statistical data, as well as a probable uneven accuracy of observations for each object. Though uneven accuracy is related to the types of MPC that are close in characteristics, but they are not quite identical. It is also affected by differences in the technology of operation, which could lead to different manifestations of a defect.

Solving the first problem is achieved by using the Student distribution, widely applied in the statistics of small samples (microstatistics). Based on formulas of the Student distribution [6], and taking into account expressions (5)–(7) and accepted assumptions (in particular, $\sigma \to s_{mean}$), it is possible to write the following intermediate value of probability:

$$P(\omega \le \omega_{\max}) = P\left(-t_p \le u = \frac{\omega_{mean} - \frac{\omega_{\max}}{2}}{s_{cp}} \le +t_p\right) =$$

$$= P\left(-t_p s_{mean} \le \omega_{mean} - \frac{\omega_{\max}}{2} \le +t_p s_{mean}\right) =$$

$$= P\left(\omega_{mean} - t_p s_{mean} \le \frac{\omega_{\max}}{2} \le \omega_{mean} + t_p s_{mean}\right) =$$

$$= P\left(2\omega_{mean} - 2t_p s_{mean} \le \omega_{\max} \le 2\omega_{mean} + 2t_p s_{mean}\right) =$$

$$= \int_{-t_p}^{+t_p} \left[\frac{\Gamma\left(\frac{\kappa+1}{2}\right)}{\sqrt{\pi\kappa\Gamma\left(\frac{\kappa}{2}\right)}}\left(1+\frac{u^2}{\kappa}\right)\right] du =$$

$$= 2\int_{0}^{+t_p} \left[\frac{\Gamma\left(\frac{\kappa+1}{2}\right)}{\sqrt{\pi\kappa\Gamma\left(\frac{\kappa}{2}\right)}}\left(1+\frac{u^2}{\kappa}\right)\right] du = S\left(t_p, \kappa\right), \quad (8)$$

where $\Gamma(z) = \int_0^{+\infty} e^{-x} x^{z-1} dx$ is the gamma function: the Euler integral of the second kind $\left(x = \mathrm{Re}(z) > 0\right)$; $\kappa = \rho - 1$ is the Student coefficient, which determines the number of degrees of freedom for the eponymous distribution.

The values of the Student function $S\left(t_p, \kappa\right)$ are determined at different values of parameters tp and κ using the reference tables [6]. The function determines the probability that a deviation of the arithmetic mean value of defect percentage ω_{mean} from the true value ω does not exceed $\Delta p = tps_{mean}$. In this case, as follows from expression (8), this function also determines the probability of finding permissible defect percentage over some interval $\omega_{\max} \in [2\omega_{mean} - 2t_p s_{mean}; 2\omega_{mean} + 2t_p s_{mean}]$, whose separate elements, as shown below, can be less than zero. Considering that the defect percentage cannot be negative, a negative value of parameter $\omega_{\max}$ is impossible, that is $\mathrm{P}(\omega_{\max} < 0) = 0$. Therefore, taking into account possible loss of coverage of segment $\left[0;\ 2\omega_{cp} - 2t_p s_{mean}\right]$, which is possible only at $2\omega_{cp} - 2t_p s_{cp} \ge 0,$ provided the permissible defect value is at the level of $\omega_{\max} = 2\omega_{mean} + 2t_p s_{mean}$, we can assume that probability $S\left(tp, \kappa\right) \le P\left(\omega < \omega_{max}\right)$, hence, it follows:

$$P(E') = P(E) - P(\Delta E) = P(\omega_{\min} \le \omega \le \omega_{\max}) \times \\ \times P_{\omega_{\min} \le \omega \le \omega_{\max}}(ll \in LL_{ij}^{e}) \le P(E), \tag{9}$$

