RESEARCH AND ASSESSMENT OF TRANSPORT MEANS OPERATIONAL QUALITY

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Abstract

In this paper there has been developed a method for the transport system operation quality assessment. The concept of the transport system quality has been defined. There has also been described the proposed evaluation method and the process of an assessment model construction. Basic features of the metrical space have been characterized and a proposition of a system operation quality evaluation metrics has been presented. Also, studies concerning the choice of assessment criteria and distinction of the most significant set of features accepted for the resultant model of the examined transport system operation quality, have been presented. It should be emphasized that using the presented method it is possible to make an assessment of the same system, in different times, with the assumption that the rating is performed on the basis of homogenous criteria, and with the use of a set of the same features, distinguished for the description of the research object.

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

1. The object of research

The object of studies is a generally understood transport system belonging to a certain class of socio-technical systems whose main task is to transport people, animals and/or loads. The studied system is classified as a real system characterized by intended behavior. It is a complex system operating in a given environment.

The complexity of such a system results from the number of its subsystems, situated at different decomposition levels, and from the sphere of activity in which the system elements, performing its specific goals, are involved.

To make the research effective it is necessary to account for the situation of each subsystem in its structure and its operation goal.

Subsystems situated at the successive decomposition levels can be treated as indivisible objects, depending on thoroughness of the problem studies. The system features as a whole, are defined not only on the basis of its particular subsystems but also on the basis of its structure.

2. Systems operation quality

The basis for these considerations is evaluations of the transport system operation quality, performed according to the defined conception of the system operation quality [12]:

„System quality – is a set of the system features expressed by means of their numeric values, at a respective moment t, determining the fulfilment level of the requirements in question".

In order to determine operation quality of a system under investigation, it is needed to perform it's identification. A set of significant features describing the system is to be determined (from the adopted point of view – assumed metacriterion – transport system operation quality) and a set of significant evaluation criteria and subcriteria is to be determined. Afterwards, an external observer starts to evaluate its operation quality. The evaluation process is to apply each criterion from the set K_n, to the features selected from the set X_i – based on their values measured at the moment t (measurable features), or on the states in which they exist at the respective moment t (unmeasurable features), by assigning adequate discriminants to them. Subsequently the measure of the system operation quality at the respective moment t is determined by the set of significant features $\{X_i\}$, i=1,2,…,p.

It should be noticed that for each criterion from the set K_n, it is possible to determine additionally such subsets of the subcriteria k_i, i=1,2,…,m which are conditions imposed on the feature values describing a respective element of the system e_i, i=1,2,…,n, from the set E. Determining these sets is intended to facilitate evaluation and enable to determine precisely influence of the respective system elements on the overall quality of it's operation.

On the basis of the considerations presented here above the Tab. 1 was elaborated. The process of creating a resultant model of the system evaluation, described in the example, is being realized from the point of view $M_2 = Q$ (transport system operation quality).

Tab. 1. Realisation stages of the process to determine the resultant model of evaluating of the transport system

<table>
<tr><td>External observer</td><td colspan="4">EO</td><td>Evaluator</td></tr>
<tr><td>Meta-criteria</td><td>M_1</td><td>M_2</td><td>…</td><td>M_n</td><td>Point of view</td></tr>
<tr><td>Study object</td><td colspan="4">S
(system)</td><td rowspan="3">System identifying</td></tr>
<tr><td rowspan="2">System elements</td><td colspan="4">E</td></tr>
<tr><td>e_1</td><td>e_2</td><td>…</td><td>e_n</td></tr>
<tr><td>Criteria</td><td colspan="4">K
$<K_1,K_2,\ldots,K_n>$</td><td rowspan="2">Criteria identifying</td></tr>
<tr><td>Sub-criteria</td><td>$k_1(e_1)$</td><td>$k_2(e_2)$</td><td>…</td><td>$k_n(e_n)$</td></tr>
<tr><td>Features</td><td>$X_1,\ldots$
$\ldots,X_{k1}$</td><td>X_{k1+1},
$\ldots,X_{k2}$</td><td>…</td><td>$X_{kn-r},..$
$..X_{kn-1}$,
$X_{kn=p}$</td><td>Features identifying</td></tr>
<tr><td>Evaluation model</td><td colspan="4">$X=<X_1,X_2,\ldots,X_p>$</td><td>Resultant form</td></tr>
</table>

