

# IDENTIFICATION AND ANALYSIS OF TRANSPORT SYSTEMS OPERATION QUALITY ASSESSMENT CRITERIA

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## **Abstract**

*The study deals with operation quality assessment of operating complex systems especially transport ones. It has been established that assessment of their operation quality depends on fulfilment level of specified criteria. Thus, determination of a set of criteria in terms of their quantity and significance is of great importance. Since the considerations refer to socio-technical systems of the type: human machine and environment <H-M-E>, and especially municipal transport systems, these criteria account for human actions, machine operation (transport means) and the impact of factors coming from the environment. The basis of their operation quality is provided by a set of significant, variable in time, measurable and independent features whose values, in a given time period, determine the fulfilment degree of the specified criteria. On the basis of fulfilment degree of the distinguished criteria, an assessment of operation quality and classification of the considered transport systems are made. In this study, one way of choosing the criteria has been proposed. This method is based on square matrixes and questionnaire survey, which are used for establishing their influence on the transport system operation quality, for selected transport means, used in urban complexes.*

**Keywords:** *transport system, operation quality, criteria*

## **1. Introduction**

The choice and specification of assessment criteria of complex operating systems, including the analyzed transport ones, from the point of view of their operation quality, is an important research problem. A criterion is defined as the fulfilment degree of set requirements. At the same time, a choice of the most important assessment criteria, whose fulfilment are values of independent and measurable features describing a given system.

## **2. General characteristics of municipal transport system**

As far as transport means are concerned, there should be made an analysis involving definition of usefulness of transport means operated by a given company with a simultaneous assessment of their technical condition and the level of modernity and evaluation of the company management policy.

The author of work [1] presents a record of quality criteria set, ordered for concrete needs and including their characteristics and desirable states, as the pattern of quality for the municipal public transport.

The notion of a transport system quality covers a set of its features expressed by means of numerical values, in a given time  $t$ , determining the fulfilment degree of the specified criteria (its users' requirements) [10].

Apart from research on transport users' preferences and behaviours which inseparably connected with the quality of provided services (especially transport postulates and assessment of work of the staff involved in the service provision) there are also many other kinds of tests using primary and secondary information sources.

The secondary external sources which can be used for assessment of transport services quality include:

- direct or indirect data obtained from passengers (most frequently in the form of complaints and critical comments more rarely positive ones), personally and by telephone, from talks with workers of the marketing department;
- information and reports obtained from passengers (most frequently by means of media (most frequently local press));
- reports and analyses made by self-government institutions, statistic offices, organs of economic control, one of whose elements, is information on the subject of the municipal transport system functioning.

Secondary internal sources include:

- standardized and systematically made reports of traffic control and supervision services, on the basis of observations performed in stationary and movable control stations,
  - reports from research on economic-operating efficiency, performed by the company on its own.
- In work [4] transport safety, regularity, punctuality and ability of adjusting to different transport conditions has been discussed in terms of the quality of transport services.

Considering cooperation of municipal transport means, such factors as the speed of connection and travel, the distance covered and carrying ability are to be given priority as comparative parameters.

In the course of the literature analysis, there arises a question connected with the specificity of municipal transportation market. According to the author of work [4] the market of municipal transportation is a market whose specificity is determined by:

- transport services in the field of passenger transportation as the subject of exchange,
- municipal transport companies as service providers and households as their customers,
- local range limited to the area of one or several towns forming an agglomeration with suburban areas with related to them towns.

Municipal transport services in the European Union countries are treated as public services, available to every citizen at an attractive price. Providing them is to be governed by rules of equality, widespread availability, continuity, management and financing transparency.

Providing transportation services is the responsibility of municipal transport companies. They can be units designated by public administration or units which are responsible for accomplishment of tasks in the field of transportation.

The range of the municipal transport market is determined by arrangement of its router, should be adjusted to reported transport demands to be met by the local public transport. The basic arrangement of routes is concentrated within a town or an urban complex area. Some of the routes cross the town administration borders if there are strong functional links between them which determine the municipal character of transport needs. Such areas are referred to as being organically linked with towns.

