CRITERIA BASED EVALUATION OF MUNICIPAL TRANSPORTATION SYSTEM OPERATION

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Summary

An analysis of experimental tests results and a literature review showthat determination of the optimal number of criteria for assessment of operation quality of a given transportation system is crucial to the assessment result. The analysis has been performed on the basis of research on operation quality of a given transportation system. This is a real transportation system providing the population with transport services in a given urban and suburban area. The operation quality of such a transportation system is affected by people's behavior, operation of the vehicles, and the impact of the environment. In order to ensure appropriate quality of the system functioning it needs to be constantly evaluated. The transportation process ought to be optimized and innovative solutions should be implemented. In this work a set of evaluation criteria has been determined, on the basis of which, evaluation and analysis of the quality of transport services provided by a given municipal transportation system have been performed.

Keywords: transport system, quality operation, criteria evaluation, principal component analysis, statistical analysis

1. Introduction

Travelling from place to place is one of the human needs which is supposed to be met during the transport process. Transport performs a useful economic and integration service to the community of urban and suburban areas whose inhabitants commute to work. It also meets various needs of people including cultural, medical, social ...etc. [21].

Municipal transportation is a special kind of transportation including suburbs which, though being areas located outside administrative borders of a town, perform the same functions as those located within its borders.

The most popular means of public transport are buses. It is due to the fact that it is easy to use them on the existing infrastructure. There is no need to construct additional tractions. The area in which transport services are performed is vast and the transport routes can be easily changed and reorganized. Despite many advantages of a municipal transportation

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system there are disadvantages as well, that is – it poses threats to people's lives, engineering objects, and the natural environment. For this reason the transportation systems are required to provide high quality transport services, with special emphasis on: reliability, punctuality, and appropriate safety.

Requirements from modern municipal transportation systems include [4,9,10,13,22,23]:
- providing the passengers with safety,
- ensuring access to transportation networks and availability of transport services,
- adjusting the vehicles to transportation of big numbers of passengers,
- adjusting the vehicles to the road conditions in the city,
- providing passengers with proper frequency, punctuality and speed of transports.

Improving the quality of life involves meeting increased demands of passengers. They expect high level services that would be similar to the comfort offered by individual transport means. Proper operation of a transport company should involve fulfilling transport needs of inhabitants of towns and districts. In order to meet the demands it is necessary to find out what the users' demands are and meet them. Getting familiar with the preferences of passengers using bus transportation involves market research thanks to which it is possible to obtain measurements of the transport services quality from the point of view of a passenger.

The quality of transport services depends on many factors, that is, criteria for assessment of municipal transportation. Transport postulates can be considered to be these criteria. It is possible to determine the standards of transport services according to these criteria. Standards of travelling are most frequently understood as the system ability to meet certain qualitative demands of the system users. Less specifically, standard means a certain boundary value characteristic for a given feature [8].

The significance and hierarchy of particular transport postulates are different for particular users of municipal transportation systems. It is impossible to establish one hierarchy of postulates that would be equal for different towns, as it is determined by local conditions. The hierarchy of postulates should be defined systematically on the base of market research to be done by those who organize the municipal transportation systems.

2. Selection of criteria for evaluation of municipal transportation system operation

In literature there have been described many methods and tools for establishing the importance of the considered variables. There are statistic methods, hierarchy process analysis, elements of fuzzy logic, correlation tests and others. One of such methods, supporting the process of selection of an assessment criteria set which has been used in this paper is the principal component analysis.

On the basis of literature analysis and the results of the author's own research there have been distinguished 16 criteria: safety, efficiency, operational readiness, ergonomics,

environmental friendliness, functional quality, atmospheric factors, availability, aesthetics, information quality, punctuality, frequency, external factors, indirectness reliability and cost (price). These have been analyzed (based on results obtained from opinion surveys) in order to determine the most important criteria for building a model that would assess the quality of a given municipal transportation system.

In opinion surveys there is usually a big number of variable features. However, the survey questions are related to each other and thus it appears to be unnecessarily increased. While analyzing the survey data there appear different problems. One of them is connected with maintaining the optimal number of variables in the set without significant loss of information. The commonly used methods of multidimensional analysis do not provide ideal statistical procedures for choosing the set of variables. One of such methods is the principal component analysis. However, the method of principal component analysis requires meeting some assumptions.

This method is based on measurable variables but it can also be used for variables of the subordination type. The examined variables r, should remain in a linear dependence and the correlation between them should be measured by Pearson coefficient.

