CONTROL METHOD FOR TRANSPORT SYSTEM OPERATIONAL QUALITY

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Abstract

This paper deals with selected problems connected with transport means operation quality. Basic concepts concerning the problems of quality have been defined, and general characteristics of the elaborated methodology have been made. Description of rules on the basis of which the method was elaborated, has been presented. An algorithm of mathematical model determination has been created and a model for quality assessment of the system operation has been built. This model is supposed to serve as a general abstract form for operation quality assessment of a wide class of real transport systems different in terms of their features, structure and operation. The further part of the paper deals with possibilities of quality control in order to provide the desired level of the transport system operation quality which will be an effect of the carried out research, especially, the results, obtained on the basis of the proposed assessment method. The presented methodology can be found to be a universal tool for diagnostic, prognostic processes, and above all, for optimization and rational control of complex systems of technical object using, especially transport ones through assessment of their states, determined on the basis of changes of significant features characteristic for the system.

Keywords: *operation quality, model, transport system, metrics*

1. Introduction

All the considerations are related with research on operation quality of complex transport systems. The analyzed objects belong to the group of real systems with an intended set of applications. These are socio-technical objects of the type <H-M-E> (human-machine –environment), where their operation quality depends on quality changes of characteristic features describing actions of operators, operation of technical objects controlled by them and the impact of the environment.

The considered issues concern interdisciplinary areas and the analyzed problems can be placed in the field of science known as ontology which is a theory of reality but its point is to cover all different walks of life and the relations occurring between them [8]. Complexity of the presented issues results from the complicated character of the operation quality: actions of operators, functioning of transport means and the environmental impact. This, in turn, involves the necessity to refer to different fields of science, such as: psychology, metrology, and widely understood mechanical sciences.

In pursuit of the goal of the paper, there has been made an analysis of a several definitions of the concept of quality and the most adequate is considered to be this one: the system operation quality is a set of features expressed by means of numerical values, in a given moment t, determining the degree to which the set requirements have been met [15].

In connection with the above, the basis for the research is to determine assessment criteria meeting the set requirements and to identify and choose the features on the basis of which the operation quality assessment will be performed.

Feature is a characteristic or an attribute of the analysis subject. We call a property such a feature which is common for all the subjects which is expressed as a physical quantity, whereas a quality we call such a feature which lets us distinguish some objects which do not have these features.

It should be noted that the features determined for assessment of the transport system operation quality should bear signs of: independence, essentiality, variability, and measurability. Independence of the features is necessary, those ones which provide the same information on the research object, have to be eliminated. In the resultant model there should be distinguished features that are of biggest significance from the point of view of the carried out examinations. Whereas, features of little significance due to their slight influence on the research results, should be neglected. Their variability conditions purposefulness of acceptance of a given feature as a feature whose values do not undergo changes in a considered period of time, does not provide any information on the system state and causes that the considered set is outsized. Measurability of the features, according to the accepted definition of quality, is the basis for the quality assessment, and it must be remembered that the set of features accepted for the examined transport system operation quality description consists of two subsets: measurable features (eg. costs) and immeasurable ones eg.(aesthetics) [11, 12].

Immeasurable features are such that, due to their nature, can not measured. The impossibility of measuring them results from their technical characteristics, or the researcher's inability or ignorance. For each measurable feature describing the examined system X_{Mi} (i = 1, 2, ..., n) there must be given permissible boundaries of their variability $X_{M,i}^{\min}$, $X_{M,i}^{\max}$, corresponding to the criteria of the system proper operation quality.

Similarly, for each conventionally immeasurable feature X_{Nj} (j=1,2,...,m), there must be established criteria so that it will be possible to state unequivocally if a given feature meets them. For this purpose, different values from 0 to m are assigned to immeasurable features. Then, the condition of the system proper operation quality, in a given time, t, $t \in [t_0, t_k]$, is demonstrated by the below notation (1):

$$J_S = \begin{cases} X_{M,1}^{min} < X_{M,1,t} < X_{M,1}^{max} \ldots X_{M,n}^{min} < X_{M,n,t} < X_{M,n,}^{max} \\ X_{N,1}^{min} < X_{N,1,t} < X_{N,1}^{max} \ldots X_{N,m}^{min} < X_{N,m,t} < X_{N,m.}^{max} \end{cases} \tag{1}$$