The demand for municipal transport services is dispersed contrary to its supply. Transport needs and the demand resulting from it are characterized by defined, specified features, that is, concentration in a limited area determining the travel slight mean distance:

- commonness,
- time-special irregularity,
- mass character.

The demand for municipal transportation services occurs in combination with given requirements concerning the travel conditions which are transport preferences. Accounting for the structure of national economy, within the national transport, there can be distinguished a municipal transport (parish) and the intercity (inter-parish) one.

Assuming the character of transport as a criterion of the municipal transport division, the following kinds of transports can be distinguished:

- collective,
- individual.

A division of transport means operated in a municipal transport system can be made basing on the criterion of the number of carried passengers [10]:

- individual (bicycle, scooter, motorcycle, passenger car-used by one person, taxi –carrying one passenger),
- group (van, taxi – carrying a few passengers ),
- public (bus, trolley bus, tram, tube, city train).

### **3. Criteria for transport means operation assessment**

Accomplishment of service tasks by public transport, over a given area, can be evaluated according to the following criteria [7]:

- safety,
- operation,
- ecology,
- economy,
- serviceability,
- organization,
- impact of environment.

In each of the specified criteria there can be distinguished subsets of subcriteria according to the presented division:

- safety criterion: human action, machine operation safety, external threats,
- economic criterion: optimization, financial outcome, effectiveness,
- ecological criterion: noise ,vibrations, emission of pollution, wastes,
- operation criterion: providing fitness for use, serviceability, operation capabilities (reliability, availability, susceptibility to damage, controllability),
- serviceability criterion: customer’s satisfaction, adjustability to clients’ needs, punctuality, demand, information provision, competitiveness, decision making, control and analysis,
- organizational criterion: strategy, planning, decision making, control and analysis.

It should also be kept mind that the set of accepted assessment criteria, especially, their kind, and number will be different for the considered research objects and can depend on the structure and specificity of a given system functioning, characteristics of the service area, demand for the provided services [9].

### **4. Determination of criteria for assessment of municipal transport system quality operation**

The basic goal of a transport system operation is accomplishment of passenger transports over a given territory, in a given quantity an in a given time. An assessment and providing the systems with the required operation quality in terms of efficiency, reliability, safety and economy is the main factor in the process of their operating.

On the basis of literature analysis and the author’s own research, a method and a resultant model for transport systems operation quality assessment have been developed. The developed method enables assessment and comparison of operation quality of different transport systems of the same type. It is also a one of rational control factors of processes carried out within the discussed systems, depending on value changes of the features describing actions of operators, controlled by them objects, and the impact of the environment. For this purpose, metrics on the basis of which the transport system operation quality assessment made were developed. Values of the metrics described by dependence (1), is determined basing on the values of significant features describing the system, accounting for values of weights attributed to particular features. For the analyzed system A random process is defined for the analyzed system, reflecting the system operation quality, in the form:

$$Z_X(t) = \sum_{i=1}^p \alpha_i X_i(t), \quad (1)$$

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

It should be emphasized that an important task for determination of a given system operation quality assessment is to specify a set of the most significant assessment criteria and basing on them to choose significant features conforming with the accepted criteria and establish their significance. The choice of an optimal method enabling determination of values of weights –significance of the accepted criteria as well as features, is the main factor determining reliability and accuracy of the obtained results. In connection with these there have been presented methods: an expert one – square matrix (meanings) and survey methods whose purpose was to determine values of weights defining significance of the accepted quality criteria.

#### 4.1. Assumptions and description of square matrix

Matrix A ( $n \times n$ ) is given.

$n_{ij}$  - number on position  $n$  ( $i, j$ ), where  $n_{ij} = 1, 2, \dots, n$ ,

$\sum_{i=1}^n n_{ij}$  - sum in the  $j$ -th column,  $j = 1, 2, \dots, n$ ,

$\sum_{j=1}^n n_{ij}$  - sum in the  $i$ -th row,  $i = 1, 2, \dots, n$ .