If the analyzed variables are not interrelated, then using the method of principal components is not advisable. On the basis literature analysis [20] it is obvious that if all coefficients of correlation are smaller than 0.3 than application of this method is not effective. The higher the correlation coefficients are the more advisable application of this method is. At the beginning of the statistical analysis it is necessary to use Bartlett test [1]. Bartlett test answers the question whether all the correlation coefficients are equal to zero. Application of the main factor method requires a sample with appropriate size 50 [19]. The assumption about normality of the distribution is not necessary to describe the relations between variables. However, when statistical tests are used to define significance of the components, an assumption about multidimensional normality of the examined features distribution is necessary.

The analyzed data sets are numerical matrixes with dimensions nxp, where n stands for the number of surveys, p denotes the number of criteria. For a given matrix $\mathrm{X(nxp)}$, a matrix of correlation coefficients is determined. Matrix of correlation coefficients is subjected to Bartlett test which decides about advisability of application of the principal component analysis. If R denotes a matrix of correlation coefficients, then Bartlett test involves verification of the statistical hypothesis form:

$$\mathrm{H0 : R = I}, \tag{1}$$

where:

I – is a unit matrix of dimension pxp.

Hypothesis $\mathrm{H_o}$ means that all coefficients of correlation contained in matrix R are equal to zero. Test statistics for this hypothesis has the form:

$$U = -(n-1-\frac{2p+5}{6})\sum_{i=1}^{p}\ln\lambda_i \tag{2}$$

where:
p = number of variables,
n – number of tests
λi – i-th value of matrix R.

It is assumed that proper values are arranged in non-ascending order, which means:

$$\Lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_p, \tag{3}$$

For the assumption that hypothesis H_0 is true, statistics U has chi-square distribution with p(p-1) freedom degrees. Results of Bartlett test application for group is presented in table 1.

Tab.1. Bartlett test results

Statistics U value	p-value
226.56	0.000001

The analysis of results of H_o hypothesis testing: R=I shows that for a very low p-value, it is necessary to reject the null hypothesis, for all the analyzed groups of data.

This means that it is justified to use the principal component method.

The principal component analysis enables determination of linear transformation of the form:

$$Z = A\,X, \tag{4}$$

where:
A is a matrix of pxp dimension linear transformation,
X is a column matrix of $X^T = [X_1, X_2, \ldots, X_p]^T$.
Z is a column matrix containing dependent variables $Z_1, Z_2, \ldots, Z_p$ called components.

The principal component analysis determines the first row vector of matrix A in such a way that component Z_1 has the maximal variance with limiting the form:

$$\sum_{i=1}^{p} a_{1i}^2 = 1 \tag{5}$$

Next, the second component is determined so that variance of variable Z_2 will be maximal for proper limits.

One of the main reasons for using the principal component analysis is verification of the hypothesis:

$$H_0 : \lambda_{k+1} = \lambda_{k+2} = \ldots = \lambda_p, \tag{6}$$

In relation to the alternative hypothesis:

H1 : not all $\lambda_{k+1}, \lambda_{k+2}, \ldots, \lambda_p$ are equal.

Testing statistics for Ho hypothesis has the form:

$$\chi^2 = -(n-k)\left[\sum_{j=1}^{p} \ln \lambda_j - q \ln \frac{1}{q} \sum_{i=k+1}^{p} \lambda_i\right] \tag{7}$$

where:
$\chi 2$ has distribution,
$\chi 2$ z $df = q(q+1)/2 - 1$, $q = n - k$ freedom degrees, for the assumption that the hypothesis is true.

Statistical hypothesis described by dependence (6) was verified successively for $k=0,1,2\ldots,p-2$. Results of the verification are presented in table 2, which contains proper values λi, $i = 1, 2, \ldots, p$ for „set 1". The analysis of data from table 2 shows that the 9 highest proper values vary considerably.

Tab.2. Test results for the analyzed set of criteria [6]

No.	Eigenevalues	p – value	Test result
1	3	0.000	X
2	2.48	0.000	X
3	1.93	0.001	X
4	1.33	0.019	X
5	1.17	0.031	X
6	0.94	0.044	X
7	0.88	0.028	X
8	0.87	0.022	X
9	0.74	0.04	X
10	0.63	0.075	
11	0.57	0.123	
12	0.46	0.382	
13	0.31	0.895	
14	0.23	0.980	
15	0.2	0.934	
16	0.18		

In a graphic representation of the principal component method, a chart of successive eigenvalues, in an ordered sequence depending on the number of the eigenvalue, is commonly used (3). Such a chart is called an avalanche. To place all the sequences in one chart the charts need to be normalized by dividing each eigenvalue by the first(maximal) one , the chart of an avalanche for the analyzed set has been presented in fig.1.