This notation means that in a given time t, the systems meets the requirements of proper operation quality, only when values of its measurable features are contained within established boundaries and their immeasurable features meet the established quality criteria. It must also be remembered that in the set of features, distinguished for a given transport system operation quality assessment, there can be features evaluated in a constant way (e.g. pollution emission) and a discreet way (eg. the vehicle equipment). The desired assessments of some features are such whose values are the highest (eg. degree of transport task accomplishment) but in the considered set there can also occur such features for which the most favourable values are the lowest ones (eg .noise emission) [14].

For the purposes of this work, there has been accepted that "criterion" is one of the basic conditions imposed on the feature value. The basic criteria of the transport system operation quality assessment include: safety, reliability, availability, ergonomics, efficiency, modernity and eco-friendliness.

While taking up the research and constructing a resultant model, it should be remembered that the kind and multiplicity of the distinguished features set is closely conditioned by the set criteria and complexity, destination and specificity of a given system operation.

2. Systems operation quality

This point includes description of the rules, on the basis of which a method to evaluate the quality of the transport system operation has been formulated. A general evaluation scheme is shown in Fig. 1.

As it can be seen in Fig. 1, an external observer - EO determines the criteria set to evaluate quality of the system operation K. Afterwards, he identifies the investigated object, and on this basis, he sets the set of features - X describing the system from the point of view of its operation quality.

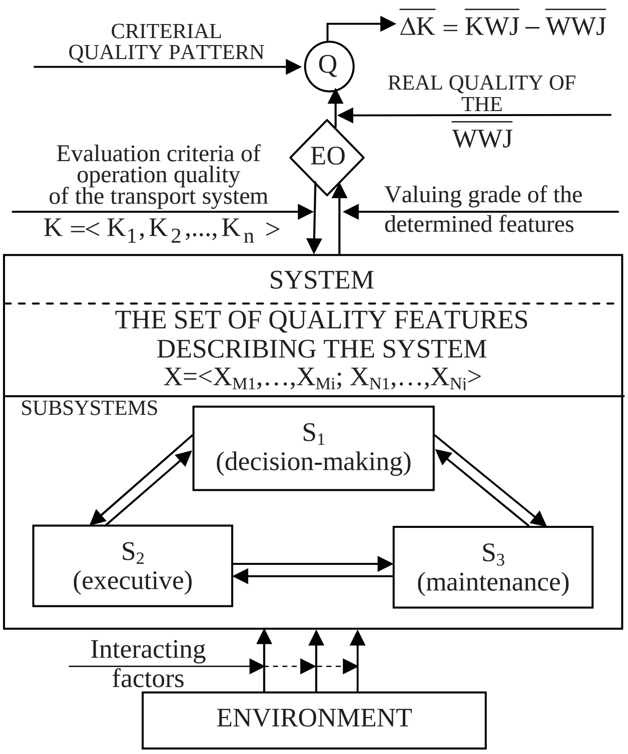

Fig. 1. Scheme of evaluating operation quality of the transport systems [7]

After having completed identification of the system, selection of the set of the attributes describing the system from the given point of view (meta-criterion) and estimation of the set of the important criteria and sub-criteria, the external observer can start assessment of the quality of the system operation.

The estimation process is to use each criterion from the K_n set to the distinguished features from X_i – based on the values measured at t time (measurable attributes), or based on the states at time t (non-measurable attributes) by assigning to them appropriate distinguishing features.

The measure of quality of the system operation at time t is a group of values of important features used for description $\{X_i\}$, i=1,2,…,p.

It should be taken into consideration that for every criterion from K_n set, additional criterion sub-sets k_i, i=1,2,…,m could be selected . These sub-sets are the conditions imposed on the attribute values describing the system element e_i, i=1,2,…,n from set E. The reason for determining these sets is to make the estimation easier and to allow precise determination of the influence of the system elements on the quality of the system operation.

Using the built resultant model, the values of separate attributes describing the system and their importance can be estimated, then the quality of the system can be evaluated [16].