The matrix characteristic feature is the fact that on the matrix diagonal there are 2 (twos), and for each  $i, j$  there dependence occurs:

$$\bigwedge_{ij} n_{ij} + n_{ji} = 4 \quad i, j = 1, 2, \dots, n. \quad (2)$$

For a matrix of  $n$  degree in which elements beyond the diagonal (there are  $n - n$  elements) satisfy an equation, described by dependence 2, and on the diagonal there are 2s, it is enough to know elements ( beyond the diagonal), in order to determine all the remaining ones.

The sum of values of all element sof matrixes  $N$ , is determined from dependence:

$$\sum_{i=1}^n \sum_{j=1}^n n_{ij} = \frac{n^2 - n}{2} 4 + 2n = 2n^2 = N. \quad (3)$$

As for each  $i, j$ , dependence 2 is satisfied, the sum of the  $i$ -th matrix row is equal to:

$$\begin{aligned} \sum_{j=1}^n n_{ij} &= \sum_{j=1}^n (4 - n_{ji}) = \\ &= (4 - n_{1i}) + (4 - n_{2i}) + \dots + (4 - n_{ni}) = \\ &= 4n - (n_{1i} + n_{2i} + \dots + n_{ni}) = \\ &= 4n - \sum_{k=1}^n n_{ki}, \end{aligned} \quad (4)$$

where  $4n$ , reduced by the sum of values of elements in the  $i$ -th column.

Weights for particular features are determined on the basis of a quotient of the sum of elements of the  $i$ -th row, by the sum of values of the matrix all elements.

$$\alpha_1 = \frac{\sum_j n_{1j}}{2n^2}, \alpha_2 = \frac{\sum_j n_{2j}}{2n^2}, \dots, \alpha_n = \frac{\sum_j n_{nj}}{2n^2}, \quad (5)$$

$$\sum_k \alpha_k = \frac{\sum_j n_{1j} + \sum_j n_{2j} + \dots + \sum_j n_{nj}}{2n^2} = \frac{2n^2}{2n^2} = 1. \quad (6)$$

Weights  $\alpha^{\wedge}$  form a stochastic vector  $[\alpha_1, \alpha_2, \dots, \alpha_n]$  and can be treated as probability distribution in within the space of considered features.

If for the analyzed square matrix A of n degree, satisfying the above features, number 2 will be subtracted from each element of the matrix, then the resultant matrix will be antisymmetric, that is:

$$\bigwedge_{ij} n_{ij} + n_{ji} = 0 \quad i, j = 1, 2, \dots, n. \quad (7)$$

Let  $A = [n_{ij}] \quad i, j = 1, 2, \dots, n$ . Let B matrix of n degree be formed, whose elements values are 2, then:

$$A - B = [n_{ij} - 2] \quad i, j = 1, 2, \dots, n. \quad (8)$$

In such a case matrix (A-B) is antisymmetric because:

$$(n_{ij} - 2) + (n_{ji} - 2) = n_{ij} + n_{ji} - 4 = 0. \quad (9)$$

On the basis of carried out tests there have been determined 5 most significant criteria:

- A – reliability,
- B – ergonomics,
- C – economic aspect,
- D – environment friendliness,
- E – safety.

In order to establish significance of the specified criteria, the presented method of matrix of meanings has been used.

N = 5 elements have been accepted. A square matrix (5×5) was determined. The sum of values of all elements of matrix:  $N=2n^2=50$ . On the basis of a scale of grades (0-4), experts made an assessment of the influence (significance) of particular features in relation to each other.

Since the feature described by dependence 2, it is a feature characteristic for the considered matrix, experts who give grades must know (apart from the diagonal),  $\min. (n^2 - n)/2$ , that is, 10 elements of the matrix for it determining.

In spite of this, the author proposes determination of all 20 elements of matrixes in the following way: first, experts determine e.g. the upper part of the matrix and then, independently, the lower one. In this way using the attribute described by dependence 2, it is possible to check reliability and accuracy of grades given by experts, as their sum on positions  $n_{ij}$  and  $n_{ji}$  must be equal to 4, in each case.