On this basis, using the resultant model built, it is possible to determine the values of the respective features describing the system at the given moment t, determine their validity, and perform evaluation of the system under investigation at the respective moment [14].

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:

$$X(t) = \langle X_1(t), X_2(t), ..., X_p(t)\rangle. \qquad (1)$$

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:

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

$$Z(t) = Z_1(t) \cup Z_2(t) \cup ... \cup Z_n(t). \qquad (2)$$

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 [3] a general model to evaluate operation quality of the complex transport systems has been built:

$$\begin{aligned} &Z_1(t) = \{X_1(t), ..., X_{k_1}(t)\}, \\ &Z_2(t) = \{X_{k_1+1}(t), ..., X_{k_2}(t)\}, \\ &Z_3(t) = \{X_{k_2+1}(t), ..., X_{k_3}(t)\}, \\ &\ldots \\ &Z_n(t) = \{X_{k_n-r}(t), ..., X_{k_n-1}(t), X_{k_n}(t)\}. \end{aligned} \qquad (3)$$

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 [2]:

$$\begin{aligned} &Z_1(t) = \{X_1(t), ..., X_{k_1}(t)\}, \\ &Z_2(t) = \{X_{k_1+1}(t), ..., X_{k_2}(t)\}, \\ &Z_3(t) = \{X_{k_2+1}(t), ..., X_{k_3}(t)\}. \end{aligned} \qquad (4)$$

where $k_3 = p$.

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

$$Z_x(t) = \sum_{i=1}^{p} \alpha_i X_i(t), \qquad (5)$$

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

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.

$Z_X(t)$ - 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:

$$Z_x(t) \le \sum_{i=1}^{p} \alpha_i q_i \ . \tag{6}$$

The above mentioned inequality indicates that the process $Z_X(t)$ determined by means of the equation (5) 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 (6).

For the investigated system S at any moment t it is possible to determine the length between the point describing the operation quality of this system at the moment t, from the model system by means of the following formula:

$$d(X(t), q) = (\sum_{i=1}^{p} (X_i(t) - q_i)^2)^{\frac{1}{2}} \ . \tag{7}$$

The formula (7) may be applied as a tool to classify the systems in terms of their operation quality.

The functions (5) and (7) are particular cases of additive functionals set on p – dimensional stochastic process X(t).

4. Using essential concepts of the metric space

The formula (7) is one of the examples to describe the operation quality of the system at the moment t, in the space R^P. The space R^p is composed of p – elements number sequences:

$$R^p = \{(x_1, x_2, \dots, x_p)\ x_i \in R, i=1,2,\dots,p\}$$

In the p – elements space of the sequences consisting of the real numbers, it is possible to determine the length (metric) – the operation quality grade of the system ($\overline{\Delta K}$), for many different ways. If:

$$\overline{x} = (x_1, x_2, \dots, x_p) \in R^p,$$

$$\overline{y} = (y_1, y_2, \dots, y_p) \in R^p,$$

then the metric, called Euclidean one is described as follows:

$$\rho_2(\overline{x}, \overline{y}) = (\sum_{i=1}^{p} (x_i - y_i)^2)^{\frac{1}{2}} \ . \tag{8}$$

The next metric, called a Manhattan one, may be described by means of the following formula:

$$\rho_1(\overline{x}, \overline{y}) = \sum_{i=1}^{p} |x_i - y_i| \ . \tag{9}$$

And the metric described with the dependence:

$$\rho_\infty(\overline{x}, \overline{y}) = \max_{1 \le i \le p} |x_i - y_i| \ , \tag{10}$$

is called the Chebyshev metric.