3. The model to evaluate operation quality of the transport systems

Let $X_i(t)$, i=1,2,…,p, stand for a feature being a random variable which depends on the time, realisation of which at the given moment t describes the quality of the system operation. The following vector of the quality features is being considered:

$$X(t) = \langle X_1(t), X_2(t), ..., X_p(t) \rangle. \tag{2}$$

The component $X_i(t)$, i=1,2,…,p, of the vector X(t), is one-dimensional random process in the space R, describing ith feature of the quality of the operation system. While the vector X(t) is a p - dimensional random process describing comprehensively the quality of the system operation within the space R^p, at the given moment t.

In order to set valuation of the operation quality of the system under investigation, it is needed to determine such a set of significant features of the quality $Z = X_i$, i = 1,2,…,p, which is divided into n – separable subsets $Z_1, Z_2, \ldots, Z_n$, meeting the following dependences:

$$Z_i \cap Z_j = \emptyset \text{ for } i \neq j;$$

$$Z(t) = Z_1(t) \cup Z_2(t) \cup \ldots \cup Z_n(t). \tag{3}$$

Each of the nth subsets Z_i, where i=1,2,…,n, is a set of features describing the operation quality of the individual elements of the system. The number of the elements of the system and the features describing it depends on its kind, complexity and characteristics.

Based on our own investigations [5] a general model to evaluate operation quality of the complex transport systems has been built:

$$\begin{aligned}
&Z_1(t) = \{X_1(t), \ldots, X_{k_1}(t)\},\\
&Z_2(t) = \{X_{k_1+1}(t), \ldots, X_{k_2}(t)\},\\
&Z_3(t) = \{X_{k_2+1}(t), \ldots, X_{k_3}(t)\},\\
&\ldots\\
&Z_n(t) = \{X_{k_n-r}(t), \ldots, X_{k_n-1}(t), X_{k_n}(t)\},
\end{aligned} \tag{4}$$

where:
$k_n = p$; $n \leq p$; $k, n, r, p \in N$,
Z_i - feature subsets describing operation of the individual elements of the system, $Z_i = e_i$, i = 1,2,…,n,
$E = \{e_i\}$ – elements of the system,
X_i - set of the features describing comprehensively the quality of the system operation, i=1,2,…,p,
$i=\{1<\ldots<k_1<k_1+1<\ldots<k_2<k_2+1<\ldots<k_n-r<\ldots<<k_n-1<k_n=p\}$.

Having in mind, that the paper deals with evaluating the operation quality of the transport systems of <H-M-E> type, the elements of which are: human (operator) – e_1, machine (technical object) – e_2, environment– e_3, subsequently the resultant model to evaluate its operation quality takes the form which is described with the following dependence [12]:

$$\begin{aligned}
&Z_1(t) = \{X_1(t), \ldots, X_{k_1}(t)\},\\
&Z_2(t) = \{X_{k_1+1}(t), \ldots, X_{k_2}(t)\},\\
&Z_3(t) = \{X_{k_2+1}(t), \ldots, X_{k_3}(t)\},
\end{aligned} \tag{5}$$

where $k_3 = p$.

In these considerations it has been assumed that evaluation of the operation quality of the transport system is a reflection of:

$$Y : T \times \Omega \rightarrow R, \tag{6}$$

what means that $Y(t,\omega)$, $t \in T, \omega \in \Omega$ is a measure of the quality of the system operation at the moment t, which depends on an elementary event ω, where:
Y - measure of evaluating the quality of the system operation, being the function of the random variable vector X(t), (representing the length of the vector $\overline{\Delta K}$),
T = <0, +∞) – set of the time moments,
Ω - set of the elementary events,
R - set of the real numbers,
Ω - elementary event.

In the considerations regarding the operation quality of the system it has been assumed that each of the coordinate of the vector X(t) is smaller or equal to a certain limiting value of the pattern for the individual quality features.

$$X_i(t) \le q_i \tag{7}$$

for $t \in T$, i=1,2,…,p.

For the investigated system a random process is defined, representing the operation quality of the system, and is formulated as:

$$Z_x(t) = \sum_{i=1}^{p} \alpha_i X_i(t), \tag{8}$$

$$\alpha_i \ge 0, \sum_{i=1}^{p} \alpha_i = 1,$$

where:

α_i, i=1,2,…,p stand for the values of the quality weights for the individual features, determining the operation quality of the investigated system [17].

