Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 149 (2019) 246–251

Procedia Computer Science

www.elsevier.com/locate/procedia

ICTE in Transportation and Logistics 2018 (ICTE 2018)

The criteria choice of evaluating the effectiveness of the process and automatic control systems

Oleksiy Fomin[a], Alexander Akimova[b], Julia Akimova[b], Anton Mastepan[b,*]

[a]*State University of Transport Economy and Technologies, Kyrylivska str. 9, Kyiv, 04071, Ukraine*
[b]*Ukrainian State University of Railway Transport, Feuerbach Square 7, Kharkiv, 61050, Ukraine*

Abstract

Problem statement in general. Modern automatic control systems (ACS) of energy objects are characterized not only by a large number of elements, but also by the complexity of the internal structure. Even with absolute reliability of all elements of the ACS in the course of its work, it is impossible to speak of the performance of the entire system of the task assigned to it as a reliable event. A complex ACS due to its specific technical imperfections and the peculiarities of the tasks solved by the managed object may not fully perform the functions assigned to it. Thus, management and control systems created on the basis of relay-contact elements, due to failures in the operation of the relay, can give inaccurate control results and incorrectly working off the control operations of an object.

Thus, the question arises of quantifying the quality of such complex systems. Since performance indicators are usually introduced for such an assessment, the question posed is transformed into an assessment of the effectiveness of ACS.

Peer review under responsibility of the scientific committee of the ICTE in Transportation and Logistics 2018 (ICTE2018).

Keywords: Automatic control systems; Quality of control system; Railway transport

* Corresponding author. Tel.: +38-066-417-52-14.
E-mail address: antonua86@gmail

1877-0509
Peer review under responsibility of the scientific committee of the ICTE in Transportation and Logistics 2018 (ICTE2018).
10.1016/j.procs.2019.01.130

1. Introduction

The choice of the criterion for evaluating the effectiveness of the process and automatic control system is the subject of a large number of works.

The following is their critical review to determine the possibility of their use. In [1], the criterion is formed by multiplying the indicator of the accuracy of the system by the rate of its work. The last indicator is the value obtained by comparing the amount of information and bandwidth of the communication channel, which is not decisive for the considered ACS.

In [2], an expression similar to the signal volume is taken as a criterion (where P_c – is the signal power, ΔF – is the frequency band,T – the duration of the code combination.):

$$K = P_c \Delta F T \tag{1}$$

In [3], the quality of systems is estimated by the magnitude of the probability of erroneous reception of a message with fixed values of other parameters. Moreover, the system quality criterion is the product $P_э$T, where $P_э$ – is the equivalent probability of an erroneous reception of a signal element, and T – is the average duration of a signal element.

In [4], the quality of work is estimated by the amount of information transmitted. Common to these works is an approach that takes into account a small number of parameters. In addition, the use of information characteristics as parameters of a system is not sufficiently substantiated. And, finally, it is theoretically not justified to construct a criterion based on the multiplication of the values of the system parameters.

Consider a number of more complex criteria. In [5], a criterion E was proposed for comparing the quality of complex systems:

$$E = \log_2 \frac{P/P_П}{(T_П/T) + \mu(C_П/C)} \tag{2}$$

where P and T – are respectively the probability of erroneous reception of the message element and the average duration of the code combination before applying the method of increasing the reliability; $P_п$ and $T_п$– the same values after applying the method of increasing the reliability; $C_п$ and C– the number of elements, respectively, with the device increasing the reliability and without such a device; μ – is a weighting factor. The advantage of this criterion in an attempt to take into account the factor of complexity of the equipment, the disadvantage - is in the arbitrary formation of the expression (2).