In result of application of the matrix of meaning, weights for particular criteria have been determined, which is described by the following dependence:

$$Z_K < 0,26A, 0,12B, 0,2C, 0,12D, 0,3E >. \quad (10)$$

The next step in the assessment process can be a repeated use of the discussed method for determination of weights for particular features describing particular criteria which, in a general form (without ordering features into particular criteria), has been described by dependence 1.

It should be emphasized that the presented method of square matrixes is a method with possibilities of wide application, used as one of expert tools for ranging the discussed factors.

*Tab. 1. Evaluation of significance of assessment criteria with the use of the method of matrix of meanings*

	<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>	<b>E</b>	$\Sigma$	$\alpha$
<b>A</b>	2	3	4	3	1	<b>13</b>	$\frac{13}{50} = 0.26$
<b>B</b>	1	2	1	2	0	<b>6</b>	$\frac{6}{50} = 0.12$
<b>C</b>	0	3	2	3	2	<b>10</b>	$\frac{10}{50} = 0.20$
<b>D</b>	1	2	1	2	0	<b>6</b>	$\frac{6}{50} = 0.12$
<b>E</b>	3	4	2	4	2	<b>15</b>	$\frac{15}{50} = 0.30$
					$\Sigma\Sigma$	<b>50</b>	<b>1.00</b>

#### 4.2. Analysis of survey examinations

In order to accomplish the process of municipal transport systems operation quality assessment there were carried out surveys, on the basis of which the set of the most important assessment criteria [10, 11] was established:

- Safety ( $K_1$ ) – it is a feature of the analyzed transport process which is characterized by a lack of life and health threats of people, and threats to material objects involved in the process, as well as characterized by occurrence of practical guarantees for absence of threats in a predictable future,
- Time of the service accomplishment ( $K_2$ ) – time of travel accounting for possibility of the course choice (slow, fast and express),
- Availability ( $K_3$ ) – area of the service provision by the carrier with location of bus stops,
- Ergonomics ( $K_4$ ) – adjustment of technical devices to physical and psychical features of the man,
- Confidence of users ( $K_5$ ) – knowledge and accomplishment degree of users’ needs,
- Informativeness ( $K_6$ ) – availability, method and range of providing information on the services,
- Demand ( $K_7$ ) – demand for provided services,
- Reliability ( $K_8$ ) – ability of the transport task accomplishment in a given time period, over a given territory with variable influence of environmental factors,
- Punctuality ( $K_9$ ) – providing transport services according to a fixed schedule,
- Costs ( $K_{10}$ ) – travel costs (assessed in comparison with other competitive costs of other carriers),
- Aesthetics ( $K_{11}$ ) – aesthetic impressions concerning buses, junctions, (bus stations) bus stops, and other objects and municipal transport means connected with appearance, colors, architecture and consistence with the latest trends.

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. 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 [10].

On the basis of the correlation coefficient significance test it was found that the particular criteria are closely correlated [6].

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, an 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.

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.

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 [11]:

- safety,
- accomplishment time,
- availability,
- ergonomics,
- reliability,
- punctuality,
- costs,
- aesthetics.

## **5. Conclusions**

In the study, methods for the choice and specification of criteria there have been presented there have been presented, accepted for assessment of transport systems operation quality. As it can be seen, despite differences in the sets of the obtained criteria, it should be noticed that definition of their importance with the use of the method of square matrixes (meanings) was performed, using five accepted 'in advance' assessment criteria. However, in the second case, the users evaluated 11 criteria, eight of which were accepted for further analysis, and they received more than 5 points in a fixed 10 degree scale. It should be emphasized, though, that the distinguished most significant criteria, were also the most significant ones in the considered set, regardless of the accepted assessment methodology.

The issues studied in the article are an attempt to provide an alternative solution to the problem of specification of criteria features or any assessment indexes. It should be emphasized that this is only one of many existing methods which include: multi-process analysis, qualitymetrics and qualitylogics methods or fuzzy logic elements.

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