On the basis of tests performed with the use of the main factor method it was found that in the analyzed set of criteria there are 9 statistically different eigenvalues.

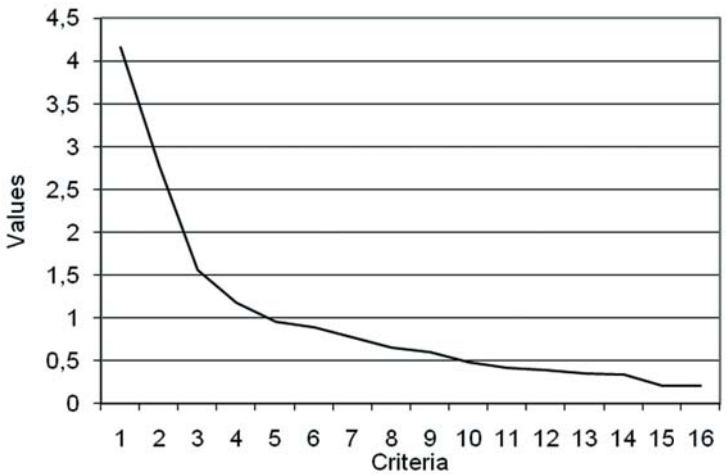

Fig.1 Chart of avalanche for the analyzed data sets

The fact proves that there is redundancy of the considered set dimension. Having in mind the above, and the results of studies [5, 6, 7, 11, 21] a set of 9 most important criteria: punctuality, frequency, safety, reliability, availability, cost, connection directness, information and ergonomics were accepted for the study.

3. Research on municipal transportation system users'demands concerning the quality of transport services

A recorded set of quality criteria, containing their characteristics and desirable states, ordered according to particular demands, is considered to be the quality model [1,8]. One of significant conditions assigned to the feature value has been assumed as a criterion [6].

The main stage of the process of quality assessment can be construction of a quality model which would reflect preferences of passengers passed to the organizers of transports and transportation companies. This model should be the point of reference for an analysis of data on the offered and implemented parameters of quality [18].

The quality model has always a multi-dimensional form including many qualitative features reflecting transport postulates formulated by passengers. The model of quality should contain a comparison of properly matched qualitative features so that the analyzed quality will be related to the users' opinions [3,4].

Building a quality model should be included in quality assessment of a public transportation system involving formulations of preferred, planned, and accomplished quality.

To modify this model it is necessary to carry out periodic control and evaluation of the transport services quality, examine the quality gap and verify the quality model for the next period of time [15].

The obtained quality provides the basis for basis for the analysis. In order to examine the quality of transport services from the point of view of passengers, it is necessary to get familiar with their expectations and preferences.

4. The reaserch object

The research object is a transportation system from the class of socio-technical systems of the type ‚⟨H-M-E⟩(H Human, M-machine, E-environment), whose main task is to perform transports of passengers (according to fixed schedules) their animals and their belongings [21].

It is a complex system operating in a given environment providing services in order to meet transportation needs of city dwellers. The basic goal of the company is to provide transport services involving meeting the public transport demands of people on an assigned territory as well as:

- expose adverts on buses,
- offer repair services to outside entities,
- hire premises and construction objects to other economic entities,
- retail sale of fuels for mechanical vehicles.

5. The research description

On the days from 17 September to 10 October 2012 (when both schoolchildren and students came back to schools after the school break), marketing research was carried out. This research was supposed to find out preferences and the satisfaction degree of public transportation users with the transport services offered by the analyzed bus transportation company.

The transport system user was the statistical user of transport services – simple unit , and the size of the set of respondents was N=200. Variability criterion was – significance of the evaluated criteria in points with grading scale being {0,1,....5}.

The results of carried out surveys allowed to make an analysis of the passengers' qualitative demands from the public transport services offered by a municipal bus company.

The opinion surveys were carried out on weekdays, during morning and afternoon rush hours. The places were selected in such a way that the surveyed population would include passengers who use the transportation company services always, sometimes or seldom.

6. The research methodology

The market research was carried out with the use of a direct measurement by Servqual method [14].

The research tool was a question of closed character whose advantage is that it provides the respondent with a full range of responses. Moreover, respondents were provided with the possibility to openly express their opinions on the subject of municipal transportation in the point "Comments".