The set R^p along with the metric (8) or (9) or (10) create a metric space. The metric space (R^p, ρ_2) is most commonly used in practice.

In general the pair (R^p, ρ), where ρ is one of the metrics, we call the metric space, if to each pair of the elements $\overline{x}, \overline{y} \in R^p$ a non-negative number $\rho(\overline{x}, \overline{y})$ is assigned in such as way that the following metric conditions are satisfied:

$\rho(\overline{x}, \overline{y}) = \rho(\overline{y}, \overline{x})$ - symmetry,

The first axiom of the metric means that the distance from the point $\overline{x}$ to $\overline{y}$ is the same as the distance $\overline{y}$ to $\overline{x}$.

$\rho(\overline{x}, \overline{y}) = 0$ only then, if $\overline{x} = \overline{y}$.

The next axiom of the metric means that the distance between two points $\bar{x}, \bar{y}$ is greater than 0 then and only then, when these points do not coincide.

$\rho(\bar{x}, \bar{y}) + \rho(\bar{y}, \bar{x}) \geq \rho(\bar{x}, \bar{z})$ - (triangle inequality).

The third axiom of the metric means that the points $\bar{x}, \bar{y}, \bar{z}$ create a triangle or they lie on a single straight line. It is known that the sum of the lengths of two sides is always greater or equals to the length of the third side in this triangle [8].

5. **Evaluation of the transport system operation quality**

One of the most important elements for assessment of the system operation quality, using the presented method, is to determine evaluation criteria and the proper choice of features both, qualitative and generic ones.

On the basis of carried out expert tests and then, surveys, 11 criteria were determined. Next, with the use of 'Start-graph' program and one module of 'Statistica' program, a test of correlation coefficient significance was performed, on the basis of which correlations between particular criteria were defined.

A statistic analysis a and bar charts of the obtained assessments were made for the obtained tests results. The statistic analysis of tests results is presented in Tab. 2.

Tab. 2. Statistic tests results

	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9	K_{10}	K_{11}
Number of observations	150	150	150	150	150	150	150	150	150	150	150
Arithmetic mean	9.35	8.01	7.19	5.75	4.53	3.91	4.14	8.17	8.96	6.39	5.24
Mediana	10	8	7	5	4	3	4	8	9	6	5
Mode	10	8	7	5	4	3	2	9	9	6	5
Variation standard	0.87	1.96	1.89	2.79	2.13	3.50	5.74	1.62	0.84	3.15	1.58
Deflection	0.93	1.40	1.38	1.67	1.46	1.87	2.40	1.27	0.92	1.77	1.26
Minimum	5	5	4	2	1	1	1	4	5	2	3
Maximum	10	10	10	10	10	10	10	10	10	10	10
Variability coefficient	9.99	17.4	19.1	29.0	32.2	47.8	57.9	15.6	10.2	27.8	23.9

In order to examine the correlation between particular criteria and find out if the analyzed criteria set is excessive, there was made a test for the correlation coefficient significance. Results of the carried out test, are shown in Tab. 3, in the form of a matrix.

Tab. 3. Correlation coefficient significance test

K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9	K_{10}	K_{11}	
1.00	-0.03	0.27	0.20	0.02	0.32	0.19	0.10	0.26	0.24	0.06	K_1
	1.00	-0.24	0.25	-0.21	-0.25	0.33	-0.39	-0.26	0.22	0.11	K_2
		1.00	0.25	0.31	0.34	0.50	0.25	0.22	0.25	0.18	K_3
			1.00	0.30	0.49	0.41	0.22	0.24	0.29	0.27	K_4
				1.00	0.48	0.32	0.15	0.36	0.27	0.08	K_5
p	$R_{kryt.}$				1.00	0.59	0.41	0.24	0.58	0.28	K_6
0.05	0.16					1.00	0.30	0.25	0.34	0.19	K_7
0.02	0.19						1.00	0.28	0.23	0.18	K_8
0.01	0.21							1.00	0.24	-0.09	K_9
0.001	0.26								1.00	0.28	K_{10}
0.0001	0.35									1.00	K_{11}

On the basis of the correlation coefficient significance test it was found that the particular criteria are closely correlated. Values of correlated very closely coefficients (for $R_{kryt.} \geq 0.35$) are highlighted in the table, whereas, values of coefficients for the remaining closely correlated criteria ($0.26 \geq R_{kryt..} \leq 0.35$), are shown in italics.