where ΔE is the event that implies that the defect percentage of MPC of the appropriate type matches the interval $[0;\ \omega_{min}]$, is incompatible with the event E' : $P(\Delta E) = P(\omega < \omega_{min})$; $\omega_{min} = 2\omega_{mean} - 2tps_{mean}$ is the conditional minimum estimated value of parameter ω. According to the obtained inequality, it is possible to use, instead of the probability $P(E)$, the probability $P(E')$, which is not larger than that. Then the acceptable value of $P(E')$ enhances the result of prediction. In this case, possible loss of values on the probability $P(\Delta E)$ is the cost of using microstatistics. Here, in the case when $\omega_{min} < 0$, true is the expression $(\Delta E) = P(\omega_{min} < 0) = 0$, which implies: $P(E')\Delta E = \{\omega_{min} < 0\} = P(E)$. That is, the accuracy of prediction improves; in this case, the appropriate indicators of probability get better. To resolve the second problem related to the uneven accuracy of observations, it is possible to use the weighing method proposed in article [7]. The method implies that each observation is assigned with its weight, which is an integer. The least reliable observations receive the least weight while others are assigned with the weight depending on the accuracy of observations. In this case, weight mjh is regarded as a multiplication of an observation, that is, it is considered that an observation with weight mjh is equivalent to mjh observations with a unit weight, which corresponds to the reduction in the mean error by $\sqrt{m_{jh}}$ times. In this case, the corresponding expressions in formula (9) for ωmean and smean take the following form:

$$\omega_{mean} = \frac{1}{\sum_{h=1}^{\kappa+1} m_{jh}} \sum_{h=1}^{\kappa+1} \left[m_{jh} \left(\omega_{jh} - a \right) \right] + a, \tag{10}$$

$$s_{mean} = \sqrt{\frac{1}{\kappa(\kappa+1)} \left\{ \sum_{h=1}^{\kappa+1} m_{jh} \left(\omega_{jh} - a \right)^2 - \frac{1}{\sum_{h=1}^{\kappa+1} m_{jh}} \left[\sum_{h=1}^{\kappa+1} \left(\omega_{jh} - a \right) \right]^2 \right\}}, \tag{11}$$

where a is an arbitrary number, similar in value to ωmean, determined according to (6). By combining formulas (3), (5)–(11), it is possible to obtain the following expression for finding the probability $P(E')$:

$$P(E') = 4 \left(\frac{\sum_{h=1}^{\kappa+1} m_{jh} \left(\omega_{jh} - a \right)}{\sum_{h=1}^{\kappa+1} m_{jh}} + \sqrt{\frac{1}{\kappa(\kappa+1)} \left\{ \sum_{h=1}^{\kappa+1} m_{jh} \left(\omega_{jh} - a \right)^2 - \frac{1}{\sum_{h=1}^{\kappa+1} m_{jh}} \left[\sum_{h=1}^{\kappa+1} \left(\omega_{jh} - a \right) \right]^2 \right\}} + a \right) \times \\ \times \int_0^{+t_p} \frac{\left(t_p - \kappa \right) \Gamma\left(\frac{\kappa+1}{2} \right) \sqrt{\frac{1}{\kappa(\kappa+1)} \left\{ \sum_{h=1}^{\kappa+1} m_{jh} \left(\omega_{jh} - a \right)^2 - \frac{1}{\sum_{h=1}^{\kappa+1} m_{jh}} \left[\sum_{h=1}^{\kappa+1} \left(\omega_{jh} - a \right) \right]^2 \right\}}}{\kappa \sqrt{\pi \kappa \Gamma\left(\frac{\kappa}{2} \right)}} dt_p. \tag{12}$$

Given that parameters κ, m_{jh}, ω_{jh} and a do not depend on tp, it is possible to displace the appropriate constant part beyond the sign of integral in equation (12). Upon computing integral

$$\int_0^{+t_p} \left(t_p - \kappa\right) dt_p = \int_0^{+t_p} t_p \, dt_p - \kappa \int_0^{+t_p} dt_p = \frac{t_p^2}{2} - \kappa t_p = t_p \left(\frac{t_p}{2} - \kappa\right),$$

accepting in this case

$$\mathrm{a} = \frac{1}{\kappa+1} \sum_{\mathrm{h}=1}^{\kappa+1} m_{jh},$$

expression (12) for determining P(E') is written as follows:

$$\mathrm{P(E')} = \frac{4\kappa^2 t_p \left(\frac{t_p}{2} - \kappa\right) \Gamma\left(\frac{\kappa+1}{2}\right)}{\sqrt{\pi(\kappa+1)\Gamma\left(\frac{\kappa}{2}\right)}} \sqrt{\frac{\left(\sum_{h=1}^{\kappa+1} \mathrm{m_{jh}}\right)^2 \sum_{\mathrm{h}=1}^{\kappa+1} \mathrm{m_{jh}} \left(\omega_{jh} - \frac{\sum_{\mathrm{h}=1}^{\kappa+1} m_{jh}}{\kappa+1}\right)^2 - \left[\sum_{h=1}^{\kappa+1} \left(\omega_{jh} - \frac{\sum_{\mathrm{h}=1}^{\kappa+1} m_{jh}}{\kappa+1}\right)\right]^2}{\sum_{h=1}^{\kappa+1} \mathrm{m_{jh}}}} \times \tag{13}$$