A quality criterion is proposed in [6] (where $f(A,Q)$ – the quantity of production of the established quality, A – the number of production, Q – production quality, Э – total economic costs).

$$W = \frac{f(A, Q)}{Э}, \tag{3}$$

It should be noted that the use of expression (3) as a criterion is not theoretically justified, since it is built from arbitrarily constructed indicators. General disadvantages of the criteria considered:

- They are formed largely on the basis of intuitive representations, which is rather subjective
- It is assumed that when designing criteria it is possible to choose weights that take into account the values of various system parameters. However, there is currently no rigorous mathematical theory supporting this assumption

That is, it is not possible to conduct a high-quality expert assessment with reliable results. Thus, there is no solution for assigned task in the literature. Announced questions can only be used as approaches to assess the effectiveness of ACS.

The purpose of the article is to select and justify ACS performance indicators. The following ACS performance indicators are proposed: the probability of fulfillment the assigned task by managed object, information ability and information volume, information ability of the ACS algorithm, cost and weight/size characteristics of the automatic control system.

2. The probability of fulfillment the assigned task by managed object

The process of monitoring the state of the object and managing it is intended to ensure the readiness of the object with a given probability at any time to complete the assigned task. From the point of view of the reliability of a managed object, a suitable criterion for the efficiency of its operation may be the probability $P(t,\tau)$ to find an object at any time t in working condition, which will work without fail for a time τ:

$$P(t,\tau) = K_{\Gamma}(t)P(\tau), \tag{4}$$

where $K_{\Gamma}(t)$ – the readiness factor of an object, defined as the probability to find an object in working condition at any time t.

In the case of the simplest flows of failures and restoration of a non-reserved managed object, when the exponential law is valid, the readiness of the object to fulfillment assigned task at any time moment t is described by a differential equation:

$$\frac{dP_{\Gamma}(t)}{dt} = -\lambda P_{\Gamma}(t) + \mu(1 - P_{\Gamma}(t)), \tag{5}$$

where λ and μ – according to the intensity of failures and recovery, $P_{\Gamma}(t)$ – probability to find an object in working condition at any time t.

Equation (5) considering that, $P_{\Gamma}(0) = 1$, has the solution:

$$P_{\Gamma}(t) = K_{\Gamma}(t) = \frac{\mu}{\lambda+\mu}\left(1 + \frac{\lambda}{\mu}e^{-(\lambda+\mu)t}\right). \tag{6}$$

According to (4) and (6)

$$P(t,\tau) = \frac{\mu}{\lambda+\mu}\left(1 + \frac{\lambda}{\mu}e^{-(\lambda+\mu)t}\right)e^{-\lambda\tau}, \tag{7}$$

where $P(\tau) = e^{-\lambda\tau}$ – the probability of no-failure operation of the object in the time interval τ.

With the process established, i.e. with $t \to \infty$, $K_{\Gamma}(t)$ tends to its asymptotic value $K_{\Gamma} = \frac{\mu}{\lambda+\mu}$, independent of time. Then:

$$P(t,\tau) = \frac{\mu}{\lambda+\mu}e^{-\lambda\tau},\ t \to \infty \tag{8}$$

If consider that with the exponential law of reliability $\frac{1}{\lambda} = \overline{T}_0$ and $\frac{1}{\mu} = \overline{T}_B$, where $\overline{T}_0$ and $\overline{T}_B$ – respectively, the average uptime and average recovery time, can write:

$$P(t,\tau) = \frac{\overline{T}_0}{\overline{T}_0 + \overline{T}_B}e^{-\frac{\tau}{\overline{T}_0}}. \tag{9}$$

The information capacity of ACS - is the number N of different values of the information parameter. The maximum amount of information H_{max}, contained in the message, proportional to its length, i.e.:

$$H_{max} = \log_2 N \tag{10}$$

Consequently,

$$N = 2^m,\ 0 < m \le H_{max},$$

where m – length of the signal sequence.

The information capacity depends on the law of distribution of the information parameter, the laws of the distribution of errors, and on the working information range of the transfer characteristic.

The working information range of the transfer characteristic is the multiplicity of changes of the values of the input signal, at which the amount of information for one value of the output signal is not zero.