On the basis of an analysis of the obtained results, it was found that the considered criteria make up an excessive set. This means that some of the considered criteria can be neglected, with insignificant loss of information, which is provided by the neglected criterion, as this information is provided by the remaining, closely correlated criteria.

The analysis of statistic results, especially, the arithmetic mean, which is the most effective, not burdened, estimator of an unknown expected value, reveals that users of the examined transport system consider safety (9.35%) and punctuality (8.96%) as the most important criteria. They were given the maximum rates by more than half of the respondents. Besides, values of the variability coefficient for these criteria, in the analyzed set, are the lowest and they are, respectively: 9.99% and 10.2%. This means that the responses given by respondents on the subject of the above criteria are the least diversified. Such criteria as: the task accomplishment time and reliability were rated in such a way that their mean values do not exceed 8 points which makes them significant, as well, and therefore they must be accounted for in the process of the considered system operation quality assessment.

However, such criteria as: information availability, demand for the customer's comprehension, were considered the least significant from the point of view of the carried out transport service. They were given grades within the range from 3.91 to 4.53 points which means that they have the smallest influence in terms of the realized assessment, and can be neglected. Besides, analyzing the span within the considered criteria set, measured by variability coefficient, it can be seen that it is the biggest for the same features: K_5, K_6 and K_7 which reflects the least precision in specifying their values by the users.

The remaining criteria: aesthetics, ergonomics, costs and availability were given medium rates, within the range from 5.24 to 7.19 points, which makes them meet the demand for minimum significance threshold (in this work it is assumed to be equal to 5).

Summing up the above examination results: surveys, statistic ones and the correlation coefficient significance test, significance of the analyzed criteria was established, from the accepted point of view. On this basis, there was determined a set of eight most significant criteria, being conditions imposed on values of particular features, accepted for assessment of the examined transport system operation quality [13]:
- safety,
- accomplishment time,
- availability,
- ergonomics,
- reliability,
- punctuality,
- costs,
- aesthetics.

On the basis of the accepted criteria, there was determined a set of 17 features X_i, i=1,2,…17, which was divided into three disjoint subsets Z_1, Z_2, Z_3, satisfying the above dependencies:

$$Z_1 \cap Z_2 = \varnothing; Z_1 \cap Z_3 = \varnothing; Z_2 \cap Z_3 = \varnothing \, , \tag{8}$$

$$Z = Z_1 \cup Z_2 \cup Z_3 = X(t) \, , \tag{11}$$

where:

$$Z_1=\{X_1(t),...,X_3(t)\}, \tag{12}$$

$$Z_2=\{X_4(t),...,X_{13}(t)\}, \tag{13}$$

$$Z_3=\{X_{14}(t),...,X_{17}(t)\}, \tag{14}$$

Z_1 - is a subset of features describing drivers' operation qualitym,
Z_2 - is a subset of features describing quality of buses functioning,
Z_3 - a subset of features describing quality of factors connected with the environment.

For the set of distinguished features, the system operation quality in given time t, can be demonstrated in a geometric interpretation, as a seventeen – dimensional space consisting of vectors, determined on the basis of values of the particular features. However, it must be remembered that the resultant vector describing the system operation quality, changes its position in space, in a given time, depending on value changes of the features, it is determined by.