The question: "What are your requirements as regards the quality of transport services and how do you rate the services provided by the considered municipal bus transportation company".

The respondents were supposed to express their expectations and evaluate the quality of offered services in relation to p=9 distinguished qualitative features. They were provided with a five degree grading scale. They were also asked to indicate the hierarchy of importance of those factors as well as the one of most importance. The following transport postulates, being also the assessment criteria for the quality of transport services, were to be rated:

- punctuality – time consistence of transport services accomplishment with the schedule, accounting for the accepted intervals of tolerance;
- frequency–daily number of rides, in a given time interval, satisfying the demand;
- safety–characterizes accomplishment of the transport process featured by the lack of threat to human life and health as well as transported loads and animals involved in this process;
- reliability–it characterizes the system ability to accomplish the tasks in a given time and with established levels of forcing factors; in a normative approach reliability can be referred to as probability of the task being accomplished by an object in given time t and for established impact levels of forcing factors;
- availability– distance between bus stops available to passengers of a Niven bus Line;
- cost –process for particular kinds of tickets and price reductions;
- directness of connections–ability to provide successfully the transport service using one type of transport means operated over a given bus line or distance;
- informativeness- - availability of information on provision of transport services;
- ergonomics–adjustment of construction solutions and elements of equipment and infrastructure to psycho-physical traits of humans.

The level of expectations and the quality of services provided by the transportation company were evaluated according to a 5 grade scale. In terms of expectation level grade '5' stood for very good and '1' for very bad, whereas in terms of the quality of provided services '5' stood for a very good service and '1' for a poor quality service.

The analysis of the group of respondents was performed according to the following criteria:

- gender (woman, man),

- age (to 18, from 18-25, from 26 -50, from 51 to 60 and more),
- employment status (school children, students, the employed, the unemployed, the retired/annuitants),
- frequency of using the municipal public transportation: always, sometimes or seldom,
- kind of ticket they use (regular ticket, reduced or normal, seasonal ticket reduced or normal price, or entitlement to free of charge transport services).

The respondents' grades were used for calculation of the mean values of particular postulates in terms of the expectation level from a given service as well as the from the relative and absolute gap in quality.

7. Results of surveys

Figures 2-6, show the characteristics provided by the surveyed passengers, according to the groups of respondents.

Users' preferences and their evaluation of the operation quality of a municipal bus transportation system.