The transfer characteristic (input-output characteristic of the element or system) is the relationship $x_{вых} = f(x_{вх})$ between the output and input signals in a steady state.

Amount of information is a generalized information characteristic of ACS. The actual amount of information contained in the process is equal to the entropy of the object and control system:

$$V_{пр}(t, \tau) = H_0(t, \tau) \tag{11}$$

The entropy of the state of the object subsystem can be determined by the formula:

$$H_{0i}(t, \tau) = -[P_{0i}(t, \tau)\log_2 P_{0i}(t, \tau) + (1 - P_{0i}(t, \tau))\log_2(1 - P_{0i}(t, \tau))], \tag{12}$$

where $P_{0i}(t, \tau)$ – the probability of the task execution by the *i*-th subsystem of the object.

If the object contains *m* subsystems, then:

$$H_0(t, \tau)_{max} = \sum_{i=1}^{m} H_{0i}(t, \tau) = m \tag{13}$$

Naturally, the ACS is the better, if more information about the state of the object it can transmit.

3. Information ability of the ACS operation algorithm

The ACS operation algorithm is a system of algorithms of functionally - related devices of this system. The amount of information issued during the system control process is equal to:

$$I_{ПК}(t, \tau) = H_0(t, \tau)_{max} - \Delta H_{алг}(t, \tau), \tag{14}$$

where $\Delta H_{алг}(t, \tau)$ – entropy due to imperfection of the algorithm.

The ACS operation algorithms are implemented by automation devices, so the accuracy of the system is determined by the accuracy of the algorithm system and the accuracy of the automation devices.

In doing so, there is always some loss of information. Its total losses are associated with two types of errors in the work of ACS. These are undetectable failures and false failures.

The probability of the existence of at least one undetectable failure in a series of measurements of m parameters can be determined by the formula:

$$P_{НО}(t, \tau) = 1 - \prod_{i=1}^{m}(1 - P_{НОi}(t, \tau)) \tag{15}$$

The probability of the existence of at least one false failure in a series of measurements of *m* parameters is determined by the formula:

$$P_{ЛО}(t,\tau)=1-\prod_{i=1}^{m}\left(1-P_{ЛОi}(t,\tau)\right) \tag{16}$$

Probabilities $P_{НОi}(t,\tau)$ and $P_{ЛОi}(t,\tau)$ are determined depending on the laws of distribution of monitored parameters and errors of automation devices.

Knowing probabilities $P_{НОi}(t,\tau)$ and $P_{ЛОi}(t,\tau)$ according to the formula of total probability, it is possible to determine the probability of a task being performed by a managed object, taking into account errors in the operation of automation devices:

$$P(t,\tau)=\frac{P_0(t,\tau)\cdot\left(1-P_{ЛО}(t,\tau)\right)}{P_0(t,\tau)\left(1-P_{ЛО}(t,\tau)\right)+P_{НО}(t,\tau)\left(1-P_0(t,\tau)\right)}, \tag{17}$$

where $P_0(t,\tau)$ – the probability of the working condition of the managed object.

4. Cost and weight/size characteristics of ACS

When assessing the effectiveness of the monitoring and control process, take into account the costs of its implementation, and when evaluating it for moving or compactly placed objects - weight/size indicators of automation devices are taken into account.

The average cost of ACS is determined by the total cost of development and operation:

$$C(t,\tau)=C_P(t,\tau)+C_Э(t,\tau), \tag{18}$$

where $C_P(t,\tau)$ – cost of development and manufacture of ACS, $C_Э(t,\tau)$ – cost of operating the ACS.