For the purpose of simulation examinations performance, consistence of empirical distributions with theoretical ones, for each of the distinguished random variables – features X_i, i = 1,2,…,17, describing the system operation quality was checked, and verification of zero hypothesis H_0, was made, with the distributions:

- Exponential,
- Gamma,
- Weibul's,
- Normal,
- Beta.

For the purpose of verification of the accepted hypothesis, consistence test χ^2 (Pearson's) was applied. On the basis of the results analysis of the carried out consistence test it was found that, for three features: X_5, X_{10}, X_{13}, of the analyzed set, there is no basis for rejection of hypothesis H_0 as there was observed consistence of their empirical distributions with the theoretical ones.

Whereas, for the remaining 14 random variables – features describing the examined system operation quality, on the basis of the carried out analysis, hypothesis H_0 about consistence of empirical distributions with theoretical ones , was rejected. The carried out analysis results reveal that for the considered set of features, in this case, it is impossible to model value changes of most of features in consistence with the analyzed theoretical distributions. Whereas, the quality is a summary feature and even in case of consistence of all features with theoretical distributions, the obtained combination of distributions would be complicated for description and interpretation [12].

Having in mind, its verification, especially, checking excessiveness of the accepted set of 17 features and determination of their significance, there were used elements of fuzzy logic. For this purpose, a method of medium, fuzzy charts was applied. The process of fuzzy modeling was performed on the basis of an analysis of values of features determined during operational tests, describing the transport system from the point of view of its operation quality. For selected values of each of the accepted features, a cross-section through the surface was determined for a set variable value [6].

For the purpose of analysis of real data, it is necessary to fuzz the value, set for the crosssection, by measuring points. This eliminates problems connected with non-uniform and non-constant coverage of the solution area. Affiliation of a measuring point to a given crosssection was acceped in the form of Guassian function:

$$\mu(X_i^*) = \exp(-(\frac{X_i^* - X_i}{b})^2), \tag{15}$$

where:

$\mu(X_i^*)$ - affiliation function for the system established, i-th value,
X_i^* - established value of the system i-th feature,
b - width of affiliation function opening.

For each crossection a mean weight value was coalculated (16):

$$Z_{śr}(X_i) = \frac{\sum_{k=1}^{nwp} \mu(X_k) \cdot Z(wp_k)}{\sum_{k=1}^{nwp} \mu(X_k)} , \tag{16}$$

where:
nwp - number of measuring vectors,
Wp - measuring vector.

Mean values of crossections form a curve whose span is a measurement of the level of dependence of the model output value on the input value.

During carrying out the examinations, an analysis was made, with the use of author's software [5]. Coefficient of affiliation function span with value 20%, was accepted. The number of fuzzy crossections equal to 10, was established and a method for the span calculation as a meansquare value was developed. Basing on the carried out analysis of the gradient form of fuzzy means (Fig. 1), value equal to 0.01 was accepted as significance boundary.

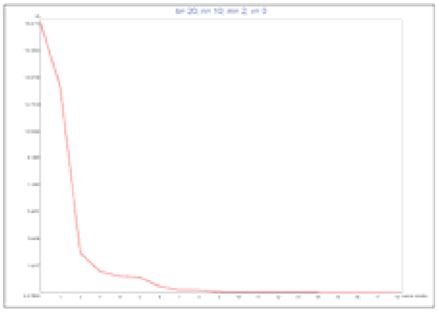

Fig. 1. Gradient form of fuzzy means

In Fig. 2, a spectral form of fuzzy means was shown. Exemplary charts of fuzzy means for significant data, on the basis of X_1 feature and data of little significance, on the basis of feature X_4, are presented in Fig. 3 and 4.