$$\times \left(\frac{\sum_{\mathrm{h}=1}^{\kappa+1} \mathrm{m_{jh}} \left(\omega_{jh} - \frac{\sum_{\mathrm{h}=1}^{\kappa+1} m_{jh}}{\kappa+1}\right)}{\sum_{h=1}^{\kappa+1} \mathrm{m_{jh}}} + \sqrt{\frac{\left(\sum_{h=1}^{\kappa+1} \mathrm{m_{jh}}\right)^2 \sum_{\mathrm{h}=1}^{\kappa+1} \mathrm{m_{jh}} \left(\omega_{jh} - \frac{\sum_{\mathrm{h}=1}^{\kappa+1} m_{jh}}{\kappa+1}\right)^2 - \left[\sum_{h=1}^{\kappa+1} \left(\omega_{jh} - \frac{\sum_{\mathrm{h}=1}^{\kappa+1} m_{jh}}{\kappa+1}\right)\right]^2}{\kappa(\kappa+1)\sum_{h=1}^{\kappa+1} \mathrm{m_{jh}}}} + \frac{\sum_{\mathrm{h}=1}^{\kappa+1} m_{jh}}{\kappa+1} \right).$$

Direct computation of P(E') using the obtained formula is cumbersome and requires determining in advance the Euler integral of the second kind. It is therefore more appropriate to indirectly determine this integral based on tables of values of functions $S\left(tp,\kappa\right)$, given in article [6], which is multiplied by value $P_{\omega_{\min} \le \omega \le \omega_{\max}} (\mathrm{ll} \in LL_{ij}^{\mathrm{e}})$ according to formulas (1), (3). Preliminary, in this case, parameters ωmax, ωmean and smean are found by formulas (8), (10) and (11).

Determining the weight coefficients of mjh can be conducted by any acceptable method, in particular, by the method of expert estimations. In this case, the value of function $S\left(tp,\kappa\right)$, is determined according to Table 1 [6].

Table 1. Tabulated values of function S(tp, κ).

tp	Values of S(tp, κ) at values of κ					
	1	2	3	4	7	11
0.1	0.063	0.071	0.073	0.075	0.078	0.07966
0.2	0.126	0.140	0.146	0.149	0.155	0.15852
0.5	0.295	0.333	0.349	0.356	0.373	0.38292
1.0	0.500	0.577	0.609	0.626	0.661	0.68269
2.0	0.705	0.817	0.861	0.884	0.926	0.95450
3.0	0.795	0.905	0.942	0.960	0.988	0.99730
5.0	0.874	0.962	0.985	0.992	0.999	0.99999

Computed directly by formula (13) or indirectly by formulas (9)–(12), the value of $P\left(E'\right)$ preliminary determines the reliability of test-diagnostic studies (laboratory or performance tests, testing of dependences, etc.) relative to the entire respective set L_i.

By applying formula (13), we determine the value of probability of the absence of defective MPC within the same equivalence class. However, these values are not sufficient in terms of dissemination of the results over other samples that are included in the composition of other classes. In addition, the value of probability may prove to be insufficient from the point of view of the possibilities of operating a system under specific technical conditions.

Solving the problem is to conduct several cycles of studies within the framework of prediction over various MPC of a certain group by the same technique. For this purpose, for each cycle, we select an individual system of representatives, equivalent to the rest.

In order to disseminate research results, it is enough when at least one examined sample of MPC belongs to a class of equivalence (it had no defects). Events that imply simultaneous choosing a few representatives are independent, and the choice of at least one MPC without defects is the combination of the given events. Then, in accordance with the formula of finding the probability of combination of a finite number of independent events, total probability $P\left(E_{com}\right)$ of the correct distribution of results of the observations over the entire batch will reach [7]:

$$\begin{aligned} \mathrm{P}\left(\mathrm{E}_{com}\right) &= P\left(\bigcup_{k=1}^{n} E_k\right) = \sum_{\mathrm{k}=1}^{n} P\left(E_k\right) - \sum_{1\le i<j\le n} P\left(E_i \cap E_j\right) + \\ &+ \sum_{1\le i<j<k\le n} P\left(E_i \cap E_j \cap E_k\right) - \ldots + \left(-1\right)^{n+1} P\left(E_1 \cap E_2 \cap E_3 \cap \ldots \cap E_n\right), \end{aligned} \quad (14)$$

where n is the number of testing cycles and the corresponding systems of MPC representatives; $\mathrm{E1}, \mathrm{E2} ..., \mathrm{E}_n$ are the events that imply selecting a system of representatives without defects.