The average cost of developing and manufacturing of ACS is determined according to the dependency:

$$C_P(t,\tau)=b_P C_{OP}(t,\tau)\left(\frac{1-P_0(t,\tau)}{1-P(t,\tau)}\right)^{\alpha_{CP}}, \tag{19}$$

The average cost of operating ACS is determined by the formula:

$$C_Э(t,\tau)=b_Э C_{OЭ}(t,\tau)\left(1-P(t,\tau)\right)^{\alpha_{CЭ}}, \tag{20}$$

where $b_Э$ – coefficient determined during operation, $C_{OЭ}(t,\tau)$ – cost of operation of the simplest ACS, the probability of failure-free operation of which is lower than the required value $P(t,\tau)$, $\alpha_{CЭ}$ – a constant indicator determined during the ACS operation.

The analysis of dependencies (19) and (20) shows that the cost of development and manufacturing increases with an increase in the probability of ACS failure-free operation, and the cost of operating a more reliable system decreases.

To estimate the weight of the ACS, use a ratio:

$$G(t,\tau)=G_{САУ}(t,\tau)+G_Э(t,\tau). \tag{21}$$

Here $G_{\text{САУ}}(t,\tau)$ – the weight of the ACS automation devices and $G_{\text{Э}}(t,\tau)$ – the weight of the equipment providing operation of the ACS are described by the formulas:

$$G_{\text{САУ}}(t,\tau) = g_{\text{САУ}} G_{\text{O САУ}}(t,\tau)\left(\frac{1-P_0(t,\tau)}{1-P(t,\tau)}\right)^{\alpha_{G\text{САУ}}}, \quad (22)$$

$$G_{\text{Э}}(t,\tau) = g_{\text{Э}} G_{\text{OЭ}}(t,\tau)\left(1-P(t,\tau)\right)^{\alpha_{G\text{Э}}}. \quad (23)$$

A similar relationship holds for the volume of ACS devices.

The coefficients g and the exponents α in (22), (23) are established during the manufacture and operation of the ACS and in the simplest cases take values between 0 and 1.

The total cost of the control and management process takes into account the cost of achieving the effects of response, weight, volume and other characteristics of ACS:

$$C_{\Sigma}(t,\tau) = C(t,\tau) + \Delta C_t + \Delta C_G + \Delta C_V + \ldots, \quad (24)$$

5. Conclusion

Thus, four indicators of ACS effectiveness were selected and justified: the probability of fulfillment the assigned task by managed object, information ability and information volume, information ability of the ACS work algorithm, cost and weight/size characteristics of the ACS.

Promising are the creation of a generalized criterion for the effectiveness of the process and automatic control system.

References

[1] Lyubarskiy B. G., Shayda V. P., Buryakovskiy S. G. (2015), Comparative analysis of the energy storage devices for vehicles]. Zaliznychnyi transport Ukrainy – Railway transport of Ukraine, issue 6, p. 13-21.

[2] Ciccarelli F., Iannuzzi D., Lauria D. Stationary ultracapacitors storage device for improving energy saving and voltage profile of light transportation networks. Transportation Research Part C: Emerging Technologies, 2012, issue 21 (1), p. 321–337

[3] Myamlin S. Dailydka, L. Neduzha (2012) "Mathematical modeling of a cargo locomotive" *Proceedings of the 16th International Conference "Transport Means"*. – Kaunas, – p. 310–312.

[4] Iannuzzi D., Pagano E., Tricoli P. (2013), The use of energy storage systems for supporting the voltage needs of urban and suburban railway contact lines. Energies, issue 6 (4), pp. 1802–1820.

[5] Tartakovskyi E., Gorobchenko, O., Antonovych, A. (2016), Improving the process of driving a locomotive through the use of decision support systems. Eastern-European Journal of Enterprise Technologies, 5 (3 (83)), 4–11. doi: 10.15587/1729-4061.2016.80198

Fomin Oleksiy is Doctor of Technical Sciences, Associate Professor, Department of railcars and carriage facilities, The State University of Transport Economy and Technologies. Contact information: Kyrylivska str., 9, Kyiv city, Ukraine, 04071 tel.: +38 (067) 813 97 88. Contact him at fomin1985@ukr.net.