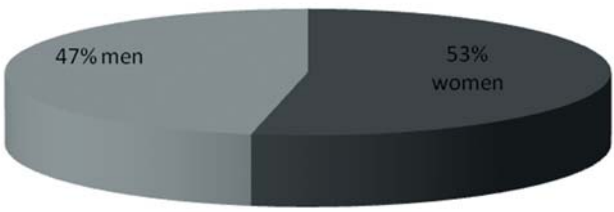

Fig 2. Division of the respondents according to gender

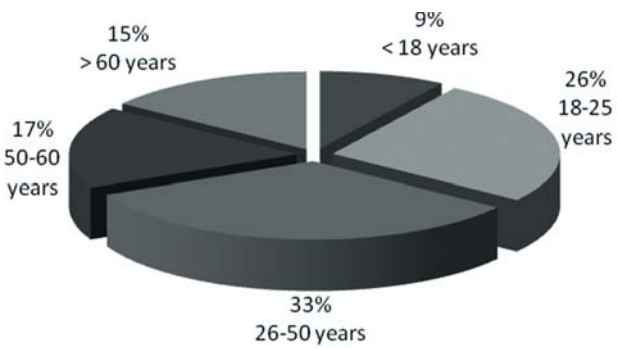

Fig. 3. Division of the respondents according to age

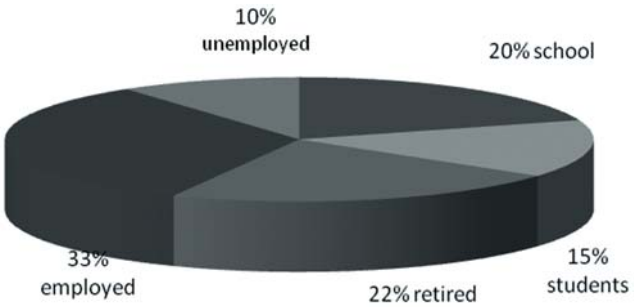

Fig. 4. Division of the respondents according to employment status

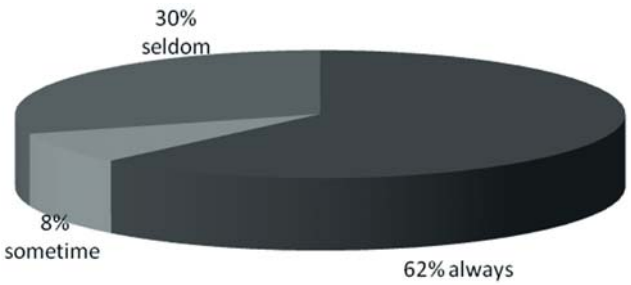

Fig. 5. Frequency of using the public means of transportation

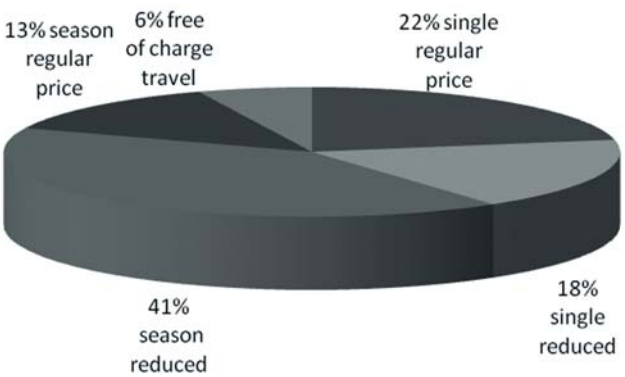

Fig.6. Kind of entitlement to use public transport means

The results of surveys concerning the users' preferences and their significance have been presented in table 3.

Tab.3. Presentation of mean results concerning preferences for particular criteria of public transportation evaluation in 2012 including their significance

No.	Quality criteria	Preferences of passengers	Significance of feature
1.	Punctuality	4.60	1
2.	Frequency	4.56	3 - 4 - 5
3.	Safety	4.56	3 – 4 - 5
4.	Reliability	4.54	6
5.	Availability	4.52	7 - 8
6.	Cost	4.50	9
7.	Directness	4.59	2
8.	Information	4.56	3 - 4 - 5
9.	Ergonomics	4.52	7 - 8

According to the respondents, the most important in terms of preferences, was punctuality (4.60) and directness of connection (4.59). In their opinion the least important was cost (4.50).

The second part of the survey covered the issues connected with the quality of services provided by the public municipal transportation company. The survey results are shown in table 4.

Tab.4. Presentation of the mean results concerning the grades given to particular criteria characterizing the research object

No.	Qualitative feature	Grades	Signficance of feature criteria
1.	Punctuality	3.95	2
2.	Frequency	3.55	7
3.	Safety	4.20	1
4.	Reliability	3.72	4
5.	Availability	3.92	3
6.	Cost	3.30	9
7.	Directness	3.60	6
8.	Information	3.70	5
9.	Ergonomics	3.53	8
Average grade		3.72	

The best grades were given to such criteria as: travel safety (4.2), punctuality (3.95), availability (3.92). The lowest grades were given to such features as: cost –price of tickets (3.30). The average grade of the transport services quality was: 3.72.

8. Characteristics of quality gaps

The carried out surveys on the subject of passengers preferences allowed to identify gaps in the relative and absolute quality.

- relative quality gap is calculated as a difference between real preferences and the respondents grades.
- absolute quality gap – is calculated as the difference between the maximum, possibly ideal expectations concerning the services and the respondents' real grades. [17].

Tab. 5. Presentation of average results concerning the respondents preferences and grades for particular qualitative criteria with the use of a five grade scale

No.	Quality criterion	Maximal preferences	Passengers preferences	Grades of passengers	Relative quality gap	Absolute quality gap
1.	Punctuality	5.00	4.60	3.95	0.65	1.05
2.	Frequency	5.00	4.56	3.55	1.01	1.45
3.	Safety	5.00	4.56	4.20	0.36	0.80
4.	Reliability	5.00	4.54	3.72	0.82	1.28
5.	Availability	5.00	4.52	3.92	0.60	1.08
6.	Cost	5.00	4.50	3.30	1.20	1.70
7.	Directness	5.00	4.59	3.60	0.99	1.40
8.	Information	5.00	4.56	3.70	0.86	1.30
9.	Ergonomics	5.00	4.52	3.53	0.99	1.47

The largest relative quality gap for the discussed criteria occurred in positions:

- cost (ticketprice) – 1.20,
- frequency – 1.01,

The lowest absolute gap in quality occurred for criteria:

- safety – 0.36,

- availability – 0.60,
- punctuality – 0.65,

The highest absolute quality gap occurred for criteria:

- directness – 1.86,
- cost (ticketprice) – 1.58,
- ergonomics – 1.47.