$Z_X(t)$ - is a random process, being a finite mixture of the processes $X_i(t)$, i=1,2,…,p, $t \in T$. For the process $Z_X(t)$ the below inequality is obvious:

$$Z_x(t) \le \sum_{i=1}^{p} \alpha_i q_i . \tag{9}$$

The above mentioned inequality indicates that the process $Z_X(t)$ determined by means of the equation (8) is limited, thus the feature values determining the operation quality of the system shall not go beyond the preset threshold, that means the right side of the inequality (9).

For the average value it can be noted that:

$$EZ_x(t) = \sum_{i=1}^{p} \alpha_i EX_i(t). \tag{10}$$

The average value $EZ_X(t)$ is a linear combination of the average values $EX_i(t)$, i=1,2,…,n. The formula (10) is applicable irrespectively of the fact whether the processes $X_i(t)$, i=1,2,…,n are dependent.

For the process variation (11) there is:

$$D^2 Z_x(t) = \sum_{i=1}^{p} \alpha_i^2 D^2 X_i(t) + +2\sum_{i>j} \alpha_i \alpha_j \operatorname{cov}(X_i(t), X_j(t)), \tag{11}$$

where: cov ($X_i(t)$, $X_j(t)$) means covariation between the random variables $X_i(t)$ and $X_j(t)$. In case when the random processes $X_i(t)$, i=1,2,…,p are independent, all the covariations cov($X_i(t)$, $X_j(t)$) are equal to zero. In this case the process variation $Z_X(t)$ is a sum of the variations.

In the real cases the processes $X_i(t)$, i=1,2,…,p are dependent and it is to be expected, that the covariations cov($X_i(t)$, $X_j(t)$) will be positive. This fact may be expressed in such a way that the processes $X_i(t)$ are positively correlated by pairs. That means that the coefficient of the correlation between the random variables $X_i(t)$ and $X_j(t)$, i,j=1,2,…n, is positive [18, 19].

It is assumed that using dependence (8) it is possible to make assessment of the same system operation quality in different times, two different systems in the same time, and different systems in different times, with the assumption that the qualifying assessment is made on the basis of homogenous criteria, using a set of the same features, distinguished for description of the object examinations.

4. Quality control of transport systems

The methodology described in this paper makes it possible to make an assessment of operation quality for complex operation systems, including the considered transport ones. This assessment can be expressed by an outsized quality vector whose particular components are values of features determined for time t. This vector is called Outsized Quality Vector (OQV). In such a case the point of reference for assessment (placement of OQV vector end), can be comparison of the examined system quality state with previous or successive assessment times or comparing it with the so called Criterion Quality Vector CQV, which is determined on the basis of maximum or desirable values of the same features.

It has been assumed that the system operation quality assessment can be made in many ways, using different metrics. In this work, it has been accepted that the assessment will be expressed by a random process defined by dependence (8). It should be emphasized that in real cases each of the features, in the distinguished p-element set, is different, differently measured, with different assessment scale and different significance. Therefore, to make the research result reading clear, it is necessary to establish the same assessment scale for each feature and, if necessary, perform their recoding so that the highest values for each of them will be values reflecting the desired level of the system operation quality[1].

Interpretation of the obtained results can be the basis for taking actions aiming at increase and maintenance of a given level of the system operation quality. However, it is indispensable to develop a method which will enable, on the basis of the performed evaluation, its quality control, in times t.

Generally, control involves affecting the controlled object, by means of input signals, in such a way that its output signals can reach the desired value. Quality control is a method and system operation used for satisfying quality demands through giving the process or product appropriate characteristics or features.

It has been accepted that for a set of p-elements, on whose basis evaluation of a given system operation quality is performed, an identical, qualitative evaluation scale is set. This range was divided into three sections:

- favourable range
- limited range
- unfavourable range

These ranges are established separately for each of the distinguished attributes, and their affinity is determined by their influence on the system operation quality, expressed by the values of assessments obtained in result of the carried out research, in given time t.