According to the properties of independent events and previous considerations on the random selection of MPC, events $\mathrm{E1}, \mathrm{E2} ..., \mathrm{E}_n$ are equiprobable [7]:

$$\mathrm{P}\left(\mathrm{E1}\right) = \mathrm{P}\left(\mathrm{E2}\right) = \mathrm{P}\left(\mathrm{E3}\right) = \ldots = \mathrm{P}\left(\mathrm{E}_n\right) = \mathrm{P}\left(\mathrm{E}\right), \quad (15)$$

hence, the following form of formula (14) for this case:

$$\begin{aligned} \mathrm{P}\left(\mathrm{E}_{com}\right) &= C_n^1 P^1\left(E\right) - C_n^2 P^2\left(E\right) + \\ &+ C_n^3 P^3\left(E\right) - \ldots + \left(-1\right)^{\mathrm{n}+1} C_n^n P^n = \sum_{\mathrm{k}=1}^{n} \left(-1\right)^{\mathrm{k}+1} C_n^k P^k\left(E\right). \end{aligned} \quad (16)$$

When deriving the formula (16), we considered the rule of finding a probability of the intersection of independent events:

$$P\left(\bigcap_{k=1}^{n} E_k\right) = \prod_{k=1}^{n} P\left(E_k\right),.$$

In addition to probabilities $P_j\left(\mathrm{E}_{com}\right) = \mathrm{P}\left(\mathrm{E}_{jcom}\right)$, for separate types of MPC, very important is also the probability $P\left(D_{com}\right)$, which implies the absence of defects in the entire chosen system of representatives. Events that imply the selection of representatives from different groups are independent, which is why

$$D_{com} = \bigcap_{j=1}^{m} E_{com}^j,$$

hence, it follows

$$P\left(D_{com}\right)=\prod_{j=1}^{m}P_j\left(E_{com}\right),$$

where m is the number of groups of MPC.

Thus, by generalizing the data obtained for a control system to all similar systems, we can assume that the probability $P\left(D_{com}\right),$) in a general case depends on each value of $P_j\left(E_{com}\right)$, the number of groups m and the number of testing-diagnostic cycles n and, according to formula (16), it is determined as [7]:

$$\begin{aligned}\mathrm{P}\left(\mathrm{D}_{com}\right)&=\prod_{j=1}^{m}\sum_{\mathrm{k}=1}^{n}\left(-1\right)^{\mathrm{k}+1}C_n^kP_j^k\left(E\right)=\\&=\sum_{\mathrm{k}=1}^{n}\left[\left(-1\right)^{\mathrm{k}+1}C_n^k\prod_{j=1}^{m}P_j^k\left(E\right)\right]=\sum_{\mathrm{k}=1}^{n}\left[\left(-1\right)^{\mathrm{k}+1}C_n^kP^k\left(D\right)\right],\end{aligned} \tag{17}$$

where D, is the absence of any defective MPC per one cycle.

When comparing the last expressions in formulas (16) and (17), one observes their isomorphism relative to the operations over variables $P\left(X\right)$, where $X=E\vee D$. Note the equality that follows from equality (15):

$$P\left(D\right)=P\left(D_1\right)=P\left(D_2\right)=P\left(D_3\right)=\ldots=P\left(D_n\right)=\sum_{k=1}^{n}\prod_{j=1}^{m}P_j\left(E\right),$$

where D_1, D_2, …, D_n are the events that imply choosing appropriate systems of representatives for different appropriate testing cycles; $Pj\left(E\right)$ is the probability of choosing a defect-free MPC from the j-th group.

4. Conclusion

We defined a criteria, which is used to predict a technical condition of microprocessor devices in railway automation. We established as such a criterion determining the probability of manifestation of production defect or other failure of a microprocessor controller or a group of controllers that are operated as part of a particular control system. From a formalized point of view, the specified criteria is interpreted as a violation of equivalence relation by the faulty device to other identical devices of the corresponding class. The indicated principle allowed us to reduce the prediction procedure to a probabilistic assessment of the violation of integrity of the equivalence class of a particular type of controllers. This is achieved using a structural-functional attribute.