The smallest absolute quality gap:

- travel safety – 0.80,
- punctuality – 1.05,
- availability – 1.

9. Analysis of the research results

Functioning of public transportation is an important aspect of the quality of life in every town. Improvement in the quality of passenger service involves first of all elimination of the inconveniences connected with the conditions of traveling. The possibility of measuring the quality of public transportation services is one of the conditions necessary to take actions improving the service standards.

On the basis of the obtained tests, a statistical analysis has been made and it has been presented in table 6.

Tab. 6. Results of carried out statistical analysis

	Punctuality	Frequency	Safety	Reliability	Availability	Cost	Directness	Information	Ergonomics
Number of observations	100	100	100	100	100	100	100	100	100
Arithmetic mean	3.95	3.55	4.20	3.72	3.92	3.30	3.60	3.70	3.53
Median	4	4	4	4	4	3	4	4	4
Mode	4	4	5	3	4	3	4	3	3
Variance	0.71	0.69	0.63	0.81	0.59	0.94	0.75	0.7	0.64
Standard deviation	0.85	0.83	0.86	0.9	0.77	0.97	0.86	0.83	0.8
Minimum	2	2	2	2	3	1	2	2	1
Maximum	5	5	5	5	5	5	5	5	5
Coefficient of variability	21.5	23.3	20.4	24.1	19.5	29.3	23.8	22.4	22.6

The analysis of the results shows the preferences and demands of users concerning transportation services they are provided with. The analysis of statistical results, especially the arithmetic mean, being the most effective unburdened estimator of the unknown expected value [12], proves that according to the respondents,the most significant criteria are: safety (4.20), punctuality (3.95) and availability (3.92). Values of variability coefficient for these criteria are: 21.5%, 20.4% and 19.5%.This means that answers provided by respondents on the subject of the above criteria are the least diversified. Criteria such as: reliability, information, connection directness and frequency were given medium grades within the range from 3.55 to 3.70 points.

However, such criteria as: cost, and ergonomics, were found to be the least significant, from the point of view of the offered transport services, and they were given grades from 3.30 to 3.53 points. This means that, according to this research, these criteria have the smallest influence on the evaluation of the quality of provided services. Therefore, it would be advisable to consider omitting them in further research. Besides, analysing the dispersion of the discussed criteria set, measured by means of the coefficient of variability, it can be observed that its value is the highest for ergonomics and cost which means that respondents were the least precise in this case.

The surveys show that this is the safety of transportation which has scored the highest grades and that it meets the respondents' requirements. Having equipped the buses with monitoring systems has improved the passengers' sense of security.

Yet, it should be remembered that due to the public transportation system common character and function it performs, the surveys were performed on a representative group (diversified) of respondents. If the respondents had been divided according to age or social status, their preferences and requirements concerning the transport system operation quality could appear to be significantly different.

10. Conclusion

An increasing level of the quality of life affects the demands of the city dwellers. They expect the public transportation to provide services possibly the most similar to the comfort of their own cars. Proper operation of transportation companies should involve fulfilment of people's transport needs. Finding out about the preferences of passengers using public bus transportation services is connected with the necessity of carrying out opinion surveys thanks to which it is possible to obtain measurements of the quality of services provided by municipal bus transportation systems from the point of view of their passengers.

Having analysed the results obtained by using the method of principal components it can be said that it would be advisable to limit its dimensionality, that is, to reduce the number of the accepted criteria. Having in mind that the group of respondents consists of users of a given transportation system who are the ones to set standards concerning the quality of these services – requirements connected with functioning, their opinions should be

accounted for in the final decisions, as to whether dimensionality of the final vector of criteria should be reduced or not.

A clear diversification of stabilization rate of the avalanche curves for the analysed group shows that it is advisable to carry on the research on the subject of their statistical dimensionality.

On the basis of the research, there have been identified three sets of assessment criteria according to which the evaluation of a given object has been made.

The results of the research on the criteria significance can be accepted to be directives for decision makers how to design, operate and control the system operation in order to come up to passengers' expectations, by ensuring the desirable level of its operation quality.

It must be noted that in order to perform a comparative analysis of the operation quality of selected transportation systems, or evaluation of a given system operation in different periods of time, it is necessary to use the same set of criteria whose values need to be referred to their model or desirable states, which will allow to determine the object operation quality in the multi-criteria evaluation.

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