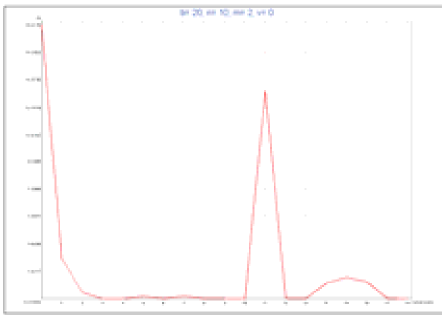

Fig. 2. Spectral form of fuzzy means

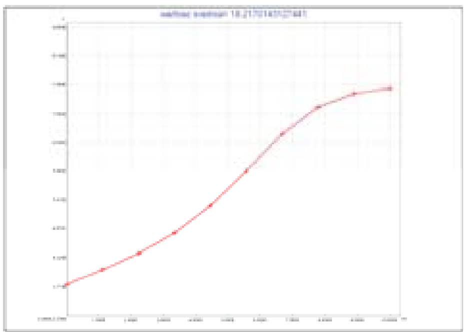

Fig. 3. Form of fuzzy means chart for significant data, on the basis of X_1 feature

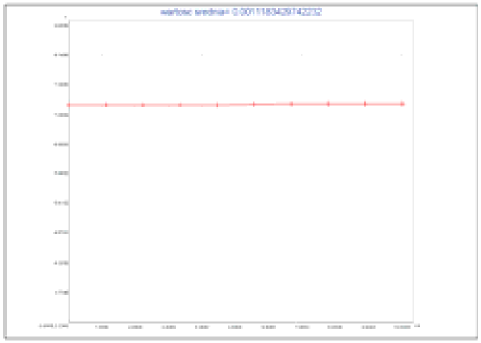

Fig. 4. Form of fuzzy means chart for data of little significance on the basis of X_4 feature

On the basis of an analysis of the spectral form of fuzzy means and the value of fuzzy means span, nine features characterized by the highest significance for the modeled process, have been chosen and presented in Tab. 4.

Tab. 4. Features of transport system chosen as input parameters of the fuzzy model [12]

Feature name	Features	Values of fuzzy mean
Mistakes made by operators	X_1	18.217
Degree of transport tasks accomplishment	X_{11}	13.890
Surface state of transport routes	X_{15}	1.1820
Visibility degree on particular routes	X_{16}	1.1798
Tire condition of vehicles	X_5	0.1714
Sum of operating costs	X_7	0.1613
Ergonomics of vehicles	X_8	0.1546
Pollution emission size	X_{12}	0.1429
Emitted noise value	X_{13}	0.1411

Taking into consideration prognosis of the examined system qualitative state, a computer simulation algorithm has been developed in this section. This algorithm makes it possible to assess the influence of value changes of features distinguished for the description of the system, on its operation quality [15]. In order to perform simulation tests, the following schedule of their accomplishment has been accepted:

a) give the number of generated observations,
b) give the number of the system analyzed features,
c) define the type of distribution for particular features,
d) specify parameters for the distribution of particular random variables on the basis of verification of hypothesis of consistence of the empirical distribution with the theoretical ones,
e) generate values of the i-th feature (1=1,2…,p), form distribution: discrete or constant,
f) determine boundary values for particular features,
g) set norms for values for generated random variables , according to accepted assumptions,
h) determine mean values for the obtained assessments,
i) calculate values of features on the basis of accepted metric (proposed Z(t) and d(t)),
j) for metric z(t) determine weight values for particular features,
k) define models of particular feature value changes,
l) generate results of carried out tests in the form of reports,
i) form archives of the simulation results,
ł) print the computer data.

The developed simulation algorithm can be used both for prognosis of the system operation quality state and as a tool for checking the built model sensitivity and evaluation of the model reaction to change of its input parameters – features, determined for the description of the system, significant from the point of view of its operation.

6. Summary

The method presented in this paper and the model built to evaluate the operation quality of the transport systems make a tool to support rational control of the processes being carried out within the discussed systems, depending on the changes of the changeable values describing the actions of the operators, technical objects controlled by them and influence of the environment.

The above discussed problems are part of the research on operation quality of transport systems. Further works concern the problems concerning control and decision making, depending on the examined object changes of quality states, determined on the basis of values of features accepted for its description.

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