We substantiated the apparatus of mathematical statistics to process results under conditions of limited data. By applying a Lyapunov theorem, we justified expediency of employing the methods of unevenly accurate observations, maximal likelihood and the Student spread. The latter allows us to process microstatistical data when performing a probabilistic evaluation of the manifestation of a defect in controllers.

Mathematical models are constructed that implement the developed method of prediction in two variations. The first of these is based on the direct use of microstatistics. The second is based on its combination with additional experimental studies conducted in the course of implementation of forecasting.

Based on the developed models, we established common regularities in the application of the devised method. The patterns hold both for the controllers of a separate class and for the systems of representatives of all equivalence classes of the entire set of micro-electronic equipment. The patterns were represented both analytically and graphically. These dependences make it possible to unify the approaches to single or multiple predictions when using the proposed method of forecasting.

Thus, we developed and proposed the method to predict technical condition of microelectronic equipment of railway automation that can be applied under conditions of limited statistical data on its operation at the infrastructure sites.

It should be noted that the developed method has some drawbacks and limitations. The drawbacks are associated primarily with the forced understatement of original operational reliability indicators of the examined equipment. Therefore, a subsequent complex of studies is required aimed at improving processing of microstatistic data. Based on this, promising are the appropriate modifications of the method for different microelectronic systems of railway automation

References

[1] Panchenko, S., I. Siroklyn, A. Lapko, A. Kameniev, and S. Zmii. (2016). "Improvement of the accuracy of determining movement parameters of cuts on classification humps by methods of video analysis" *Eastern-European Journal of Enterprise Technologies* **82 (4/3)**:25–30.

[2] Listrovoy, S., V. Butenko, V. Bryksin, and O. Golovko. (2017) "Development of method of definition maximum clique in a non-oriented graph" *EasternEuropean Journal of Enterprise Technologies* **89 (5/9)**:12 – 17.

[3] Lomotko, D., E. Alyoshinsky, and G. Zambrybor. (2016). "Methodological Aspect of the Logistics Technologies Formation in Reforming Processes on the Railways" *Transportation Research Procedia* **(14):**27262–2766.

[4] Tang, L. (2015). Reliability assessments of railway signaling systems: A comparison and evaluation of approaches. Trondheim : Norwegian University of Science and Technology: 41 – 43.

[5] Watanabe, Y., and Y. Matsumoto. (2014) "Online Failure Prediction in Cloud Datacenters" *Fujitsu scientific & technical journal* **50 (1)**:67 – 71.

[6] Moiseenko, V., O. Kameniev, and V. Gaievskyi. (2017) "Predicting a technical condition of railway automation hardware under conditions of limited statistical data" *EasternEuropean Journal of Enterprise Technologies* **88 (3/9)**:26 – 35.

[7] Bojnik, A., O. Kameniev, A. Lapko et al. (2018) "Development and investigation of methods of graphic-functional modeling of distribute systems" *EasternEuropean Journal of Enterprise Technologies* **94 (4/4)**: 59 – 69.

Valentin Moiseenko is Professor, Doctor of Technical Sciences. Academician of the Transport Academy of Ukraine. Head of the department of specialized computer systems of the Ukrainian State University of Railway Transport. Author of more than 150 scientific publications, monographs, inventions. A recognized scientist in the field of ensuring the safety of the integrated automation systems in transport. Contact information: Kharkov, Ukraine, sq. Feuerbach, 7, tel. +380577301062. Contact him at mojseenko@kart.edu.ua.

Oleksandr Kameniev is Associate Professor, PhD. Associate Professor at the Department of Automation and Computer Remote Control of Train Traffic, Deputy Chairman of the Council of Young Scientists of the Ukrainian State University of Railway Transport. Author of more than 80 scientific publications, including monographs and patents. In the field of scientific interests he specializes in the synthesis of safe train control systems and the simulation of distributed technological objects of automated control. Contact information: Kharkov, Ukraine, sq. Feuerbach, 7, tel. +380577301032. Contact him at alexstein@meta.ua.

Volodymyr Butenko is Associate Professor, PhD, Senior Researcher. Associate Professor at the Department of Specialized Computer Systems of the Ukrainian State University of Railway Transport. Author of more than 100 scientific publications, inventions and utility models. In the scientific field specializes in the automation of programming processes and the configuration of automated control systems software. Contact information: Kharkiv, sq. Feuerbach, 7, tel. +380577301062. Contact him at butenko@kart.edu.ua.