In extreme cases, it can happen that the assessment will be of two-state character, that is, when only the maximum value of a given feature will correspond to the favourable qualitative range, whereas, it will not be possible to distinguish the range of its limited quality operation.

Let us assume that for each of the features distinguished from a p-element set, there is a possibility of its variability division into three subsets. In connection with this, there can be determined 3, of possible quality states, for given time t.

It must be remembered that the system operation quality is a collective feature and the above considerations concern assignment of particular feature values to each quality range. Thus, analogically, there can be distinguished three quality areas (favourable, limited and unfavourable) which are qualitative operation states of the system, determined on the basis of quality evaluation of all features accepted for the resultant model.

Due to a general quality assessment of the system operation and a different influence of each of the features, it is necessary to carry out research and classify particular quality states to one of the three ranges of features. In a geometrical interpretation, there should be determined two planes which will run between the quality boundary states determining, in this way, three operation quality areas of the examined system. The discussed issues can be included to science called threshold logic. In fact, it is necessary to determine two such threshold planes that will divide the area of quality states into areas: favourable, limited and unfavourable for the system operation quality. For this purpose, there must be determined two threshold functions for a p-element set of features $f(x_1,x_2,\ldots,x_p)$ and $f'(x_1,x_2,\ldots,x_p)$, where crossing them will mean a significant change in the system operation quality. Change of the area for a limited or unfavourable will be a signal forcing to make a decision on the actions to be taken in order to provide the object with the desired quality level. An exemplary graphic interpretation of quality state areas for two quality areas has been demonstrated in Fig. 2.

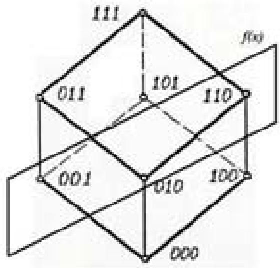

Fig. 2. Graphic interpretation of quality states determined on the basis of three features

It should be noted, though, that in practice, the number of features accepted for the system operation quality will be higher, thus, the number of quality states will increase, as well. Also, it must be defined which transitions between states are feasible and for this purpose, a transition probability matrix should be built. On the basis of this matrix it is possible to identify a graph of quality states with determined areas of its operation quality. An exemplary graph of the system quality states is shown in Fig. 3.

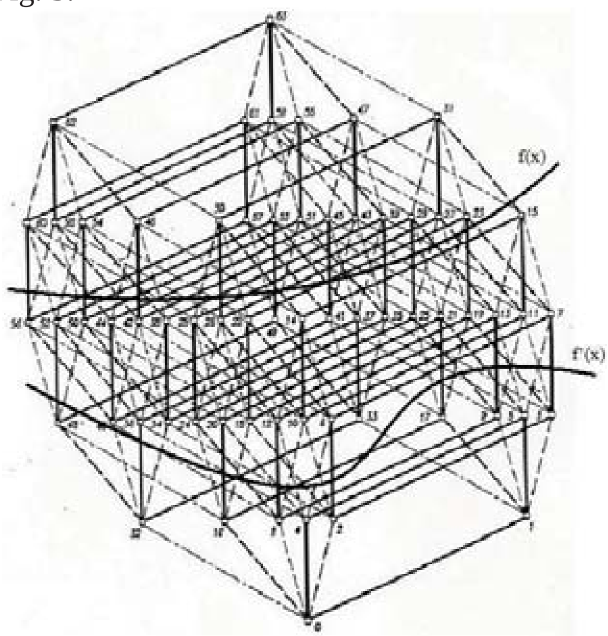

Fig. 3. Exemplary graph of states with separated quality states [1]

It should be emphasized that in order to provide the proper level of the system operation quality it is essential to make an analysis of transitions between boundary states (crossing the boundary planes) and to take up appropriate actions for control (decision) aiming at reaching the system state considered as the favourable state of its operation quality.

5. Summary

The presented methodology can be found to be a universal tool for diagnostic, prognostic processes, and above all, for optimization and rational control of complex systems of technical object using, especially transport ones through assessment of their states, determined on the basis of changes of significant features characteristic for the system.

Currently, there is being conducted research aiming at determination of the system time of stay in particular quality states and finding probability of transition into a particular state. The author hopes that it will be possible by using semi-Markov processes and will be a solution to the decision making problem in the process of

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